STEM 2021

PROCEEDINGS

6th International STEM in Education Conference

University of British Columbia, Vancouver, Canada, July 5-9

STEM 2021
JULY 5-9 | VIRTUAL CONFERENCE
HOSTED BY UBC, VANCOUVER CANADA

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STEM 2021 Proceedings Preface

September 2, 2021

When in the fall of 2019 the Local Organizing Committee of the *6th International STEM in Education Conference* (STEM 2020) at the University of British Columbia, Vancouver, Canada was thinking of a conference theme, nobody could have even imagined then how timely and fitting the theme of *Changing the Story* would turn out to be. As the COVID-19 pandemic entered Canada and spread around the world, it became clear that we would need to change the original story much more than initially anticipated.

In the spring of 2020, the Local STEM 2020 Conference Organizing Committee took a bold decision to postpone the conference by a year and rebrand as STEM 2021 – a decision that was subsequently affirmed by the STEM International Executive Committee. Then, in the summer of 2020 with international borders continuing to be closed, we decided to move STEM 2021 to a fully online mode of delivery. While none of us had ever had an experience in organizing a virtual conference, it was the only choice that would allow us to continue the tradition of STEM in Education Conferences that began at the Queensland University of Technology in 2010. Thus, the theme reflected what potential Conference participants were experiencing:

> ***Changing the Story*** is the STEM 2021 conference theme. With the world facing numerous significant challenges – the COVID-19 pandemic, climate change, ecosystem degradation, transformation of future job markets, disease and drug management, population displacement – there is now more than ever a need for STEM educators to contribute solutions to complex problems facing the world. The 2021 conference theme provides opportunities to highlight and examine STEM Education that complements common themes of improving academic performance and/or encouraging students to pursue STEM-related fields and careers. The theme highlights STEM Education research that breaks new ground and offers new directions for innovative research, research methodologies, and teaching approaches. *Changing the Story*, as a theme, provides opportunities to examine STEM stories yet to be told, partially hidden, and not yet conceived. Research in STEM Education has the potential to transform lives, re-imagine education, and respond to some of the world's most complex issues at local and global levels. We encourage and welcome you to share your stories by being part of *STEM 2021: Changing the Story*. (see also https://stem2021.ubc.ca/conference-theme/)

Yet, with all of the challenges related to COVID-19, the pandemic has also become a catalyst for educators' acceptance of the potential of educational technologies and their roles in STEM teaching and learning. Over the last year, the educational realities of COVID-19 have shaped our views and openness towards online education and the power of technology to facilitate it. With our growing experience of teaching online (either in synchronous or asynchronous formats), we have also realized the benefits of virtual conferences, existing online platforms, and, consequently, of the opportunities they offer to STEM educators who are actively engaged in online education. With all the challenges presented by the pandemic, it was an opportune time to ask difficult questions and try to come up with answers relevant to the majority of STEM educators worldwide.

In addition to the original themes proposed for the 2020 Conference, we decided to add a few strands dedicated to STEM education in times of the COVID-19 pandemic to reflect challenges and solutions relevant to Conference participants (Figure 1). Thus, not surprisingly, the STEM 2021 Conference drew an unprecedented number of participants (almost 400) from 27 countries around the globe who presented more than 150 original papers, symposia, innovative showcases, workshops, and panels (Figure 2). The Conference also featured a number of Sponsored workshops presented by our industry partners involved in STEM education.

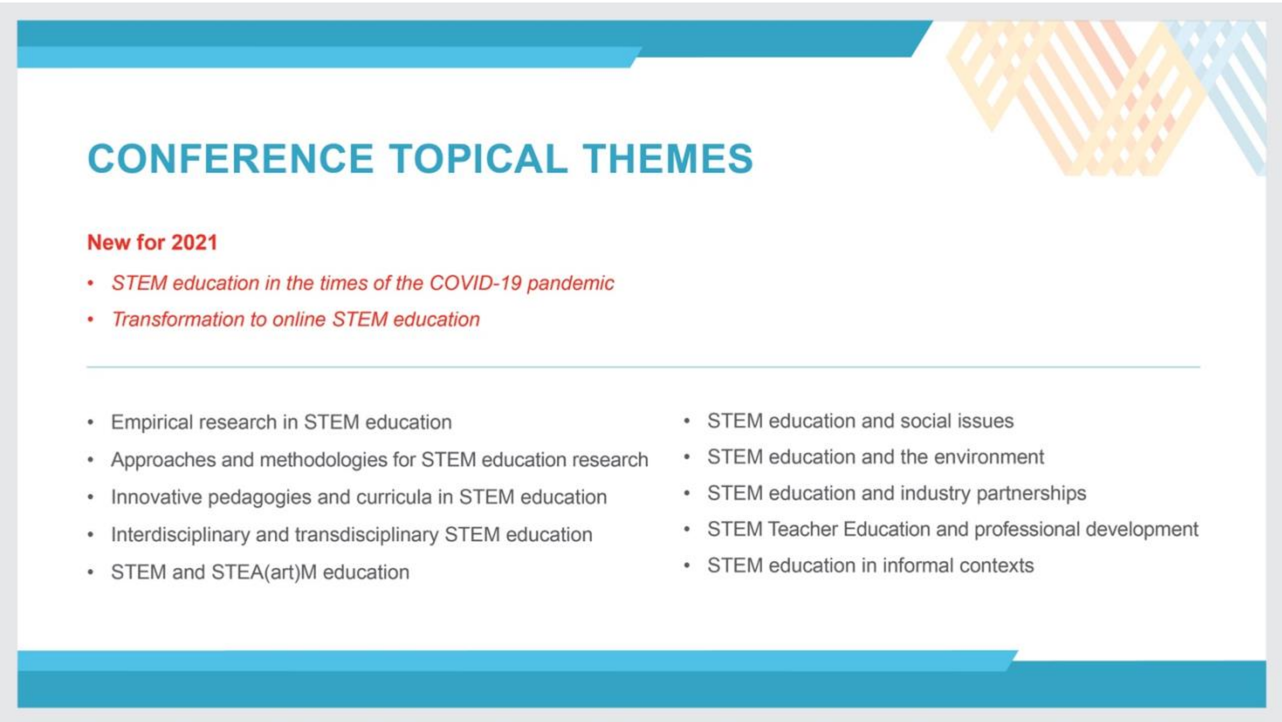

Figure 1: Topical themes at 2021 STEM in Education Virtual Conference.

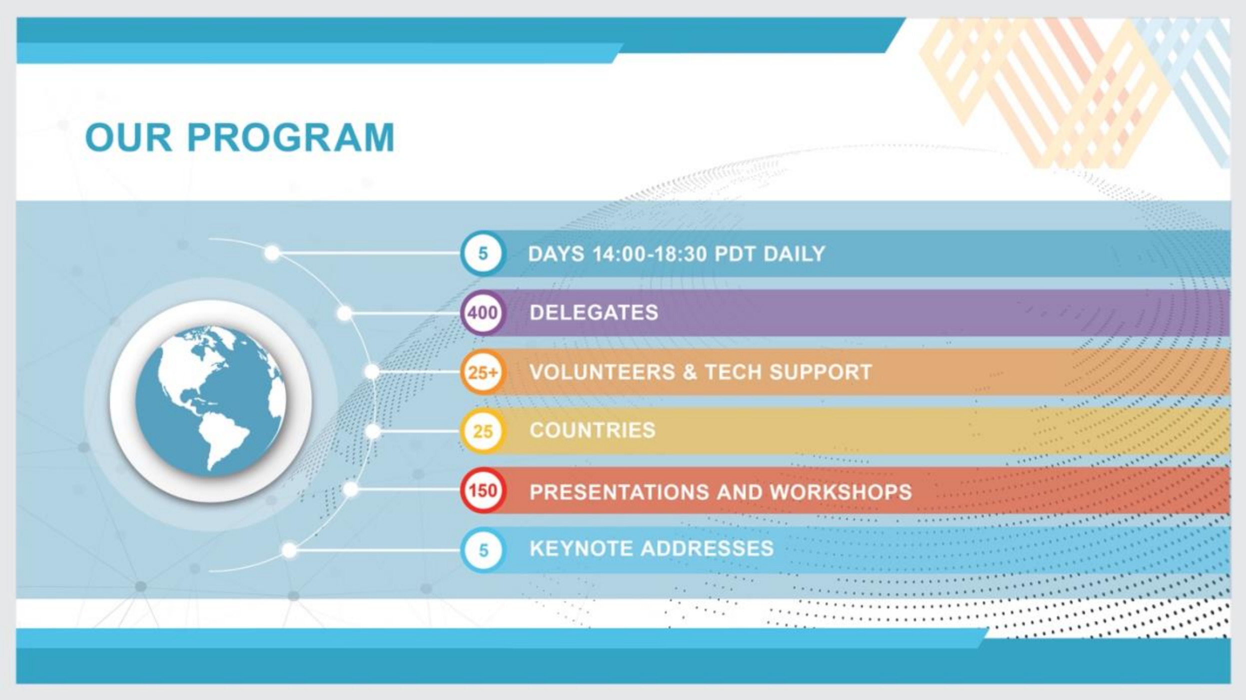

Figure 2: 2021 STEM in Education Virtual Conference at a glance.

The five keynote speakers at the conference addressed topics especially relevant to today's STEM educators and teacher educators. The topics ranged from elementary STEM education (e.g., *Exploring STEM from Roots to Flowers* by Prof. Douglas McDougall), mathematics education in the context of STEM (*Teaching Calculus to Life Science Students*, by Prof. Leah Keshet), STEAM education and the role of the Arts (*STEM + Art = Design Education: How Can Youth Education Promote STEM Learning?*, by Prof. Daniel Roehr), to indigenous and environmental education in STEM (*STEM as an Expression of Indigenous Science*, by Deborah McGregor), and to examining the role of computing and coding in STEM education (*Exploring the Promise of Disciplinary Convergence: Approaches for Integrating Computing and STEM in PK-12*, by Dr. Shuchi Grover). The diversity of topics explored by Conference participants and the diversity of the participants – from the K-12 educators, to STEM teacher educators, STEM education researchers, post-secondary STEM educators, industry representatives and business leaders – were unprecedented. Most importantly, the Conference has shown that today STEM education is a hot topic around the globe whose relevance has only increased during the pandemic.

In these proceedings, we have collected all the presentations of the Conference. These presentations have undergone a thorough peer review, conducted by the international team of STEM educators and researchers. We also included the abstracts for all the keynote addresses, panels, innovative showcases, workshops, and symposia. Moreover, the virtual nature of the conference allowed recordings of all the presentations, thus conference participants were able to watch the presentations at their own convenience at a later time.

As in the previous STEM in Education International Conferences, the thorough peer review helped us identify outstanding research papers that received Best Paper Awards at the Conference. These papers included:

1. **What Is High-Quality STEM? The Development and Application of an Integrated STEM Rubric**
   Mia Dubosarsky, Donna Taylor
   Worcester Polytechnic Institute (WPI), United States of America
2. **Supports and Barriers for Teacher Professional Learning and Growth**
   Richelle Marynowski
   University of Lethbridge, Canada
3. **Development and Implementation of Citizen Science Based STEAM Programs for Elementary Students in Korea**
   Soo-Young Lee[1], Youngseok Jhun[1], Kapsu Kim[1], Hae Ae Seo[2]
   [1]Seoul National University of Education, Republic of Korea; [2]Pusan National University, Republic of Korea
4. **Transforming Public Library Programs into Stem-Related Initiatives: Create, Assemble, and Play**
   Virgilio Jr Guinto Medina
   Qatar National Library, Qatar
5. **"Start with Where You Are": The View Of Indigenizing STEM Curriculum From Educational Outreach**
   Richard Canevez[1], James Shaw[2], Soundous Ettayebi[2], Charlene Everson[3]
   [1]Pennsylvania State University; [2]Geering Up Engineering Outreach; [3]K'omoks First Nation
6. **Recognition of STEM Human Resources Community by Higher Education Students in JAPAN and MALAWI**
   Tomotaka Kuroda
   Graduate School of Science and Technology, Shizuoka University, Japan
7. **Inclusion in a STEM Innovation Hub: Perspectives of Teachers and Administrators**
   Katie Laux, Larry Plank
   Hillsborough County Public Schools, United States of America
8. **Curiosity-driven, Inquiry-based Science Projects Bridge Face-to-face and Online Learning Formats during Covid-19**
   Carol Rees[1], Michelle Harrison[1], Grady Sjokvist[2], Morgan Whitehouse[2], Elizabeth deVries[2], Christine Miller[1]
   [1]Thompson Rivers University, Canada; [2]School District 73
9. **Making Space for Inquiry in A High School STEM Laboratory**
   James Gauthier, Douglas Adler, Samson Nashon, Marina Milner-Bolotin
   University of British Columbia, Vancouver, Canada

Finally, many people and organizations contributed to the success of this conference. We express our sincere gratitude to the International Executive Committee Members from the Queensland University of Technology (Australia), Beijing Normal University (China), University of Sydney (Australia), Northeast Normal University (China), Southwest University (China), Shanghai Normal University (China), University of Calgary (Canada), and of course the University of British Columbia (Canada) who have supported us during these last two and a half years (Figure 3).

INTERNATIONAL EXECUTIVE COMMITTEE

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Dr. David Anderson | *Professor, Department of Curriculum & Pedagogy, Faculty of Education*
Dr. Marina Milner-Bolotin | *Professor, Department of Curriculum & Pedagogy, Faculty of Education*
Dr. Samson Madera Nashon | *Professor, Department of Curriculum & Pedagogy, Faculty of Education*

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Dr. Xianqing Bao | *Associate Professor, Director, Department of Educational Technology, College of Education*

Figure 3: International Executive Committee Members of the 2021 STEM in Education Conference.

Here at the University of British Columbia, we worked with outstanding colleagues and graduate students on the Local Organizing Committee (Figure 4). We were supported and advised by the Head of the Department of Curriculum and Pedagogy, Prof. Samson Nashon. And, we are indebted to the creative work of our Artistic Designer, Kirsty Robbins, who helped design logos and conference-related art to reflect the spirit and theme. Our Departmental staff, Saroj Chand, Vindy Lin and Anna Ip were helpful all along the way which allowed us to make the Conference a reality.

Figure 4: University of British Columbia Local Organizing Committee Members of the 2021 STEM in Education Conference.

The success of any conference depends on the work of many dedicated volunteers at different stages of preparation. This conference is no exception. The numerous volunteers — secondary, undergraduate, and graduate students, faculty members, and staff — were instrumental in making STEM 2021 run smoothly and efficiently. In addition, we are grateful for ongoing support from our sponsors (Figure 5). The STEM 2021 virtual conference would not have succeeded without this generous support. This also allowed us to invite a number of international participants (teachers, graduate students, teacher educators, and researchers) who could have not taken part in the Conference otherwise.

Figure 5: STEM in Education 2021 International Virtual Conference Sponsors.

The University of British Columbia, Conferences and Accommodation staff and technical support personnel at the University of British Columbia, Library and AV departments were indispensable. Their expertise, dedication, and problem-solving skills were instrumental in the success of the event. Without them, the Conference would not have become a reality.

Last but not least, we congratulate and thank all the educators who took a leap of faith and decided to take part in the first ever virtual 2021 STEM in Education Conference. We are confident their efforts were rewarded by the active engagement of the Conference participants and many unique opportunities to showcase their research and network on the world stage.

We anticipate you will agree that these Proceedings reflect the intellectual richness of the Conference and will inspire continuing fruitful scholarship in the field of STEM Education.

Sincerely,

The Editors of the STEM 2021 International Conference Proceedings

Figure 6: The Editors of the STEM 2021 International Conference Proceedings.

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KEYNOTES

Exploring STEM: From Roots to Flowers

Dr. Douglas McDougall | Professor
Professor of Mathematics Education, Ontario Institute for Studies in Education
University of Toronto, Ontario, Canada
Editor in Chief of Canadian Journal of Science, Mathematics and Technology Education

BIOGRAPHY

Professor McDougall is a Professor at the Department of Curriculum, Teaching and Learning at the Ontario Institute for Studies in Education (OISE) at the University of Toronto. He is also an Associate Dean, Programs at the Faculty of Education at the University of Toronto. He served as Co-Director of the Master of Teaching Program from 2000 to 2004 and Coordinator of the Master of Teaching Program from 2004 to 2009. In addition, he served as Associate Chair of the Department of Curriculum, Teaching and Learning (CTL) from 2005 to 2008, and Chair since 2010. In 2018, Prof. McDougall became Chief Editor of the Canadian Journal of Mathematics, Science and Technology Education - one of the leading international journals in the field.

With a distinguished record of scholarship and teaching in mathematics education, Professor McDougall's research on improving instructional strategies at the elementary and secondary school levels has attracted funding from the Social Sciences and Humanities Research Council of Canada, the Ontario Ministry of Education, and the Toronto District School Board. He has supervised more than two-dozen doctoral students to completion. He is a former president of the Psychology of Mathematics Education, North America Chapter.

Professor McDougall’s contributions to leadership at the University of Toronto are many. He served as a member of the University of Toronto Academic Board from 2005 to 2014, Vice-Chair of the Committee on Academic Policy and Programs from 2006 to 2012, and Chair of the Committee from 2012 to 2014.

ABSTRACT

This presentation will take place in the summer time in Vancouver. We will expect to see some flowering plants. The roots of a plant anchor the plant to the ground and keep it steady. The stem carries water and other nutrients to different parts of the plant. It also provides support to keep the plant standing. The leaves and flowers provide beauty, growth and colour to the plant.

In this presentation, Professor Douglas McDougall will use the metaphor of a plant to discuss where we started with STEM (the roots), and the characteristics of successful STEM activities and emerging research findings (the stem). It is the STEM activities and the possible educational and employment opportunities that provide the variation of the present (the flowers). Finally, he will explore the possible directions we can go in the future (the seed).

To explore the stem of STEM, Prof. McDougall will summarize some of the research that has helped us identify the benefits of STEM and to keep the field moving forward. But the beauty of many plants can be seen from the flower. There are many ways to create collaborative, dynamic and interactive lessons in elementary and secondary schools. Douglas will discuss the principles of STEM-focused lessons to help teachers and researchers to create a STEM-infused classroom (and a bouquet of beautiful and colourful flowers).

Finally, we should always be asking the question "What kind of flower do you plan to have with your STEM?

Teaching Calculus to Life Science Students

Dr. Leah Edelstein-Keshet | Professor

Department of Mathematics
University of British Columbia
Vancouver, Canada

BIOGRAPHY

Professor Edelstein-Keshet's career is dedicated to using mathematics as a tool for research in the life sciences. She has become recognized as one of the world leaders in the area of mathematical biology, in which she has been at the forefront for 25 years. Her work spans many topics, from the sub-cellular to the ecological. For the past decade, she has focused on biomedical research, including autoimmune diseases such as type 1 diabetes. She also researches Alzheimer's disease.

Dr. Edelstein-Keshet earned her Bachelor of Science and Master of Science in Mathematics from Dalhousie University and received her doctorate in Applied Mathematics from the Weizmann Institute of Science in Rehovot, Israel in 1982. She held teaching positions at Brown University and Duke University before joining The University of British Columbia (UBC) as Associate Professor in 1989, becoming Professor in 1995. Her book *Mathematical Models in Biology* (Random House) is regarded as the definitive textbook in the rapidly growing field of mathematical biology.

She has been awarded the Canadian Mathematical Society's Krieger-Nelson Prize, which recognizes outstanding research by a female mathematician, and, at UBC, the Faculty of Science Award for Leadership. She has also served as President of the Society for Mathematical Biology.

ABSTRACT

Students arrive at university with little idea of what science is really about, and even less conception of why mathematics is important and helpful. Yet, many of them aspire to be MDs, or biologists, and to solve the important problems of humanity. How do we teach them not only to appreciate scientific ways of thinking but also to see the interconnections between the sciences, the power of mathematics, and the ways science, math, and medicine can illuminate one another? In my talk, I will describe an effort to use first-year calculus to introduce students to some of these notions, though at a basic and accessible level. I will discuss the curriculum and open resources that were developed locally, and showcase some of the case-studies. I conclude with some of the challenges faced by educators, and others by students and speculate on how to address these in future efforts.

STEM + Art = Design Education: How can Youth Education promote STEM learning?

Dr. Daniel Roehr | Associate Professor

School of Architecture and Landscape Architecture
Faculty of Applied Science
University of British Columbia
Vancouver, Canada

BIOGRAPHY

Professor Roehr teaches Landscape Architecture in the School of Architecture and Landscape Architecture at UBC and is a licensed landscape architect in BC and Berlin. Since 2007, he runs the research group greenskinslab http://blogs.ubc.ca/greenskinslab/. His research focuses on the integration of living roofs as part of holistic systems for storm water management.

Daniel coauthored the book “Living Roofs in Integrated Urban Water Systems” (Routledge 2015) and regularly publishes in scientific journals and professional magazines https://www.researchgate.net/profile/Daniel_Roehr. He is working on his new book "Seeing Environment: Interacting with the Landscape - A Guide for Designers" (Routledge exp. 2021) and recently developed a Low Impact Development (LID) application with his research team to calculate stormwater run-off in the initial urban design and planning phase.

He also runs a hand drawing blog https://blogs.ubc.ca/drawingsdanielroehr/ and Instagram account: https://www.instagram.com/danielroehrdrawings/?utm_source=ig_profile_share&igshid=1onvlm1tna69x which archives 30 years of his architectural hand drawings to inspire students to continue to use hand drawing as a design and research tool additional to current digital modelling applications. In 2013/14, he was a UBC Sustainability Research Fellow and was selected as a team member to compete designing the Canadian National Holocaust Memorial in Ottawa and in 2016 he received the Killam Teaching Prize from UBC. Daniel has practiced extensively in Europe, North America, and Asia. From 1995 to 2000, he was project architect of the award-winning Daimler-Chrysler Green Roof Project, Potsdamer Platz, Berlin, Germany and ran his own firm in Berlin from 1999 to 2007, and co-founded a firm in Shanghai in 2004.

ABSTRACT

Today’s youth are the biggest asset for our world’s positive development. Instilling passionate connections to future professions especially during high school right through college, university or craft education, is the foundation of youth’s professional development. High school teachers are therefore, together with the parents, the ‘General Practitioners’ (or gatekeepers) for what education a high school student will need for any future profession. One of the biggest challenges in high school education is to balance state required knowledge and skill transfer, with the youth’s own desires and interests in learning, exploring and thriving. When it comes to design education, it is therefore

important that high school teachers' oral training and syllabus creation includes a link between STEM and Art subjects. STEM should act as an education driver for other subjects, but STEM teachers need to integrate art in their teaching. The awareness of traditional academic subjects such as law, medicine and engineering is not a broad enough palette to entice the youth to be inspired to be the next generation of thinkers, developers and leaders. STEM Syllabuses should include not so well-known subjects like landscape architecture and graphic design and promote the value of an additional craft education such as carpentry, tailoring, plumbing etc. to widen youth's exposure to professional choices. In fact, teacher training and syllabuses should place priority on niche subjects. STEM subjects should be related to and combined with ART. Often isolated high school art education alone cannot manage this task but integrating the complex interconnected processes of STEM with art education could. This lecture will present examples of how STEM subjects could be integrated with the art and design disciplines of landscape architecture, environmental design or urban design. For example, youth could be applying math exercises in context of the environment to calculate how much rainwater is accumulated by different roof sizes and shapes in relation to the changing climate. This could ignite awareness in the environment, encourage respect for the usefulness of math and introduce the interdependence of design and math in calculating the quantity of water accumulated on different roof shapes. With Google being the biggest library of the world, accessible peer reviewed online research can stimulate and support syllabus content and assignments. The increasingly more complex and researched world provides many opportunities for high school educators to stimulate STEM and Art and can provide the nurturing ground for our future thinkers, craftsman and leaders of the world.

STEM as an Expression of Indigenous Science

Dr. Deborah McGregor | Associate Professor

Canada Research Chair in Indigenous Environmental Justice
Faculty of Environmental Studies, York University
Toronto, Canada

BIOGRAPHY

Professor McGregor is the Canada Research Chair in Indigenous Environmental Justice. Her work is in the area of Aboriginal environmental and resource management and governance. The approach she takes is interdisciplinary, and includes such topics as: environmental justice, health, traditional ecological knowledge, water quality, environmental assessment, sustainability, sustainable forest management, environmental planning, and Indigenous knowledge systems.

Her research focus has for the last few years centred on four areas: Indigenous knowledges in an urban context; Indigenous knowledge and environmental justice; Indigenous perspectives on water quality/quantity with a focus on gender; and Indigenous research approaches.

A core aspect of her work involves combining research and teaching in areas such as Indigenous governance and justice, Indigenous knowledge systems, Indigenous pedagogies and research approaches.

ABSTRACT

Environmental and sustainability science is frequently thought to be a relatively new discipline. Indigenous peoples, however, hold ancient and highly developed ideas of environmental and sustainability science which have significant applicability in understanding and addressing current challenges faced by all of humanity. This presentation/paper will explore concepts of environmental and sustainability science from an Anishinabe theoretical perspective. Anishinaabe worldviews, philosophies, principles and values will be described as they form the foundation for Anishinabe science. I will draw upon my own professional and personal experience in this area as an educator and practitioner to compare and contrast Indigenous and non-Indigenous paradigms of science and explore processes for mediating between two different intellectual traditions. As an Anishinaabe scholar, it has been an important goal of my professional life to seek models for how different knowledge systems can come together to address mutual environmental challenges.

Exploring the promise of disciplinary convergence: Approaches for Integrating Computing and STEM in PK-12

Dr. Shuchi Grover | Senior Research Scientist

Looking Glass Ventures, LLC
Palo Alto, California, USA

BIOGRAPHY

Dr. Shuchi Grover (Senior Research Scientist, Looking Glass Ventures, California) is a computer scientist and learning scientist by training, who has been engaged in computer science and STEM education for school-aged children for two decades. Her recent research, most of it funded by the US National Science Foundation, is centered on advancing an understanding of STEM+Computing integration in PK-12; promoting computational thinking for neurodiverse learners, building capacity for formative assessment among CS teachers, and addressing gender equity in CS through engagement in exciting emerging topics such as cybersecurity, artificial intelligence, and IoT. She edited and co-authored the recently published CS teacher handbook, *Computer Science in K-12: An A-to-Z handbook on Teaching Programming*.

ABSTRACT

Drawing on a rich palette of examples from her research spanning PreK-12 as well as the field more broadly, Dr. Grover will share a suite of pedagogical strategies for meaningful integration of computing and disciplinary learning in PreK-12 CS and STEM classrooms. She will share findings, takeaways, broad frameworks, as well as challenges, to aid the process of *changing the story* for research and practice.

SPONSORED WORKSHOPS

TEACHING DIGITAL WORKFORCE SKILLS IN THE CLASSROOM

Callysto Workshop

ABSTRACT

Coding, computational thinking, and data science are important skills for the growing digital workforce. In this workshop, teachers will learn how to add these skills into their classrooms by using Callysto – a federally-funded, online, curriculum-tied tool designed for Grades 5-12 students. Educators who use Callysto in their classrooms will lead the session. Participants are asked to bring their own laptops where possible, so they can jump into Callysto tutorials. For more information on the Callysto project, please visit Callysto.ca.

HOW EDWIN SUPPORTS INNOVATIVE PEDAGOGIES AND STEM

Edwin Workshop

ABSTRACT

The foundation of STEM education is built on the core skills of critical thinking, creativity, collaboration, and the real-world application of these 21st century skills. This session will explore how the rich array of resources in the Edwin Ecosystem support the teaching of these critical skills, the interdisciplinary planning of STEM units, and the creation of STEM performance tasks. Attendees of this session will have an opportunity to receive Free Edwin Access until July 31, 2021, and will receive access to a Edwin STEM resources. If you have questions ahead of this session, please email robyn.reekie@nelson.com.

FULL PAPERS

COVID-19'S EFFECT ON STUDENT MOTIVATION AND INTEREST IN A STEM COURSE AT A FEMALE HIGH SCHOOL IN SAUDI ARABIA

Hebah Alamr
University of Calgary

ABSTRACT

This paper investigates the effects of transitioning from a physical classroom to an online classroom in an elective STEM course to prevent the spread of COVID-19. The study took place in an urban girls' high school in Riyadh, Saudi Arabia. The data used in this paper were collected as part of a doctoral project that had started before the pandemic and continued during the pandemic. In interviews with the students before and after the pandemic, the researcher noticed a change in students' motivation and interest in the class after the shift online. Using thematic analysis, the researcher found that students lost motivation to learn STEM in the online environment. Among other reasons, the data showed that the strong sense of belonging to the STEM community of practice in the class was the main factor that maintained their motivation. The paper concludes that students lost interest in the class due to the unplanned transition to online learning.

Keywords: *STEM education, Saudi girls, STEM in COVID-19, informal STEM education*

INTRODUCTION

Saudi Arabia has made remarkable strides towards enacting STEM education in schools in all levels of education. The Saudi Ministry of Education designed programs and initiatives built around STEM education (Madani, 2020, El-Deghaidy & Mansour, 2015; Tayan, 2017). This program is an example of a ministry-sponsored STEM programs that introduces high school students in 12th grade to the community of STEM. It was designed to expose students to integrative STEM education where they can solve problems and design artifacts using their knowledge in all domains of sciences by researching and using resources around them. As education in Saudi Arabis is gender separated, this study took place in a girls-only urban high school in Riyadh city in Saudi Arabia. The program had been running for one month before the pandemic caused the course to move to an online format. Because Digital Workshops was an elective course, lessons were not available online for the students. The program continuity online was due to the teacher's effort to teach the course to the end and complete the course requirements.

Effect of COVID-19 on education in Saudi Arabia:

Coronavirus 2019 (COVID-19) had a massive effect on all human endeavors, the global economy, politics, health, and education. In rapid response to the social distancing calls to stop the spread of the virus, education moved from a face-to-face format to an online format within few days. The pandemic caused school closure on March 9, 2020 in all schools and universities in Saudi Arabia.

This fast and unplanned closure, like those in some other education systems around the world, negatively impacted the students' education. Studies show that the fast transition to online learning affected students' learning in all levels and sectors of education (Crawford et al, 2020; Sintema, 2020; Toquero, 2020). Most of these studies found that the difficulties that faced education were due to the fast and unplanned transition to online education.

The fast and unplanned transition, coupled with a lack of online teaching experience, caused a negative effect on the education system. Teachers in Saudi Arabia do not have enough knowledge and experience to teach online, some families cannot afford technology devices for their children to attend classes online, and some families do not have internet service in their houses. These factors were enough to disengage students from their learning. On the other hand, the government of Saudi Arabia worked hard to provide students who could not connect with their teachers and schools, a TV channel (IEN TV Network) that broadcast lessons for all grades and all school subjects. The channel broadcast lessons around the clock, and all lessons were also made available on IEN website (https://ien.edu.sa) and on a YouTube channel (https://www.youtube.com/results?search_query=ien+) as a reference for all students at all times. These channels were created by the Ministry of Education for the purpose of enacting digital learning for learners, parents, and educators and were available for all students before the pandemic. However, IEN was an effective resource for students to have all their lessons recorded and available at all times.

Theoretical Framework

This study investigates the reasons whys students in Digital Workshops disengaged from learning STEM after the pandemic. The paper looks at students' experiences through a situated learning community of practice theory (Bloch, Lave, & Wenger, 2016). The theory is grounded in how people learn by engaging in everyday social practices and become experts in a domain of interest. A community of practice is defined as "a group of people who share an interest in a domain in human endeavor and engage in process of a collective learning that creates bonds between them" (Wenger, 2001, p.1). Educators have used Wenger's theory to design learning spaces that intentionally develop a community of practice and invite students to become members and learn socially through interaction. What keeps a community of practice is the shared value that participants give to the community, as long as this value does not mean members disengage from the community (Gray, 2004).

The original concept of community of practice proposed by Lave and Wenger (1991) addresses learning that takes place in a physical location where participants of the community meet and learn together. Recently, Wenger and other scholars have examined communities of practice on digital platforms (Bloch et al., 2016; Gray, 2004; Inel Ekici, 2017; Roland, Spurr, & Cabrera, 2017; Wenger, McDermott, & Snyder, 2002). Studies have shown that online communities of practice can be effective. Learners in online communities develop bonds and interactions between each other in virtual spaces only if these online communities are designed to form a community of practice and allow participants to communicate actively and share experiences and knowledge.

This paper looks at an effective community of practice in a STEM classroom in Saudi Arabia where students were showing a high level of interest and engagement prior to the shift to an online format. This paper investigates how students reacted towards the course after the COVID-19 pandemic.

METHODS AND ANALYSIS

Context of The Study and Participants

The study took place in one girl's high school in Riyadh city in Saudi Arabi. The school was hosting a STEM program called the Digital Workshops sponsored by the Ministry of Education. The program's agenda included training students to master skills that correspond with the country's Vision 2030. The vision aims to reduce the dependence on oil as the main wheel driving the economy and initiating other industrial resources. The program is only offered to the 12th grade students and is one semester long. There were 15 students in the class, and 7 students consented to participate. The teacher also agreed to be observed and interviewed. The interviews took place on site, and after the pandemic the interviews were conducted online.

Research Questions

This study was specifically conducted in Riyadh, Saudi Arabia to address the following research questions:

- What factors affected students' motivation and engagement before and after COVID-19 pandemic?

Data Collection and Analysis

The data used in this study were collected for doctoral project that took place before and during and after the pandemic. Data were organized and analyzed using thematic analysis that revealed patterns in students' experiences (Braun & Clarke, 2006). This paper used the interviews that took place during the pandemic.

FINDINGS

Before Pandemic: Students were very interested and engaged in STEM course because of the following factors:

Participants' interviews show a number of factors that motivated students to attend the class.

- Some students showed interest in the classroom structure and the different atmosphere in the class that allowed them to have more freedom to innovate and work in an open space with their peers.
- Most participants reported that they came to the class with different perceptions and interests and were attached to the community of practice inside the class.
- Others showed their interest in the content of the course and its alignment with their future plans and goals.

When moving to the online format, students were less interested in the course due to:

- The disorganized and fast transition to online affected students' learning in the class as the course was designed to be delivered on site. The factors that were found to attract students to the classroom were not available for them online. Most students reported that they lost their interest in the class because they could no longer work close to their peers. o Students also reported that they lost interest in the program because of a lack of resources at home. All students had to cancel their projects and think of ways to design virtual projects.

DISCUSSION

The results from this study show that students were very interested in the class due to the nature of the class that differed from the one in their formal classroom. Studies show that STEM courses allow students to innovate in more openly structured spaces (Dou et al, 2019; EL-Deghaidy at al, 2017; English, 2016; Robinson et al, 2014; Zeldin, Britner, & Pajares, 2008; Zollman, 2012). The COVID-19 pandemic had a direct and strong effect on students' motivation and engagement in all aspects of their education. The reason for this was the fast and unplanned transition to online learning.

Participants reported a disconnection from the community of practice inside the classroom because learning STEM inside the classroom was situational. When students moved from their context of learning inside the classroom, the bond between the students broke. The community of practice in the classroom dissolved and the students disconnected from their groups. This caused students to feel isolated and far from their teacher and peers, and thus they were less motivated to continue learning about STEM. Studies on online communities of practice insist that these communities must be carefully designed and use teaching pedagogies that allow such communities to develop (Gray, 2004). Digital Workshops moved online without planning, the teacher did not have the experience teaching online, and most importantly, there was a lack of resources. This caused student to lose their motivation for learning STEM, as it is the scope of this study.

Another reason that caused students to lose their motivation is the fact that Digital Workshops is an elective course. Because of that, based on students' interviews, the government did not give this course as much attention and effort for it to take place online or provide as many learning resources as required courses.

Students' disengagement from the course was also due to the fact that they were in grade 12, where they had placement and assessment tests that are required for post-secondary education.

CONCLUSION

It was shown in this paper how the pandemic caused a great impact on students' motivation and engagement in an elective STEM classroom. One of the main reasons behind disengagement was the disconnection from the community of practice students had built inside the physical classroom. This was the primary factor that caused student disengagement. It is hoped that the Saudi Ministry of Education finds ways to continue delivering STEM courses online and trains teachers on STEM online pedagogies because the future of Saudi Arabia lies in educating its youth.

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FACTORS WHICH SUSTAIN INTEGRATED STEM CURRICULUM APPROACHES IN SECONDARY SCHOOL SETTINGS

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ABSTRACT

A year-long professional development [PD] program aimed at developing Australian secondary school (grades 7 to 12) mathematics, science and technology teachers' knowledge and understanding of integrated STEM approaches was first implemented in 2014. Between 2014 and 2017, the program was delivered to 306 teachers from 57 schools. As part of an 'outcomes evaluation', the data reported in this paper are based on analyses of retrospective interviews conducted in 2018 from a sample of 32 teachers and school leaders from 20 of the participating schools. Our aim was to investigate the factors which sustained integrated STEM approaches within their school contexts beyond the completion of the PD program. This study identified key factors supporting the implementation of integrated STEM including supportive and committed school leadership, acknowledgement and tangible support for STEM leaders and teachers, regular timetabled meetings, appropriate resourcing, and willingness to find flexible ways to work within rigid school structures and practices.

Keywords: *professional development, secondary schools, integrated STEM approaches, leadership*

INTRODUCTION

Integrated STEM education in schools has been promoted in Australia (e.g., English, 2017) and internationally (e.g., Honey, Pearson, & Schweingruber, 2014). Governments and key industry stakeholders argue for increased STEM participation to drive economic growth and competitiveness in an ever-changing world with increasingly more technology driven workplaces (Office of the Chief Scientist, 2017). To that end, Australian school systems have been promoting STEM education agendas and providing funding for schools to develop and implement integrated STEM curriculum. Universities and other external providers of PD have also offered support for schools and teachers.

One such example is the *STEM Teacher Enrichment Academy* (the Academy), a PD program initially designed for secondary school science, mathematics and technology teachers offered through the University of Sydney. First instituted in 2014, the Academy seeks to increase teachers' pedagogical content expertise through guiding teams of teachers in their development and delivery of integrated STEM units of work specific to each of their schools. The Academy program is delivered in three parts over one academic school year. First is a 3-day residential session in which each participating school, represented by six teachers (typically two each of mathematics, science and technology from the same school), works with university specialists to design integrated STEM curriculum. The Academy does not provide pre-packaged curriculum, but instead works with each school to assist their teachers in designing and delivering an integrated STEM program specific to their school context.

The first session is followed by a 9-month period in which the schools receive mentorship from the University in completing their unique curriculum design process as well as coaching in STEM curriculum implementation. The concluding part of the Academy is a 2-day follow-up session in which all participating schools gather together to share their newly developed STEM curriculum as well as the community responses to their recently implemented STEM program. While the Academy is first and foremost a PD program for STEM subject teachers to further develop their knowledge of content and pedagogy in STEM subjects as well as in integrated STEM, one of the main aims of the Academy is to improve student engagement in STEM subjects so more students pursue STEM study in senior secondary school and eventually into university.

From 2014 to 2017, five Academy programs were delivered to 306 teachers from 57 schools. This research sought to discover the factors which sustained integrated STEM approaches within these schools beyond the completion of the Academy program. Through analyzing semi-structured interviews with teachers and principals from past-participating schools, this paper reports the data and findings of factors that sustained integrated STEM approaches in these schools.

CHALLENGES TO INTEGRATED STEM CURRICULUM IN SECONDARY SCHOOLS

Integrated curriculum is not a new idea but with recent calls to promote inquiry-based learning and STEM subjects within schools, teachers have taken up the challenge of designing integrated STEM curriculum aimed at developing their students' engagement, achievement and participation in STEM (Anderson, Wilson, Tully, & Way, 2019). Within secondary school contexts this requires a commitment to change and quality PD for teachers (Darling-Hammond, Hyler, Gardner, & Espinoza, 2017). Bringing together a group of science, mathematics and technology teachers to design an integrated STEM curriculum requires time and mentoring from knowledgeable experts.

One of the first challenges in designing an integrated curriculum for STEM is being clear about the meaning of 'integrated curriculum', with many definitions evident in the literature (Honey, et al., 2014). The definition informing the Academy program was proposed by Steinberg (1998):

> … an instructional method and materials for multidisciplinary teams of teachers to organize their instruction so that students are encouraged to make meaningful connections across subject areas (p. 159)

This definition promotes the autonomy of teachers in the curriculum design process so that school teams determine how much connection between the disciplines will work in their context and acknowledges that each participating school is potentially at a different starting point on their integrated STEM curriculum journey. While some researchers discuss a continuum of integration of the STEM subjects from segregated at one end to integrated at the other, the ideal involves a "seamless amalgamation of content and concepts" so that "knowledge and process of the specific STEM disciplines are considered simultaneously without regard for the discipline, but rather in the context of a problem, project or task" (Nadelson & Seifert, 2017, p. 221).

A second challenge is managing newly designed integrated curriculum within school structures wherein school timetables, class organizations, and teacher allocations are often viewed as bounded, fixed and inflexible. Informed by these challenges, the Academy program design was based on the seven features of effective PD as described by Darling-Hammond et al. (2017) – it is content focused, incorporates active learning, supports collaboration, uses models of effective practice, provides coaching and expert support, offers feedback and reflection, and is of sustained duration (Anderson et al., 2019).

Integrated curriculum continues to resurface as a worthwhile strategy to reconnect students to schooling, through providing meaningful learning in preparation for future employment (Steinberg, 1998). While, there is some research into the efficacy of STEM integration and application in secondary classrooms (Bruder & Prescott, 2013) and there is some evidence that STEM integration is successful in increasing student engagement (Venville, Wallace, Rennie, & Malone, 1998), more research is needed. Our program has the potential to provide this research as we track the impact of integrated STEM curriculum on student engagement and aspirations, as well as examine factors influencing sustainability within schools.

PARTICIPANTS AND METHODOLOGY

Evaluation research is the most applicable methodology when examining and judging an implemented program's effectiveness (Patton, 1990). In order to determine the factors that sustained STEM approaches in secondary school settings once schools had completed the Academy, we utilized an "outcomes-based evaluation" methodology (Kellaghan & Maddaus, 2000). Qualitative data were gathered through a semi-structured interview process that focused on assessing program outcomes in participating schools. The interview protocol sought to probe the STEM initiatives in schools, the perceptions of the Academy's impact in the lives of the students, any adjustments made to their school's curriculum to accommodate STEM teaching and learning, the schools' and teachers' involvement with communities of practice, any developed partnerships with industry, and overall efforts to sustain STEM initiatives in their schools.

After ethics approval was granted from our university and the appropriate school education authorities, invitation letters were sent to the 57 principals from the Academy partner schools; 31 schools agreed to take part in this research. Based on their availability in scheduling interviews, 20 schools eventually participated (see Table 1). Of these schools, half were private, and half were public, including two girls' schools, one boy's school and 17 coeducational secondary schools.

Table 1 Outcomes Evaluation: Participating Secondary Schools

Program	Schools Participating	Private School	Public School	Teachers	Principals
2014 Program A	2	1	1	3	-
2015 Program B	5	3	2	6	1
2016 Program C	4	3	1	7	-
2016 Program D	7	3	4	9	3
2017 Program E	2	-	2	2	1
TOTALS	**20**	**10**	**10**	**27**	**5**

Note: Of the 27 teacher participants, 18 were the school's designated STEM leader

Semi-structured interviews were completed with participants from these 20 schools. Interviews were transcribed verbatim and content analysis was undertaken. Data were coded and labelled with the primary themes as outlined in the Academy's goals and objectives. Secondary themes were determined through an open coding process. Overall, this research sought to discover how schools have exercised their partnership with the Academy in furthering the growth and sustainability of STEM programs within their school contexts.

RESULTS AND DISCUSSION

This section is presented in three parts: the sustainability of STEM initiatives of the STEM Academy partner schools after program completion; key drivers that have contributed to the sustainability and expansion of the STEM offerings within each of these secondary schools; and the ongoing challenges to sustainability as experienced by these schools.

Sustainability and Growth of Schools' STEM Programs post Academy

Almost all the schools (19 out of 20) in this evaluation have not only maintained and adapted their original Academy projects (primarily grades 7 & 8) but have also added additional units of study. Some schools have included art, health or history in incorporating STEM across the subject areas. Only one school has scaled back their STEM curriculum efforts and this is most likely due to a change in school leadership that is less supportive of STEM.

After their initial involvement with the STEM Academy, more than half of the schools (13 out of 20) have now added a grade 9 and/or grade 10 STEM elective subject to their school's curriculum. For most, this is in addition to the grade 7 and 8 STEM units already being implemented. Most of these schools are using a curriculum developed by a public-school engineering teacher which has been endorsed by the NSW Education and Standards Authority (NESA) giving it added status and credibility. The iSTEM program offers a full suite of curriculum units enabling teachers to adapt to suit their students' needs (see https://maitgross-h.schools.nsw.gov.au/istem/istem-videos.html)

Most of the schools represented in this study (17 out of 20) have a STEM team of teachers forming a professional learning community (PLT). Several STEM teams have expanded beyond the six teachers who attended the Academy. These teams meet regularly from a few hours weekly or fortnightly, to full day planning workshops each term. As one teacher shares,

> the best thing we did with our group was form a PLT that meets once a fortnight, and we very much share the workload … that has been the glue, if we didn't have that I dare say the whole project would have just fallen apart

All the schools that have STEM teams that meet regularly are continuing to develop STEM initiatives in their schools, expanding STEM curriculum beyond their initial Academy projects.

Fourteen of the 20 schools in this study have established links with businesses and/or local community organizations. It was often the tenacity, diligence and perseverance of individual teachers that drove these connections. Some schools found success through contacting local government agencies, as well as reaching out to local Rotary clubs to secure funding to expand programs. Another link was formed with parents that are involved as STEM professionals.

Most of the schools are involved in STEM related student outreach programs with their local universities. These university partnerships appear to enhance the aims of the Academy and further enrich the schools' STEM programs. Additionally, some schools host extra-curricular STEM clubs. Although several of these schools were involved in STEM related competitions before their participation with the Academy, teachers indicated that their efforts in designing and developing STEM curriculum has positively impacted student success in these competitions, with several schools noting significant improvement in team outcomes.

Key Drivers that Foster Sustainability of School-Based STEM Initiatives

Unequivocally, the essential key driver in these schools' successes in sustaining and growing a STEM program is the ongoing support of school leadership. For many schools, their proposed STEM initiatives align with their school's action plan, specifically in the areas of inspired learning, inquiry-based learning, cross curriculum learning or project-based learning. Principals that act as advocates for STEM support staff through providing resources that promote project success. As one of the teachers notes,

> I think you need buy-in at a high level to make this work because it is hard. There are so many obstacles in curriculum and in timetable and in staffing, that if you don't have buy-in from the highest level then there's not a push to make it happen.

Further support was offered through creating a dedicated STEM leader position who were relieved of some teaching duties in order to effectively lead the school's STEM initiatives as well as the allocation of time for STEM team meetings. This contributed to an effective STEM community of practice within their school context. Active STEM teams, with regular allocated meeting times, seem essential to sustaining and promoting STEM endeavors within schools. Depending on the passion of a few dedicated teachers to work outside of their required teaching responsibilities cannot sustain a school's STEM program.

For schools to sustain their STEM initiatives, they also need to grow their STEM initiatives, with a focus on 'real-world' STEM learning. As one teacher reflects,

> I noticed that kids that would not normally be engaged with science, maths or TAS are engaged with STEM and achieving really well. That's something you notice. It has an appeal to kinaesthetic learners and is gender neutral as well, which is really great.

The next important link to connect engagement to achievement in STEM subjects is in guiding students to see the connections between their projects or units, to the actual STEM disciplines. Teachers who could successfully navigate that and make those connections explicit have witnessed deeper learning from students in mathematics and science.

STEM learning that happens outside the classroom enhances the STEM learning that happens inside the classroom. Taking STEM outside fosters a greater appreciation of 'real-world' applications. Enrichment activities such as participation in university outreach programs as well as participation in STEM based competitions has assisted schools in sustaining and growing their STEM programs through increased student interest and engagement. Additionally, fostering connections to local business or community organisations have provided outside resources for schools to develop their STEM programs.

Overcoming Challenges to Maintain Sustainability

Effective and successful school-based STEM programs often require a shift in how schools operate. Some of the common challenges that schools faced in designing, implementing and sustaining their programs were resources, space, staffing, time and timetable. For some schools, program funding was an issue, particularly after their initial year with the Academy. The biggest financial challenge was having the resources to purchase upgraded computer software and equipment. Implementing STEM curriculum can often require the use of large spaces and can become a challenge if there are limited places to hold large groups of students working on projects. While some schools have dedicated STEM spaces, others needed to creatively work with existing spaces to foster program sustainability.

Successful schools did not allow changes in staff to become an obstacle to program implementation. Many teachers felt time pressure with implementing STEM projects while also adequately covering the required topics in their syllabus. For many teachers this was a real tension in how to manage a project across several subjects with the perception that “time was being taken away from someone’s traditional planned content”. There is a steep learning curve in managing time with project-based STEM learning; yet, several schools have noted that the subsequent times of implementing a STEM project takes significantly less time than the initial year.

Finally, timetabling was the most consistent challenge noted by schools. Some schools indicated that their timetables were “super rigid”. A key to working within a timetable seems to be a heightened level of flexibility and good will within the staff. This allows more opportunities for “team teaching” in STEM. Schools that are moving to embed STEM within the curriculum seem committed to continue working on the timetable to encourage more team-teaching opportunities.

CONCLUSION

This evaluation raises critical issues for the sustainability of integrated STEM curriculum work in secondary school contexts. Forming a school STEM team which meets regularly, shares the design and implementation of the integrated program, and encourages the involvement of other teachers is important for sustaining and growing the program. A recognized STEM leader with time and resources to support the team, to identify other potential leaders, and to address ongoing timetabling and staffing issues appears to be a key enabler. Engaging with industry, local organizations, parents and other community members provides additional support, and the potential for further STEM learning both within and outside the school environment. Finally, a supportive school principal and executive leadership team is essential for teacher recognition and the necessary support for such change to be possible.

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LEARNERS AS PLAYERS AND DESIGNERS: A FORMAL LEARNING APPROACH TO GAME DESIGN

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ABSTRACT

Researchers have supported "design" approaches to learning for the last few decades, acknowledging the in-depth understanding the design work requires of learners. On the other hand, the perspectives of the users (players in the case of game design) are less considered as learners' designs may not be used beyond their classrooms. This paper pays attention to learners' experience as game players when taking the role of game designers in the classroom while exploring the implicit and explicit relationships of the mechanics, dynamics, and aesthetics. Moreover, we seek to understand what students learn when these relationships emerge. To reach these objectives, we analysed how ninth grade students in a west-Canadian junior high school worked together as small teams to design games in a Career and Technology Studies classroom. Learners in different groups pursued varying game ideas driven by their interest. We collected qualitative data through weekly observations and analysed the data to explore the implicit and explicit relationships existing between mechanics, dynamics, and aesthetics of their evolving game design. We found that the students developed an insight into the implicit and explicit relationships between mechanics, dynamics, and aesthetics of their game. Game design practices engaged learners in deep understanding of design as an iterative process.

Keywords: *participatory practice, game design, mechanics, dynamics, aesthetics*

INTRODUCTION

Two studies by Tan and Kim (2015) on learning design, showed that when adolescents use digital media, they "introduce their out-of-school literacy practices into their school literacy practices" (p. 181). Moreover, designing games, provide opportunities for learners "to construct new relationships with knowledge in the process" (Kafai 2006, p. 36). Studies show that practicing design (in general) and game design (in particular) help learners develop problem solving skills, communication skills, systems thinking, decision making, and social skills, such as taking and negotiating roles, that are necessary skills and competencies in modern world (Baradaran Rahimi & Kim, 2019; Kickmeier-Rust & Albert, 2012; Prensky, 2006; Redecker et al., 2011; Squire, 2006; Sourmelis, Ioannou & Zaphiris, 2017).

Poundstone (1993) suggested that the basic components of a game are player, strategy, and payoff. Players may compete against each other (e.g., Chess), cooperate with other players (e.g., Mysterium), or create an initial pattern with properties and let the game run for itself (e.g., Conway's Game of Life). Strategy is concerned with the rules and actions that players take in a game whereas payoff includes the scores and consequences of actions taken by players (Poundstone, 1993). By this definition, rules explicitly trigger the actions of the player whereas actions are implicitly motivated by payoffs. More recently, Hunicke, LeBlanc and Zubek (2004) suggested mechanics, dynamics, and aesthetics as the basic components of the games, considering games as designed artifacts that are consumed by players. From the designer's perspective, the mechanics bring about dynamics which itself prompts aesthetics (Hunicke, LeBlanc, and Zubek, 2004). From the player's perspective, aesthetics set the tone, which is brought out of perceptible dynamics and mechanics. As a game is designed for players, it is necessary to think about both perspectives of the designer and player while taking into consideration the implicit and explicit relationships of the components.

The objective of this paper is to explore the implicit and explicit relationships of the mechanics, dynamics, and aesthetics when learners as game players take the role of game designers. Moreover, we seek to understand what students learn when these relationships emerge. We discuss how ninth grade students in a west-Canadian junior high school worked together as small teams to design games in a Career and Technology Studies classroom. We collected data through weekly observations and analyzed the data to explore the implicit and explicit relationships existing between mechanics, dynamics, and aesthetics.

THEORETICAL FRAMEWORK

According to Hunicke, LeBlanc, and Zubek (2004), "mechanics is the first and the most concrete component. Mechanics describes the particular components of the game, at the level of data representation and algorithms" (p. 2). They consider that a game is a series of data and algorithms. For example, in Super Mario Bros., Mario has some data like his position. He also has actions such as jumping. Thus, Mario's position and his act of jumping are both pieces of mechanics. The authors offer a second definition and explain that "[m]echanics are the various actions, behaviors and control mechanisms afforded to the player within a game context" (p.3). This definition only references a subset of the earlier definition as it limits and binds itself to players. The second definition challenges and takes away the notion that the entirety of a game's data and actions form the mechanics. For example, the position of the Goombas (the first enemy players encounter) in Super Mario Bros. is not an action, behavior, or a control mechanism afforded to the player. The Goombas perform their role in the game and take positions regardless of Mario's position and action or a control mechanism available to the player. However, it is still a mechanism that is related to data representation and algorithms level holding the characteristics of the mechanics.

Hunicke et al. (2004) suggested, "[d]ynamics describes the run-time behavior of the mechanics acting on player inputs and each other's outputs over time" (p. 2). The term run-time refers to a program when it is executed. Thus, one is playing the game when dynamics takes place. The runtime behavior of mechanics incorporates going from one state to a new one in the game as a result of the actions which modify data. In the last two segments of the dynamics' definition authors make two assumptions. They assume dynamics arise from mechanics acting on player inputs. However, some dynamics are not dependent on the player's input while some others depend on player's inputs. For example, when the player presses B on the controller, Mario jumps as a result of the player's input. Yet, Goomba's always move in Super Mario Bros. in a linear path without receiving any inputs from the player. The second assumption is that the game mechanics works as time progresses. This conveys the idea that dynamics is the flow of mechanics taking place when the game is played. Consequently, one can consider dynamics as a group of related mechanics.

Aesthetics marks the final and most abstract components. According to Hunicke et al. (2004), "[a]esthetics describes the desirable emotional responses evoked in the player, when she interacts with the game system" (p. 2). Here, the focus is on the experience of the player. The aesthetics definition sounds like the positive feeling that a player has when playing a game. The authors give some examples to clarify this definition, including sensation, fantasy, narrative, challenge, discovery, fellowship, expression, submission, and competition. A player may be drawn into the world of the fantasy game, clash against the challenging game, or anticipate every corner of a discovery game. In the authors' sense, aesthetics grows out of dynamics because it reflects player's experience in playing the game. For example, when a player talks about a game and mentions that "it had great exploration" or "it had a poor shooting" s/he is talking about aesthetics. These are the final interpretations based on the game play experience.

Hunicke et al. (2004) define mechanics, dynamics, and aesthetics (MDA framework) from a computer science viewpoint. However, MDA can be also used for describing non-computer games as data and algorithms also exist in a non-digital format in other types of games, such as bord games and card games (Kafai & Burke, 2015). Zimmerman (2009) provided a more operable definition from a design perspective. For Zimmerman (2009), mechanics depicts the specific segments, at the level of rules and physics of the game, dynamics portray the player's interaction with the game, and aesthetics generate sensual and emotional responses in players while playing the game. However, audiovisual attributes of a game can be considered both mechanics and dynamics. Although they represent audiovisual data in the game, they are the primary sources of generating sensual and emotional perceptions in players. We believe that some aspects of the games do not emerge as mechanics, dynamics, and aesthetics but in their implicit or explicit relationships. Explicit relationships host those aspects of the game, such as audiovisual attributes, that directly belong to more than one component of MDA framework while influencing other components. Implicit relationships host those aspects of the game, such as design iterations of the characters' look, that strongly float between the components of the MDA framework and influence them without belonging to any of the components.

RESEARCH DESIGN

The study was conducted in a west-Canadian junior high school. The task was to design an interest driven game in a Career and Technology Studies classroom. In a participatory practice, nine graders worked as groups on different components of their games including aesthetics, mechanics, and dynamics. We collected qualitative data such as observational notes, video recordings of every classroom session, photos of students' in-progress games, students' reflections on their own and others' projects, and interviews. Videotapes of interviews were transcribed verbatim. Observational videos during class sessions were separately logged and notes were taken based on the classroom events. The textual materials, including the video logs, transcriptions, and observational notes as well as the students' reflections were then analyzed in Nvivo 11. We identified themes, categories, and codes related to the objectives of the project. Several sessions of discussing codes, categories, and themes were then conducted until the researchers involved in this paper reached an agreement. Quotations from the students were then selected for inclusion in this paper.

FINDINGS AND DISCUSSION

The work of students showed their developing understanding about the mechanics, dynamics, and aesthetics in their games. Game design practices included various learning outcomes, such as learning about the iterative process of design and the importance of trial and error in developing ideas in a design project. Moreover, learners found opportunities for meaning making while relying on their experiences and preferences as game players engaged in design. We observed the following learning

Figure 1. Voxel War (left) and Meme Game (right) being played.

and development opportunities, especially in two groups (Figure 1). One of these groups included five male students designing a sandbox game, Voxel War, and the other group included four female students designing a card game, Meme Game. We use pseudonyms for the learners in this paper.

Implicit Aspects of Games and Learning About the Iterative Process of Design

Data related to the game characters and representation was one of the areas that learners focused on. For example, Zeus explained the steps he took to develop parts of the Voxel War and mentioned in the interview that "I've gone from sprites to voxels to a different kind of voxel to polygon, which is the more 3D realistic design of characters". What Zeus points at is the iterative process of designing a part of data that represents the characters in the game. The graphic applications that learners used represent the binary data related to a character's look in visuals that are recognizable for players. Characters' look can influence the perception of the players as the vessel to explore and perceive the world of the game. These iterations were important to make sure that the player's perception of the characters is close to what learners want (being realistic). Here, data representation (i.e. mechanics) implicitly addresses the player's perception of the game's world and may influence the player's emotional responses (i.e. aesthetics). One may argue that aesthetics can be more about how components interaction with players evoke various emotions. However, MDA framework does not explain this. Deimos, pointed at the classification of power items in Voxel War and explained that an area which needs more time and effort is "[b]alancing all of the classes and subclasses to make sure that they are used because of the play style and not because it is an overpower". Deimos' discourse refers to the algorithm that must put in place to provide a balance between a dynamic (i.e. play style) and a certain mechanic (i.e. overpowering items). As design iterations are tied with trial and errors which are time consuming, learners needed more time and effort to reach the balance based on trial and errors. Here, mechanics implicitly influences dynamics.

Kratos talked about the mechanisms that Meme Game team embedded in their game. She explained that "[we] had to mix chance with strategies. So that's when players start enjoying it". The balancing mechanism which was implemented at the level of rules in their game (i.e. mechanics) implicitly helps player to make joy out of her playing experience (i.e. aesthetics). Her teammate, Keres, went into details and explained that "before, we were going to play chance and then if you lost you could throw a ball at somebody and that's why we had all the balls but then that didn't really work out 'cause that was all chance still so then we had to get rid of that". This shows the iterative process of design based on trial and error and the process through which learners understood that a part of design does not work. Moreover, Kares exemplified in her discourse a piece of mechanics (the mechanism of punishment and award) in run-time and the dynamics (throwing the ball) that arose from it. When asked how the game is played, Kares replied "you lay down your cards and you roll your dice and then whoever has higher than the attackers can block some of the attacks". Kares not only described the rule (a piece of mechanics) but also described the run-time behavior of the mechanics acting on player inputs (to get or block an attack by rolling dice). Here, the player follows the rule of rolling dice (a piece of mechanics) which implies following the mechanism of punishment and award (another piece of mechanics). Data shows that learners could identify the role of iterative design process in developing the game. Moreover, mechanics can implicitly influence other mechanics, dynamics, and aesthetics in a game.

Explicit Aspects of Games and Meaning Making

There seemed to be a verity of items that appeal to the designer and player in commercial games. For instance, Zeus talked about the narrative for their game, Voxel War, in the interview and explained that "[y]ou're being invaded by another kingdom, it starts in your border village and you have to get to the king, warn him about what's happening, join whichever faction your class is part of. Every 20 levels there's a main story mission that's kind of a huge scale battle. Like the last one is a huge battle in the capital city, you're being sieged, and you have to stop that, and you end up killing the enemy king". Zeus provided certain data related to the narrative, such as, background, motivation, and goal of the game. Such data are meaningful to computer only in binary codes, but the game engines and graphic applications take care of the codes while representing the narrative in audiovisual format that is more meaningful to players. This shows that the learner noticed the importance of narrative in providing a context for meaning making. Such data stand at the level of mechanics which is concerned with data representation and algorithms. Although the narrative can be considered as a piece of mechanics, it directly expresses the background, motivation, and goal of the game to keep the player engaged in dynamics. However, many pieces of mechanics (e.g. rules) implicitly influence dynamics and aesthetics, meaning that they are not directly expressed to the player. Kratos told that the narrative provides a "highly fantasy except there's no elves or dragons, at least as far as we've gone so far". Kratos gives a meaning to the narrative by describing it as highly fantasy. Narrative can alter the overall experience and emotional perception of the game as it gives meaning to the game characters, events, and environments. Here, narrative as a piece of mechanics explicitly influences dynamics and aesthetics of the game.

For Meme Game the explicit aspect of their game was different as it was a boardgame. When asked about the experience of game for players, Kares mentioned that "this one's more tactile". In a boardgame that players touch the game pieces (e.g. tiles) considering tactile attributes of the game can affect the overall experience and emotional perception. In a computer game, however, the tactile attributes of the game are limited to the hepatic feedback that a player receives from the game controller. Tactile attributes can help players to make meanings. For example, the haptic feedback can help players to make deeper meanings of getting shot in the game. Kares response can also be interpreted in relation to the texture. Texture in a computer game is usually a visual attribute. For instance, a wall represented by a rough vs. soft texture in a game motivates different senses in player. Wrong texture in a game can make different meanings for players like a black carpeted floor being represented by a glossy texture (wrong texture). Audio has a similar attribute. When the soundtrack changes during the game as a result of an encounter with the enemy (dynamics) or cheers up the player as s/he completes a level (aesthetics), it conveys different meanings to the player. Audiovisual and tactile attributes of the game can be considered at the mechanics level focusing on data representation and mechanisms. Yet, these pieces of mechanics are explicit and directly influence the aesthetics and dynamics of the game.

CONCLUSION

We described how the students were not only developing a comprehension of mechanics, dynamics, and aesthetics, but also an insight into their implicit and explicit relationships. Some parts, such as the rules of the game, can implicitly influence mechanics, dynamics, and aesthetics. Other parts, such as audiovisual attributes, of the game, can explicitly influence dynamics and aesthetics. While MDA framework is useful to describe game design approach, it still needs to consider the explicit and implicit relationships among the mechanics, dynamics, and aesthetics. We suggest a formal game design approach to learning, so that the relationships and arrangement of game components are considered in addition to the content of the game.

We advocate for adopting game design practices not only to engage learners in deep understanding of design as an iterative process, but also to make new meanings through design. We acknowledge that we could only demonstrate a part of our findings with a limited number of students in this paper. There was a range of guidance that came from teachers and researchers. In addition, students and teachers mentioned other skills, including how students could evaluate their own development, to learn from each other and learn to work together. We are further exploring ways to better support students in thinking about complex systems that they represent in the game.

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BECOMING A MORE EPISTEMOLOGICALLY FLUENT STEM TEACHER: THE MAKERSPACE AS PEDAGOGICAL FRAME

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ABSTRACT

There has been a great deal of hype around makerspaces as learning environments; however, little research has been conducted into how elementary teachers might enact making in classrooms, nor to understanding the constraints that exist within formal school settings, and the fact that many teachers lack confidence and a strong conceptual understanding of STEM subject matter. This design-based research study set out to determine how an elementary teacher might design curriculum for learning within a makerspace setting. The year-long qualitative study involved a grade six teacher and her 27 students in the co-design, co-enactment, and co-reflection of three cycles of making. Though neither the teacher nor the researcher possessed STEM backgrounds, designing and enacting making activities with the students led to the development of epistemic fluency, particularly in relation to STEM, on the part of all participants, including the teacher and the researcher.

Keywords: *STEM, makerspace, epistemic fluency, pedagogy, design-based research*

INTRODUCTION

There is a considerable impetus in education for schools to provide multiple, integrated, and rich opportunities for STEM (science, technology, engineering, and math) learning for students. However, in elementary school settings research suggests that many teachers lack the confidence (Bransford, Brown, & Cocking, 2000; Zimmerman, 2016) and conceptual knowledge in STEM topics to move away from traditional approaches to more inquiry-based methods of instruction. Roadblocks include limited access to sustained and suitable pre-service and inservice training and negative personal attitudes related to teaching and learning in STEM subject areas (Riegle-Crumb, Morton, Moore, Chimonidou, Labrake, & Kopp, 2015; van Aalderen-Smeets, Walma van der Molen, & Asma, 2012). Though teachers acknowledge the importance of students learning in STEM, another challenge facing them is knowing how to integrate multiple STEM topics at once.

There is a tendency for teachers to teach STEM subjects separately (Dare, Ellis, & Roerhig, 2018). Elementary teachers need to be supported not only in building their own conceptual STEM knowledge, but also in learning how STEM learning can be integrated successfully for their students.

LITERATURE REVIEW

Markausaite and Goodyear (2016) suggest that professionals “who are flexible and adept with respect to different ways of knowing about the world can be said to possess epistemic fluency” (p. 1). The key components of epistemic fluency include the ability to collaborate, innovate, persevere in the face of failure, while incorporating interdisciplinary skills toward the building of knowledge (Markausaite & Goodyear, 2016; McLaughlin & Lodge, 2019). McLaughlin and Lodge (2019) purport that the design studio serves as a good pedagogical model in which to develop epistemic fluency because imbued within the ethos of the studio are the very characteristics needed for epistemic fluency. When working there, students advance in their abilities to employ complex problem solving, integrate knowledge from multiple disciplines, see failure as an opportunity for learning, and engage in critical sensemaking (McLaughlin & Lodge, 2019).

The challenge for elementary teachers, who may lack confidence and interdisciplinary knowledge and skills particularly in STEM subjects, is that they require opportunities, which are not often presented to them, to develop epistemic fluency. A pedagogical consideration for STEM learning in formal school settings that is similar to the design studio is a makerspace. Makerspaces are collaborative spaces where participants interact with materials, both physical and digital to create and solve problems of personal interest (Sheridan, Halverson, Litts, Jacobs-Priebe, & Owens, 2014). Given that, makerspaces lend themselves to inquiry and integration of multiple topic areas within the context of an activity. Makerspaces have been determined as potential learning spaces for the development of STEM skills (Halverson & Sheridan, 2014; Martin, 2015) as participants construct ideas through the use of digital platforms.

RESEARCH DESIGN

This paper reports on findings from a recent design-based research (DBR) study conducted with a grade six teacher and her class in Alberta, Canada. The purpose of the study was to explore and articulate the principles that underpin a teacher's design, enactment, and reflection of learning and teaching in an elementary school makerspace. Two questions guided the research: How can teachers be supported in the development of teacher knowledge, pedagogy, and practice within an elementary school makerspace environment? How can teachers support the development of students' conceptual understanding of disciplinary topics in an elementary makerspace? Using McKenny and Reeves DBR model (2018), the study was conducted in three iterative cycles. A researcher and the teacher collaboratively co-designed, co-enacted, and co-reflected on three cycles of making with a focus each time on a particular curriculum area. DBR was chosen for this study, given its collaborative, iterative, and interventionist approach to research (Author 2, 2014;

McKenney & Reeves, 2018). Data included a) audio-taped, semi-structured teacher interviews prior to and after each making cycle, with a follow-up interview conducted early in the next teaching year; b) field notes gathered by the researcher after each making session; c) artifacts developed by the teacher and the students; d) video recordings of making sessions, and; e) text messages, videos, and emails exchanged between the researcher and the teacher. Using initial first cycle exploratory coding, the data was analyzed to determine key themes. Second cycle coding then focused on more detailed and specific theoretical coding of each theme (Saldaña, 2016). Underpinning the research were three key elements: curriculum, learning environment, and design. In particular, the researchers were interested in exploring ways in which the teacher could reframe notions of curriculum by designing for learning in a unique makerspace environment.

RESULTS AND DISCUSSION

Findings showed that in conducting this work, the teacher and the researcher, both of whom did not possess STEM backgrounds, were able to build epistemic fluency by designing, enacting, and reflecting on making activities with the students. The following specific examples will outline how making led to growth in teacher and researcher confidence and epistemic fluency as related to STEM topics.

Engaging in STEM learning Through the Making of a Sky Science Model

The first cycle in the research study began with some pre-making activities that set the stage prior to students entering the makerspace. When designing for student learning, the teacher and the researcher spent time becoming familiar with the history of sky science and prominent astronomers, as well as the ideas and theories that have been confirmed or discounted over time. This was important knowledge for them to understand in thinking about how scientists conduct scientific inquiry: that often they begin with theories based on suppositions and available evidence, which are later extended upon or disproven. Though not explicitly stated in the curriculum, the teacher and researcher decided the students needed to understand this too, so they had them conduct research to learn about key astronomers and their theories.

Another important aspect of the design was presenting to the students four personal characteristics that scientists exhibit in conducting investigations. The four characteristics of scientists: a) They are curious and are always observing the natural world. b) They develop scientific ideas by building on previous theories and understandings. c) They often build models to help them understand complex ideas that they are not completely sure about. d) They work in communities that are constantly asking questions, seeking answers, and disputing ideas. Students were asked to document, throughout the making cycle, when they exhibited the stated characteristics of scientists. This became an important theme in the cycle: noting and acknowledging a scientific way of being. It was later adopted by the teacher across all the making cycles and also within her classroom.

The teacher and researcher also shared with students many examples, through videos and articles, exemplifying how scientists over time have modelled their understanding of sky science phenomenon. They also presented some of the current and past controversies that scientists are grappling with in trying to make sense of the heavens. Finally, students were asked to select a deep thinking question they personally wanted to explore about the sky through the building of a model. Engaging in these pre-making tasks meant the students, teacher, and researcher all entered the makerspace with considerable background about the history of sky science as well as ontological and epistemological ways of being a scientist. It was this design work that the teacher and the researcher engaged in prior to making that presented an opportunity for them to develop epistemic fluency. In learning about the history and current controversies in the field, both the teacher and the researcher were able to consider the ways that scientists know about the world. This served as a powerful example for the students. As the teacher stated, “I think the thing that was beneficial was explaining that we were learning too.” By engaging in STEM learning themselves, the teacher and researcher created a culture of inquiry that wove itself through and beyond the first maker project.

Engaging in STEM Learning Through the Concepts of Democracy and 3D Modeling.

In the third cycle, the teacher and researcher offered students the chance to design a metaphor for a core concept of democracy, such as freedom, equity, or equality. Students could choose to build their metaphor with physical materials, or digitally using the 3D modeling software Tinkercad for 3D printing, or a design software Easel, for use in a CNC milling machine. Most students, though not all, chose the digital route. Neither the teacher nor the researcher nor the students were completely familiar with the design and modeling programs. Students created a hand drawn mockup of their metaphor, and then in the context of learning the modeling or design programs, iterated their designs. The teacher noticed that she and the researcher stepped back to watch the students collaborate with each other in the design and modelling process. She commented how impressed she was “in terms of the attitudes of the students. I found all of them, they really worked on the programs that they were using. I’d say the majority of them chose something out of their comfort zone . . . And they really persisted toward that final product, you know, learning the programs especially, that we didn’t really have any knowledge of.” She went on to say “they were helping each other, they were doing research on their own so I felt like I actually didn’t have a role in that, which I think is a good thing.” What emerged as a key theme in this cycle is how the students took the scientists’ characteristics from cycle one, and continued to embody them in the final cycle of making. Of particular note related to epistemic fluency, was their work as a collaborative community.

Engaging in STEM Learning Through Scientific Modeling and Computational Thinking. The following year after completion of the study, the teacher was interviewed to determine how she was taking the learning from her maker research experience forward. She identified key insights into how she "had changed" as a teacher, including a willingness to step out of her "comfort zone in teaching the kids something that I wasn't necessarily an expert in." She also referenced "the sense that I'm not the only person in the room that knows what we're doing," as well as being comfortable engaging in making tasks where she was not an expert. "I'm openly telling the kids . . . So that's been really powerful for me to learn that and be okay with it." She has also learned to spend more time watching the students, when she stated, "And I really just stepped back." She spoke of "giving them the power." At her behest, her new class had already engaged in numerous making activities that involved both digital and physical materials. A few weeks after the follow-up interview, the teacher excitedly shared an example of a STEM activity she initiated with her students. The school district technology coordinator lent her a dozen Sphero robots and encouraged her to implement them in some way in her class. Not being familiar with how they might be used, she initiated a challenge to her students based on the sky science maker work from the previous year. She asked the students to model a moving solar system using the Sphero robots, where each robot would stand in as a planet. She also explained to the students that she did not know much about the robots or how to code them, and she would like them to solve that problem. Through a series of text messages that included videos showing her students at work, she shared her idea and the student results with the researcher on Wednesday of that week.

"Using Spheros to represent our solar system. And they have figured it out so quick!"

When the researcher texted back to ask if they had the robotic spheres spinning as well as rotating, the teacher replied: "They will be rotating by Friday! We have to adjust the timing. They all just collided today. Haha." On Friday, the teacher sent a further series of texts and videos showing the robotic planetary models rotating around a robotic sun: "They did it!!!! I literally did nothing. They were so amazing. I wanted to cry." The teacher enthusiastically sharing a concrete example of how she has changed demonstrates her developing epistemic fluency. Her willingness to continue to stretch her own STEM learning without the benefit of the researcher being present is a testament to the confidence she has gained in relation to STEM. In presenting herself as a STEM learner to her students, she has empowered them to also be STEM learners. What is significant also is her ability to imbue a positive attitude toward failure (when the planets were colliding) and to exude joy in the students' and her own STEM learning.

DISCUSSION

In analyzing change in the teacher, the researchers observed four elements key to her epistemic development: (a) opportunities to learn about STEM in the context of designing for STEM learning; (b) opportunities to risk take; (c) opportunities to collaborate, leading to meaning making about STEM (d) opportunities for iterative experience, therefore building knowledge and confidence in regards to making and STEM processes. In all three of the examples, the teacher along with her students became more comfortable with disciplinary ways of being, for example, how scientists use modeling to understand the night sky, how designers iterate and play with big ideas, how coders use observable data and logic to solve problems. The teacher, over multiple iterations of making with her students accessed skills across disciplines to build knowledge and epistemic fluency. In particular, the teacher engaged in significant risk taking. She approached making tasks with her students as a way to consider specific skills used in specific STEM disciplines that were then adopted in interdisciplinary ways.

DBR, as methodology was a key factor. Through joint collaboration, the teacher and the researcher were able to create opportunities not only for the students but also themselves to become STEM learners. Working together they engaged in innovative, though sometimes risky undertakings that built confidence and epistemic fluency in themselves and their students across STEM disciplines. Over time, their confidence grew. As Markauskaite and Goodyear (2016) state, "in shared meaning making, frames are viewed as more flexible and multi-dimensional 'webs of meaning' that structure shared experiences, reduce complexity and provide a basis for taking action" (p. 541). The teacher and researcher initially did not see themselves as STEM teachers. By changing the frames of themselves and the students, they were able to actively reconsider and reconfigure how STEM learning would take place. Key was the makerspace environment where "reframing emerges as chains of coordinated epistemic actions closely coupling one's internal mental resources with the material and social affordances of the external environment" (Markauskaite & Goodyear, 2016, p. 548). The "material and social affordances" of the makerspace ensured that the teacher, the students, and the researcher could share ideas, collaboratively problem solve, take risks, and build knowledge together. This, combined with exploration and learning through the design process which employed the pedagogical and disciplinary resources of both the teacher and researcher meant that the teacher could reframe her notion of what it means to be a STEM teacher and learner.

CONCLUSION

Reframing is, as the conference theme suggests, "changing the story." Designing for making provided an opportunity for the teacher and the researcher to develop epistemic fluency, particularly in relation to STEM learning. By embracing a maker approach to STEM, the teacher was not only able to change her students' stories, she also changed her own story. Two important considerations must be noted. First, the teacher felt her development would not have taken place without the collaborative support of the researcher through DBR as methodology. This support was critical in promoting her epistemic fluency. Secondly, the researcher felt further professional development to deepen conceptual understanding in STEM disciplines would augment the teacher's learning experience in the makerspace.

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STEAM EDUCATION IN CANADA: STUDENT LEARNING AND TRANSFERABLE SKILLS

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ABSTRACT

Globally, interdisciplinary and transdisciplinary learning in schools has become an increasingly popular and growing area of interest for educational reform. This prompts discussions about STEAM (Science, Technology, Engineering, Arts and Mathematics), which is shifting educational paradigms towards art integration in STEM subjects. In a traditional classroom authentic tasks that are set in a real-world context are rarely used in teaching; yet these tasks although ill-defined problems provide experiences for addressing complex or multistep questions that are approachable through multiple pathways. Authentic tasks also offer opportunities to integrate disciplines across the science and arts, such as in STEAM. The main purpose of this study is to better understand the STEAM instructional programs offered by non-profit organizations and by publicly funded schools in Ontario, Canada. This study addresses the following research question: What interdisciplinary and transdisciplinary skills do students learn through different models of STEAM education in non-profit and in-school contexts? We carried out a qualitative case study in which we conducted interviews, observations and document analysis of curriculum documents. A total of 103 participants (19 adults – director and instructors/teachers – and 84 students) participated in the study. The four STEAM programs comparatively taught both discipline specific and beyond discipline character-building skills. The skills taught included: critical thinking and problem solving; collaboration and communication; and creativity and innovation. The adult participants described these skills as transferable and workplace skills. The findings of this study have implications for designing and implementing STEAM programs that promote the teaching and learning of transferable skills.

Keywords: *STEAM, STEM and arts, STEM and creativity, art integration, integrated curriculum, art-based curriculum, STEAM and Canada, transferrable skills, transdisciplinary, 21st century skills, domain-general skills, workplace skills*

INTRODUCTION

Globally, interdisciplinary and transdisciplinary learning in schools has become an increasingly popular and growing area of interest for educational reform. This prompts discussions about STEAM (Science, Technology, Engineering, Arts and Mathematics), which is shifting educational paradigms towards art integration in STEM subjects. According to Reeves et al. (2004), learning opportunities for students should include authentic tasks set in a real-world context, which can encourage students to integrate across the disciplines, such as in STEAM. The main purpose of this study is to better understand the STEAM instructional programs offered by non-profit organizations and by publicly funded schools, the learning tasks they offered to students and what students are observed to learn from these programs. This study addresses the research question: What interdisciplinary and transdisciplinary skills do students learn through different models of STEAM education in non-profit and in-school contexts?

LITERATURE REVIEW

Industry, political, and educational leaders rally behind initiatives that support students to develop workforce competencies, such as by "'promoting deeper' learning through skills such as problem solving and collaboration" (Allina, 2018, p.80). STEM and STEAM education scholars agree that STEAM initiatives enable students to transfer their knowledge across a discipline and solve creative problems in another context, both in the classroom and out-of-school (Gess, 2017; Liao, 2016).

According to Hughes (2017), students need these character-building skills or transferable skills "to develop and apply for successful learning, living and working" (p. 102). STEAM teaches students skills, such as "critical thinking and problem solving; collaboration and communication; and creativity and innovation" (Liao, Motter & Patton, 2016, p. 29) that can be transferred to another context.

Transdisciplinary approaches to STEAM education are highly valued by both the teacher and the student because it allows the student to view the problem or design process from multiple angles or different perspectives that can be applied to a real-world context (Costantino, 2018). Similarly, Gadanidis (2015) created "low floor, high ceiling, wide walls" activities that provide multiple entry points, multiple ways to approach a problem, and multiple representations so that students of all ages and abilities can participate.

THEORETICAL FRAMEWORK

I used three of Kolb and Kolb's (2005) guiding principals of experiential learning theory as a framework to analyze the interdisciplinary and transdisciplinary student learning in the STEAM programs. The main guiding principles of experiential learning theory according to Kolb and Kolb (p. 3, 2005) are the following: learning is best conceived as a process, learning is a holistic process of adaptation to the world and learning is the process of creating knowledge. Kolb's framework resonates with Papert's work. Papert's (1980) constructionism theory of learning is foundational to Maker education which is guiding the adoption of the broader maker culture and makerspaces (Halverson & Sheridan, 2014) in schools. Kolb's work also resonates with the emphasis of the processes as developed in design-based learning and learning of transferable skills.

RESEARCH DESIGN

According to Yin (2004), a case study focuses on a bounded-system and sheds light on a situation. This research was a qualitative case study. The main purpose of a case study is to focus on a phenomenon, such as a process, event, person, or other area of interest (Gall, Gall, & Borg, 2007). A collective case study, in which the researcher selects more than one case to provide a representative sample enables more theoretical generalizations (Cousin, 2005). We took a sample of four different STEAM programs in Ontario, Canada, two non-profit organizations and two in-school research sites with a total of 103 participants, 19 adults and 84 students. Table 1 describes differences between non-profit and in-school research sites. We collected data from document analysis, observations and interviews. The lead author observed the participants during the lessons. She also conducted conversational interviews using openended questions. Interview transcripts were manually coded to analyze emerging themes. We also searched for key words, themes, and trends in the curriculum documents, specifically those related to skills learned and to instruction. We ascertained how the emerging themes connected with the preexisting themes based on the literature on student learning, teacher pedagogy, and instruction.

Table 1. Description of Research Sites

	Description
Non-Profit 1 and 2	Non-Profit 1 is a one room STEAM lab/center with a large space divided by movable walls, while Non-Profit 2 has multiple rooms with stations on different floors. The STEAM center/lab is in a metropolitan area. Both cater for K-7 children and with programs for teens/adults. They offer paid programs. Staff at the non-profit sites consists of a director, instructors and volunteers.
In-School 1 and 2	In-School 1 has stationary work benches, while In-School 2 has both stationary and mobile stations. Both in-school sites are urban public schools, K-8, in a metropolitan area and set in the Maker Lab (i.e., Library Learning Commons). Staff at the in-school sites consists of a teacher librarian and selected school teachers.

RESULTS AND DISCUSSION

This paper presents the research results of the observations, interviews and curriculum document analysis.

Student Learning and Transferable Skills

The curriculum documents that were shared with the researchers from each of the STEAM programs showed that students learned character-building skills, which are transferable skills to other contexts, such as in post-secondary education. The students also learned academic skills from the STEAM activities. In the field, the directors, instructors, teachers, teacher librarians used the word "soft skills" to describe the character-building skills, such as critical thinking and problem solving. These encompass skills learned beyond the STEAM content curriculum. During the observation of the sessions, the lead researcher noticed and took field notes on these skills. Participants also commented about these skills when responding to interview questions. At In-School 1, for example, the teacher librarian commented on these skills.

> Interviewer: What would you say are the learning objectives for this STEAM program?
>
> Teacher Librarian: "I'm all about giving them skills to express their ideas, transferable skills so they can take with them to the next grade level [and use it] in unconventional ways."

Curiosity

Both non-profit cases used games and storytelling to pique the interest and curiosity of their students. At Non-Profit 1, the director explained that "the first stage is play so that they can experiment with the technology [to] get an idea of what it can do, [and] get excited about it." At Non-Profit 2, students were given the opportunity by the instructors to tinker and play with the craft materials and technologies, such as Tinkercad (i.e., 3D modeling program) to spark their interest and curiosity. In Contrast, both inschool cases used inquiry-type questions to get students to wonder, stir their imagination and pique their curiosity. In the post-observation interview, the special education teacher expressed that the "inspiring piece [is] . . . doing these type of learning activities . . . you are activating kids' natural curiosity, their natural interest in figuring out how things work and how they can make things better" (In-School 2).

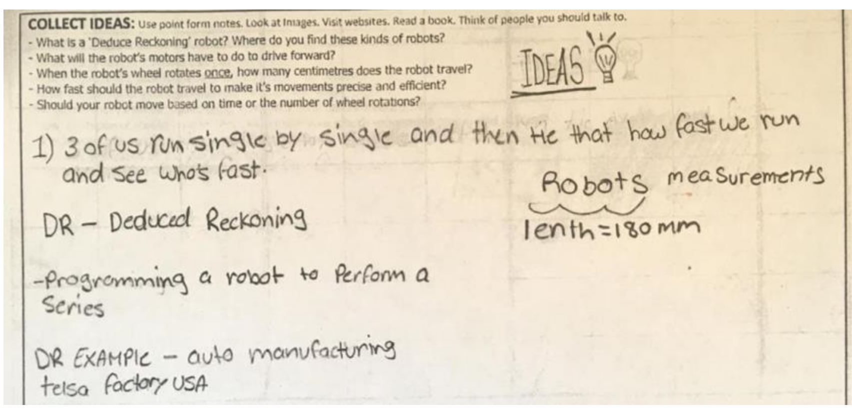
Oral Communication

Non-Profit 1 and 2 facilitated group discussions with their students and prompted them to answer inquiry-type questions as a class. At the in-school research sites, students documented the "making process" and expressed their thoughts verbally. At In-School 1, the students documented every stage of the making process in a video to capture their observations, creations and group discussions. The teacher librarian commented that the intent of the documentation was to "drive their thinking forward" and appeared to deepen the students' understanding as they reflected on, articulated and then shared their thoughts and ideas.

Written Communication

The two non-profit sites provided students with the opportunity to write during the activities. NonProfit 1 clearly indicated specific tasks in their lesson plans where students communicated their ideas in writing. For example, when coding in Scratch, a visual programming language, students were asked to write a story by creating a plan and a sequence of events for their characters. At Non-Profit 1, during the planning stage of their projects, students sketched their ideas and expressed their thoughts through writing and drawings on paper.

In-School 1 encouraged students to document the making process by writing and completing a handout provided by the teacher librarian. The handout provided space for the following student communication: to write their answer to the inquiry questions about the activity, to write notes resulting from their internet searches and to write out a plan for their design (as seen in Figure 1). Similarly, at In-School 2, the Grade 5 students were, specifically, prompted to complete a written log that documented every stage of the design-inquiry process.


COLLECT IDEAS: Use point form notes. Look at Images. Visit websites. Read a book. Think of people you should talk to.
- What is a 'Deduce Reckoning' robot? Where do you find these kinds of robots?
- What will the robot's motors have to do to drive forward?
- When the robot's wheel rotates once, how many centimetres does the robot travel?
- How fast should the robot travel to make it's movements precise and efficient?
- Should your robot move based on time or the number of wheel rotations?

IDEAS

1) 3 of us run single by single and then tie that how fast we run and see who's fast.

Robots measurements

lenth=180mm

DR – Deduced Reckoning

-Programming a robot to Perform a Series

DR EXAMPLE – auto manufacturing telsa factory USA

Figure 1. At In-School 1, students wrote information in the Collecting Ideas section to answer the inquirytype questions that would help them build/program their robot.

Perseverance and Adaptability

At Non-Profit 1, the instructors used picture books to get kids (6-9 years old) to discuss the selected transferable skills such as adaptability and persistence skills. Students, for example, discussed their views on making mistakes. The instructor at Non-Profit 1 said she wanted her students to "not be afraid of making mistakes and trying new things." When asked about "what type of curriculum or instructional models do you commonly use in the STEAM lab/centre?" the director at Non-Profit 1 responded that "the main thing I want them to learn is perseverance" and he has built into the lesson "failure and iteration." Both non-profit and in-school cases got students to plan, design, make a prototype, test, redesign and, when the prototype did not work, repeat the design-inquiry process to develop persevere (see Figure 2).

Prototype: test and redesign Final product:

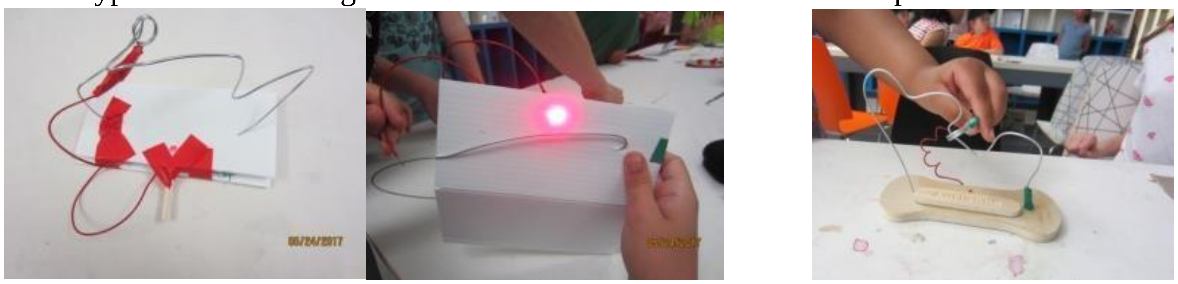


Figure 2. At Non-Profit 2, students designed and built a prototype to make their own buzz wire game. Student changed the material used to make a more efficient version of the buzz wire game.

At the in-school and non-profit sites, 12 out of 15 adult participants mentioned perseverance during the interviews. For example, when the teacher librarian was asked what the students learned she answered, “developing perseverance and grit in an openness to try new things” (In-School 2). The teacher librarian explained “that’s one of the things that we’re trying to build is perseverance and risk taking and grit” (In-School 2). The teacher librarian at In-School 1 talked about “growth, . . . persistence and keeping a positive frame of mind.” Similarly, the Grade 5 teacher mentioned that he “saw a lot of [perseverance]. . . and problem solving even with robotics, they had to code the robot to move around a shape and escape the maze through using trial and error and you know they had to keep going and not give up” (In-School 1).

Collaboration

Both non-profit cases encouraged students to collaborate and work as a team when they were given group challenges. For example, in the spaghetti challenge, students had to build the tallest free-standing structure, or in the class mascot challenge where students had to design an original mascot character for their team using wood and the laser cutter (see Figure 3). In the interview, the director at Non-Profit 1 explained that their goal was to teach the students’ “personal skills . . . which are collaboration, knowledge about themselves, . . . [knowledge] about their own personal strengths and challenges” so they can effectively work as a team. On the other hand, the two in-school sites provided students with the opportunity to work collaboratively on mini-assignments or group projects that were more in depth and could take multiple days to complete.

Figure 3. Students sketched, designed and created a team mascot using the laser cutter at Non-Profit 1.

The in-school STEAM programs provided students with several opportunities to work in groups whether they were designing a robot, creating a pattern in Minecraft, programming a robot such as LEGO EV3, Ozobot or Sphero to move around a perimeter or move to the beat of a song. At In-School 1, a Grade 2 teacher expressed that she "think[s] that collaboration is absolutely key." A Grade 5 teacher found that when kids did not know what to do "after they explore[d] and [then were given opportunities to] collaborate with their own teammates . . . they would create these amazing things" (In-School 1).

Critical Thinking

Non-Profit 1 was not as concerned with the product as much as the process. The director said that one of the student learning objectives "is critical thinking, so that they can make a plan . . . and critically analyze your plan" (Non-Profit 1). At Non-Profit 2, students were given various tasks that would prompt them to use critical-thinking and problem-solving skills, such as creating a conditional (if-then) statement in a programming language for novices (e.g., Scratch or Java script) in which they had to check for errors when their program was unsuccessful. At the in-school sites, the learning objectives for two of the STEAM disciplines, science and mathematics, appeared to enhance students' opportunities to use critical-thinking and problem-solving skills. Each lesson at In-School 2 focused on a question or set of questions that prompted students to brainstorm about a real-life context, like "How might we get Georgie [the robot] home and describe the path?" Students were given the opportunity to answer questions such as this one by representing Georgie's path home using multiple approaches. Further, students used unplugged methods (i.e., methods with no digital and screen technology, such as string stories, drawings, LEGO creations and arrow diagrams), as seen in Figure 4, to focus their minds on and solve selected problems. In this example, students had to think critically about mathematics concepts such as distance, direction, angles and scale factor of the path they defined for the robot. Thus, the students had to further use problem-solving skills to transfer their unplugged solution to their digital solution simulated by programming a robot to follow a specific path.

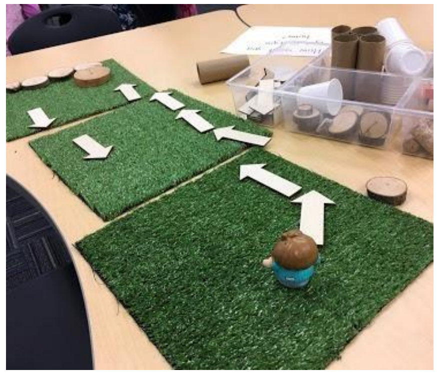


Figure 4. At In-School 2, students made an arrow diagram or collage.

The STEAM programs in this study were observed by the researcher to teach character-building skills, such as critical thinking and problem solving; collaboration and communication; and creativity and innovation that can be used in another context (i.e., home, post-secondary education and the workforce). This appeared to provide teachers with the opportunity to design activities that encouraged students to learn holistically by finding both purpose and meaning as well as creating their own knowledge (Kolb & Kolb, 2005). These findings are in line with the literature on STEAM education in which students can transfer their knowledge across disciplines to solve problems in another context (Gess, 2017; Liao, 2016). A Grade 5 teacher at In-School 1 echoed the development of learning workforce competencies among students by saying "I think the biggest thing is [STEM/STEAM] just speaks to kids, this is their language right now. This is their world if you think about like future job opportunities this is like 21st Century learning for kids."

CONCLUSION

Politicians, education and industry leaders tend to focus on the academic skills and career paths of students whereas in the STEAM programs in this study the instructors/teachers valued the process and the character-building skills that students developed, which is inline with Kolb and Kolb's (2005) guiding principle of the experiential learning theory which states that learning is best conceived as a process. For example, students were given the opportunity to document the making process to develop a deeper understanding. Students were also encouraged to persevere by taking risks, making mistakes, and by developing grit to persevere on tasks that as described in this paper were multi-step tasks. The activities appeared to start with "low floor" entry questions such as those that made students curious or in which they wrote about their design plans. Also, the activities appeared "high ceiling" as students moved on to learn the technology hard skills of fabricating, programing, soldering and wiring their designs. The activities were also "wide walls" activities because they allowed multiple ways to approach a problem and encouraged both creativity and curiosity (Gadanidis, 2015). As educators, researchers and policy makers the goal should be to seek to provide STEAM learning experiences in classrooms for all learners to get students to engage, learn and transcend their knowledge across individual disciplines so that their knowledge can be applied to other contexts and may provide students with more meaningful experiences. The findings of this study have implications for designing and implementing STEAM programs that promote the teaching and learning of transferable skills. The scope of this paper is limited since it focused mainly on the character-building skills and briefly discussed the academic skills.

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MEASURING CHANGES IN SCIENTIFIC SKILLS AND ATTITUDES FOR NONSCIENCE MAJORS IN A THREE-WEEK LABORATORY COURSE

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ABSTRACT

A 3-week block course, Interdisciplinary Studies 137 (IDS 137) was recently introduced at our campus. IDS 137 is a laboratory course designed to introduce students registered in nonscience majors to scientific skills and attitudes using four-day rotations through biology, chemistry, and physics laboratory experiments. The course objective is to maximize student learning of scientific modes of thinking and doing while minimizing disciplinary content. To evaluate whether the course was achieving this objective, our newly developed Augustana Interdisciplinary Scientific Literacy Evaluation (AISLE) was administered to all students as a pre- and post-test to quantify changes in scientific skills and attitudes. Numeric AISLE scores for study participants (n=102) drawn from students registered in 2018 and 2019 were analysed using a paired Student's t test. Our analysis revealed post-test scores increased for the majority of participants and the increase was highly significant (p=0.007). Separate analyses of questions coded for scientific skills or attitudes revealed a significant increase (p=0.023) only for questions coded for scientific skills, but no significant change in scores on questions coded for scientific attitudes. These results demonstrate that an interdisciplinary science laboratory course can facilitate learning of scientific skills by non-science majors using a compressed course format that does not emphasize content. The AISLE was also shown to be a convenient and useful tool for measuring changes in participants' scientific skills and attitudes.

Keywords: *post-secondary, scientific skills, scientific attitudes, quantitative survey, non-science students*

INTRODUCTION AND LITERATURE REVIEW

Institutional Context

Augustana is a Liberal Arts and Sciences campus of the University of Alberta located in Camrose, Alberta. As a Liberal Arts and Science faculty functioning within the research-intensive University of Alberta, part of Augustana's mandate is to serve as a "living laboratory for teaching and learning innovation, to the benefit of the entire university" ("University of Alberta Strategic Plan,"). With approximately 1000 students enrolled across disciplines, STEM faculty at Augustana encounter learners with a wide variety of academic backgrounds and prerequisite knowledge in STEM. One innovation at Augustana initiated in 2017 was the campus-wide adoption of the new Augustana Academic Calendar that introduced a new semester structure; a 'block-hybrid' model. Rather than students enrolling in five courses simultaneously for each of Fall and Winter semesters, semesters are divided into two portions. Each semester begins with a 3-week 'block' course in which students take only a single course (meeting each day for three hours) followed by an 11-week session in which students simultaneously take four courses.

Course Design Goals

The new Augustana Academic Calendar provided us the unique opportunity to design a laboratory course targeting non-science learners. Our objective was to invite non-scientists to experience one of the intrinsic ways in which scientists learn about the world: through laboratory experimentation. This course was designed to help non-science learners fulfil their degree distribution requirements rather than as an entry point to STEM programs. Therefore, our overarching goals were to make sure learners enjoyed the lab experience (affective domain) and developed a general appreciation for modes of thought common in STEM disciplines rather than focusing on particular content knowledge (cognitive domain). So while some introductory lab techniques and disciplinary knowledge were necessary, we primarily focused learning on developing general scientific skills (eg. graphing and numeracy) and attitudes (eg. relying on experimental evidence).

Interdisciplinary Studies (IDS) 137

Interdisciplinary Studies (IDS) 137 – *Scientific Laboratory Experiences* has no prerequisites and enrolment requires participants to have completed no more than three credits of science courses that have an associated laboratory. Typical students are registered in a B.A. majoring in the Fine Arts, Humanities or Social Sciences. The course begins with one introductory meeting to familiarize learners with the course structure and the basics of scientific thinking, followed by four experiments in each of biology, chemistry, and physics. The class is divided into three cohorts who will each encounter the three disciplinary 'blocks' in a different order to increase throughput in the laboratory spaces. Each instructor presents the same four experiments three times successively with different groups of students. For a schematic overview of the course structure, see Figure 1.

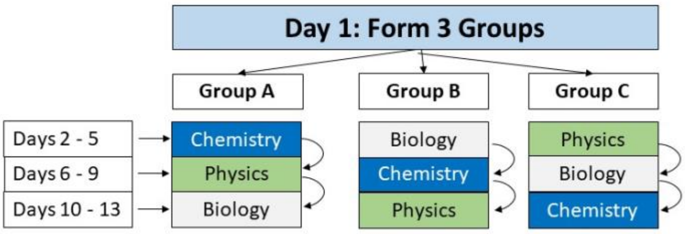

Figure 1. Schematic representation of IDS 137 course structure.

Each disciplinary block has a similar evaluative structure. First, there are two types of prelab assignments. Before each lab, a brief assignment focused on safety and experimental design is submitted. Prior to each of the first three experiments there is a second assignment intended to introduce learners to relevant theory or a common mode of disciplinary thinking. Second, following each of the first two experiments, participants submit a brief data analysis assignment that guides the learners to practice manipulating their data and drawing conclusions about the data. After the third experiment, learners prepare a short laboratory report in the structure of a scientific article. Finally, following the last experiment in a block, participants deliver a brief oral report in the form of a conversation with the lab instructor to describe their experimental results and demonstrate their learning from that block. For an outline of the evaluative components of the course structure, see Figure 2. For a summary of individual laboratory exercises, see Table 1.

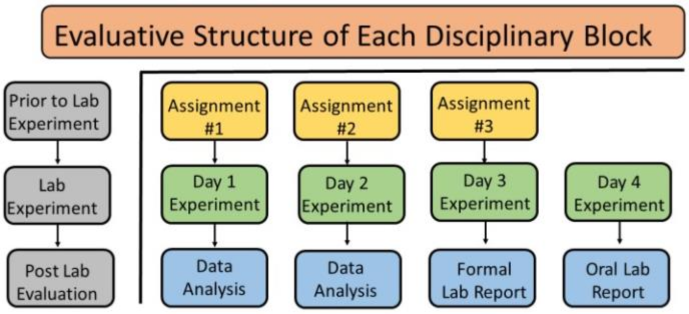

Figure 2. Schematic of IDS 137 disciplinary block structure with associated evaluative components.

Table 1: Summary of IDS 137 Laboratory Exercises and Topics		
Discipline	**Experiment Title**	**Topics/Themes**
Biology	#1: Microbial Transmission	testing hypotheses, experimental design, recording data, scientific writing
Biology	#2: Extraction and Analysis of DNA	cellular fractionation, colour changes, graphing
Biology	#3: Microscopy	observations, qualitative data, instrumentation
Biology	#4: Transpiration in Tomato Plants	testing hypotheses, experimental design, analysing data, real-world applications
Chemistry	#1: Dye-Sensitized Solar Cells	green energy, popular science
Chemistry	#2: Reactions of Copper	colour changes, glassware, simple reactions
Chemistry	#3: Bleach/Food Dye Reaction Kinetics	instrumentation, solutions
Chemistry	#4: Soda Geyser	experimental design
Physics	#1: Terminal Velocity	experimental records, graphing
Physics	#2: Measuring Musical Frequencies	instruments, testing hypotheses
Physics	#3: Finding Absolute Zero	thermodynamics, extrapolation
Physics	#4: The Polarization of Light	designing models, real-world applications

With these goals in mind, the question remained how to evaluate whether a 3-week intensive, lab-based experience could produce improvement in learners' scientific skills and attitudes (SSA).

Augustana Interdisciplinary Scientific Literacy Evaluation (AISLE)

To measure whether completing IDS 137 produced gains in SSA, we wanted to use a quantitative pre- and post-test instrument. While there are a number of excellent concept inventories (CIs) available in each of biology (for example: (Newman, Snyder, Fisk, & Wright, 2016), chemistry (for example: (Bretz & Mayo, 2018), and physics (for example: (Hestenes, Wells, & Swackhamer, 1992)) that can be used to measure gains in scientific knowledge, these tools do not suit our purposes. First, CI tools are designed to measure changes in knowledge for science students (often disciplinary majors), which excludes our IDS 137 students. Second, the CI tools are focused on specific topics within a discipline, rather than general scientific skills. Similarly, while there are useful tools for measuring attitudes towards science at both post-secondary (Adams et al., 2006) and K-12 levels (Moore & Foy, 1997), these tools were not designed to simultaneously measure changes in participants' general scientific skills. To our knowledge, there is no published tool that simultaneously measures SSA for non-scientists. Furthermore, we are not aware of any tool designed to quantitatively report on students' scientific attitudes that does not rely on a Likert scale. We desired a tool for our particular context, that was easy to administer and gave numeric data that was easy to analyse, and could potentially detect any statistically significant changes in participants' scientific skills and/or attitudes.

To meet our needs, we designed and calibrated the Augustana Interdisciplinary Scientific Literacy Evaluation (AISLE). Briefly, AISLE is a series of twenty multiple choice questions designed to provide a quantitative measure of a participant's SSA. Students are asked to select the best response to questions about either a scientific skill or way of thinking, with the potential answers having been categorized by scientific experts (science faculty members holding a Ph.D. in a scientific discipline) as either "expert", "intermediate" or "emerging"(Adams & Wieman, 2011; Bass, Drits-Esser, & Stark, 2016). For a full listing of the target skills and attitudes in AISLE, see Table 2. Each question has one answer coded as "expert" which is scored for two points, two answers coded as "intermediate" which are scored for one point, and two answers coded as "emerging" which are scored for zero points. Thus, a perfect AISLE score is forty points, and the average score that should be obtained by guessing is sixteen points (8 points from guessing the expert level answers on four questions and eight points for guessing one of the two intermediate answers on eight questions). Complete details for the development and calibration process for AISLE will be presented elsewhere (*In Preparation*).

Herein, we describe our efforts to measure whether completion of IDS 137 produced gains in students' scientific skills and/or attitudes using our recently developed tool AISLE.

Table 2: Summary of Target Scientific Skills and Attitudes in AISLE

Scientific Skill	Scientific Attitude
Graph interpretation	Instruments and measurements
Estimation and checking the reasonableness of results	Trust in the scientific process
Relating theory to observation	Mathematical models and experiments
Proposing an experiment to test a hypothesis	Disagreement in science
Measurement units	Ethics in science
Simplifying models and limiting cases	Serendipity in science
Numeracy	Scientific theories
Uncertainty in measurements and interpretation	Science and the media
Types of variables	Scientific thinking
Inductive reasoning	Who are scientists

RESEARCH DESIGN

Our research was motivated by genuine curiosity whether completion of IDS 137 produced gains in SSA among our target population of non-science students, especially given the compressed (3-week intensive) format and the experiential nature of laboratory learning. The AISLE was administered as a pre-test (Day 1 of the course) to obtain baseline data for each student and a posttest (end of Day 13 of the course). Any changes in AISLE scores were assumed to arise from the IDS 137 learning experience. Data from students registered in five separate sections (Winter 2018 and 2019) were pooled and analysed. No specific demographic data was collected, although the course prerequisites made it such that no learner could have completed more than three credits in science courses with associated labs. At Augustana, this excludes students in biology, chemistry and physics majors from enrolling in IDS 137.

Students received a small participation grade for completing AISLE as both a pre- and posttest. AISLE numeric scores were only used for course evaluation purposes and did not contribute towards students' course grades. If enrolled students consented, then the AISLE scores were also used for research purposes as described below. Out of a total of 110 students that completed IDS 137, 103 students agreed to participate in our study. Each participant was assigned a research code then the anonymized data were recorded in Microsoft Excel. Statistical analysis of the AISLE pre- and post-test scores was done using a paired samples Student's t test with open source software (JASP version 0.11.1, JASP team 2019). This study has been reviewed and approved by the University of Alberta's human research ethics board (Study no. Pro00077148).

RESULTS AND DISCUSSION

Our study includes AISLE scores pooled from participating students enrolled in five different sections of IDS 137 over two terms. A normality test (Shapiro & Wilk) of the data set revealed that one data pair deviated significantly from normality, so this pair was removed from the statistical analysis (data set, n=102). By administering a paired t test, each participant's AISLE pre- and post-test scores were compared and trends in the change between those two scores detected. The pre-test mean AISLE total score was 29.7, which is in close agreement with the value obtained from our previously collected calibration data (29.2, n=107) from 1st-year students registered in a non-science major (*In Preparation*). Thus, using the AISLE in a different setting yielding similar pre-test scores supports the validity of the tool.

Pre- and post-test comparison of AISLE scores indicated 55 study participants had an increased score, 15 had no change and 33 had a decreased post-test score (Figure 3). Statistical analysis of the total scores of all participants using a paired t test indicated the average post-test score increase of 0.863 was highly significant (p=0.007, Table 3). Separate examination of the questions coded as measuring scientific skills revealed an average change in score of 0.618 that was statistically significant (p = 0.023). Questions probing scientific attitude also had an increase of the paired score average of 0.245; however, this increase was not statistically significant (p=0.197). Thus, our analysis indicates that the majority of the improvement in overall scores can be attributed to improvements in learners' scientific skills.

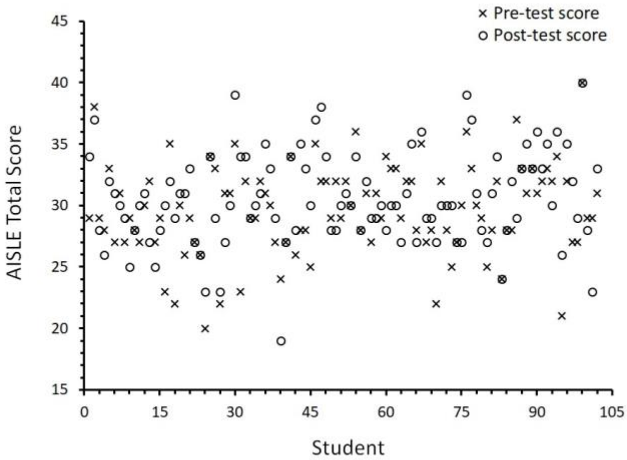

Figure 3: Paired pre- and post-test AISLE scores for IDS 137 students (N=102).

Table 3. Average Paired Score Differences and Statistical Analysis		
AISLE Question Type	**Paired Score Difference**	**Paired t test**
Total	0.863	0.007
Skills	0.618	0.023
Attitudes	0.245	0.197

Although IDS 137 students completed exercises and assignments that were designed to foster both scientific skills and scientific attitudes, AISLE scores indicate that scientific skills were acquired more effectively than scientific attitudes. The data suggest that scientific skills are more easily acquired than attitudes in the context of the condensed laboratory course, which could be attributed to the experiential nature of the learning experience. The question of student motivation (Ambrose et al., 2010) is also likely a contributing factor; learners will inherently be forced to employ scientific skills (eg. Graphing) to succeed in the course because many of the graded assignments require use of such skills. In contrast, it is possible to adopt an extrinsically-motivated, utilitarian approach to success in the course that does not require internalization of scientific attitudes (eg. Relying on experimental evidence).

The highly significant change in total AISLE scores is evidence that, over the duration of the course at least, the 3-week experiential laboratory course IDS 137 produced measurable gains in participants' SSA. The significant increase in score for questions coded as measuring scientific skills demonstrate that skills can be effectively taught to non-science majors in a compressed course format. One outstanding question is whether a similar gain in SSA could be achieved in a classroom-based course in the 3-week block format. It can be hypothesized that the active nature of laboratory learning may help learners acquire SSA, but that cannot be determined from the present data.

CONCLUSIONS

The AISLE was used as a pre- and post-test to quantitatively measure gains made by nonscience students (n = 102) who completed IDS 137, a 3-week, interdisciplinary science laboratory course at Augustana. We designed IDS 137 to provide non-science majors with an interdisciplinary laboratory experience that maximized their learning related to scientific skills and attitudes while minimizing disciplinary content. The overall average increase in post-test AISLE scores as well as average score increase for questions coded as measuring either scientific skills or scientific attitudes were collected from students who completed IDS 137 in 2018 and 2019 and analysed for statistical significance. Statistical analysis of the pre-test and post-test AISLE scores using a paired t test indicated the overall score increases were highly significant ($p=0.007$). This trend provides strong evidence that students did increase their SSA over the duration of IDS 137. Separate analyses of paired scores for questions coded for either scientific skills or attitudes revealed that the improvement in overall scores primarily arose from increases in students' scientific skills, which showed significant overall post-test score increases ($p=0.023$).

The most important result is that in a 3-week laboratory block course that exposes students to experiments related to biology, chemistry and physics in four day rotations, students registered in a variety of non-science majors show improvements in their scientific skills and attitudes. Further research is needed to determine the relative importance of the experiential nature of laboratory learning, condensed nature of the 3-week block course, and exposure to different scientific disciplines to the measured gain in SSA.

Based on the encouraging results from improvement in AISLE scores and student reaction to the course (as measured by Student Evaluation of Teaching (SET) scores), IDS 137 will continue to be offered at Augustana and further AISLE data collected. Future research directions include indepth analysis of performance on individual questions that can be linked to specific course assignments and objectives to investigate whether changes in overall mean scores can be directly tied to performance on certain questions and improvements in understanding of particular concepts.

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STUDENT CLUB INTEGRATED INTERNAL EXPEDITIONARY OUTREACH

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ABSTRACT

It is common among university graduates to fulfil curriculum expectations, but when students are competing for limited entry-level jobs without additional experience, they will be less successful in securing employment than their counterparts with correlated vocational skills. Students greatly benefit from integrated exposure to social volunteerism and/or industrial exposure to learn associated vocational skills to be competitive as a new hire. This study examines a strategy for combined course and student club activity that results in a new expeditionary learning strategy that generates undergraduate student-led research. The resulting publication can enhance post-graduate success by generation of tenable productive output demonstrating their acquired skills. In the examined case-study the student led research funnels into further infrastructure development for the university, while providing real-world engineering solutions to a common community challenge. Examination of correlated course programming to allow for external club activities to be inserted into the academic program alongside faculty research efforts demonstrates a strategy to reduce demand on university resources, enhance faculty research output, improve facility-wide experiential learning immersion, and give students much needed practical vocational experience.

Keywords: *undergraduate, integrated expeditionary learning, club activity, research, case-study*

INTRODUCTION

Global education platforms are evolving to adapt to new ways information is passed and to new ways of emergent learning. E-learning surpassed $100B in 2015 and is projected to grow to $325B by 2025 as assessed by a leading market research firm, Research and Markets (McCue, 2018). The rise of online learning models and free access to information, such as from free/inexpensive published books and open-access journal movements such as ‘Free the Science’ is allowing enhanced access to increasingly technical information. The increase in online access to self-publication is also increasing the number of independent sources that reduce literature costs and allows for greater access to information (Catalano, 2018). The growth of this online network of information is constantly evolving, and efforts to quantify this change has been first described through ‘altmetrics’ and further refined by ‘open metrics’ that measure, reward and create incentive for open science (Herb, 2016). As this ‘free’ approach to information access increases, the value of university experience and the ability of the facility to provide for a return on investment that competes with these sources requires both increased facility efficiency to reduce costs while providing for more tangible results to facilitate competitive advantages for students post-graduation.

Value of the university experience as a substantive element in preparation for postgraduate success can be thought of as to how we prepare students to be adults; reflect upon how society functions (both interpersonally and industrially with technical and social lenses), take responsibility for the ownership of their reality with self-confidence in their ability to be a valued community member, and engage society seeking to change the world from their critical perspective. Focusing the student experience to lead societal change by practicing skills engaging real-world problems will set them apart from their peers to ensure vocational placement after graduation by providing exemplary results accompanying this outreach. The presented research illustrates the role educators must play in order to co-ordinate integration of directing curriculum and course evolution with foresight on growing social challenges, involvement in student clubs to focus efforts towards productive activities, and increasing the breadth of their own research focus correspondingly in both course and club spheres.

METHODOLOGY

This paper examines a teaching approach for post-secondary education and considers the problems of limited facility and research funding, modern skills preparation of students for industrial and other post-graduate roles, difficulties in finding ways of integrating active experiential learning into courseware, and curriculum focus to enhance industrial and societal engagement. Involvement of student-led club expeditionary learning is the key to improved productivity in all these areas but requires faculty direction. The paper discusses both teacher-centric and student-centric roles in this approach to learning. Expeditionary learning is traditionally focused on nature/adventure for discovery; this study expresses that expedition can also occur locally, hence the term ‘Internal Expeditionary Learning’.

The breakdown of graduate skills preparation enhancement in STEM education examines student club activity, classroom activity and university resource use that can be framed as a new university wide expeditionary learning model. The data being gathered will involve both qualitative data from student survey results from club and class participants (and the crossover therein) to measure vocational skill acquisition from correlated extracurricular academic activity. The survey will be conducted before and after completion of the assigned engineering courseware to measure perceived growth in the vocational skillsets between the club engaged and the general student population. Quantitative results as to university funding redistribution as a result of this program development will also be formalized upon program completion.

DISCUSSION

Student Preparation for Graduation

A problem facing industry is for students to acquire practical skills in conjunction with technical theory (Abbot, 2014). Technical theory is increasingly easy to obtain by student-centric study from free online resources, so practical skill acquisition through project immersion with correlation to technical theory is a meritorious approach to enhance student preparation. Practical skills include teamwork, problem solving, and other critical thinking skills. These skills are best practiced on industrially relevant facilities, or with engagement with real-world problems, respectively correlating to exposure to state-of-the art industrial and social practices.

Through observation of new environments, new ideas and practice in critical thinking, problem solving and analysis follow. Guidance of these student-centric introspective skills can be intrinsic but modelling and coercion of questioning to prompt investigation of these skills can be aided by direction through facultycentric guidance. Inspiration to drive creativity, curiosity, imagination, and innovation stem from the contemplation and divergent thinking afforded by observation of these new environments.

The breadth of student training can be increased by exposure to commonplace information and communication technology utilized by industry as well as industrially practiced data interpretation and analysis. Immersion in this workflow through internship and other mentor-centric co-operative positions can play an integral role for modelling vocational behaviour and provide opportunities for learning these practical skills (Skrzypinski, 2017). Unfortunately, co-op program development is not widespread, nor do present industrial-academic options afford placement for all students. An alternative to industrial exposure is critical analysis of society and introduction to the 'grand problems' society faces in the 21st century. With faculty approaching the student body with questions regarding civic, ethical, environmental and humanitarian issues improvement in student social-justice, multicultural and conservation literacy can be directed. An overarching systems understanding will provide for a global awareness of other factors that may be tied to industrial practice. Awareness of these multifaceted and complex issues can take place with liberal arts community driven student centric methodologies or through directed guidance by impassioned faculty members.

Student preparation for graduation through immersion of practical skill training in conjunction with their technical work acclimatizes them to be a more productive contributing member of a company or cause. Gaining confidence through practiced exposure to tasks that they have had real-world experiential learning with can help them recognize new directions and strategies. If industrial experience is not readily available, engagement with 'grand challenges' or other societal needs can be a ready alternative for vocational practice, but guidance of similar industrial methodologies must be nurtured by faculty.

Student Club Activity

Some clubs help students academically, others focus on civic engagement, and some are meant simply for leisure or recreational activities. They can focus on thematic or programmatic areas of interest, such as debate, human rights, arts and music, technology, and more. These forms of student activities offer a way for students to come together with guidance from staff and faculty advisors to pursue their passions, strengthen their community through fellowship, further exercise the values of teamwork and collaborations, and otherwise improve the campus community's social fabric.

The freedom that clubs afford is in intrinsic motivation of students through involvement driven by their interests and club direction is largely student-centric. Student club activity could benefit from strategic direction in awareness and alignment of expeditionary learning practice through involvement in global challenges. While this may detract from student-centric direction and potentially affect intrinsic drive it also can offer more focused growth. Influence of club direction in this regard can come from the guidance of staff and faculty to help cooperatively scaffold the direction rather than dictate it. Altered club direction to more fully engage social programs may affect intrinsic student engagement and will also be further assessed in the student survey.

For guidance of student clubs, modelling engineering work based on societal observations with faculty engagement can lead to data driven metrics for investigating aspects of a social challenge. As an example, an e-vehicle design club was tasked with incorporating battery research into the testing of their prototype vehicles. The student led research was framed with the premise that evehicles use expensive and hard to recycle batteries. The student group was posed questions of how we can help reduce this waste and was led by the faculty member to how the factors in battery disposal are caused by human-interface driven variables: how batteries are charged and discharged and how this affects their lifetime in a product. The selection of e-vehicle components has a direct effect in this behavioural cycle. An analysis of the contemporary use-cycles of the student population via a rideshare model could generate data to better design e-vehicles based on their designated use. The technical program of examination of the proper use of battery systems to prolong their lifetime with fleet demonstration generates data for a peer-reviewable publication in collaboration with the faculty advisor. The collected data is also applied to two social projects: The first social application is used to design infrastructure of a fleet of e-vehicles to connect a transportation hub 3 km from the main campus in an effort to provide a clean energy method of transportation for commuting students. The second social application is using club outreach events for further education of the general public as to how their actions enhance e-waste generation. Open attendance events at the university focused on the effects of misuse of battery systems can illustrate how society's understanding of technology can change behaviour and the reciprocity of this action can have a large reduction in global battery waste. The club's activities can be shown to have a multiplicative effect on society at large, expanding the scope of the student's experiential impact and expose them to more in-depth analysis of their practice.

It is through the directing of club leadership to plan and develop overarching methodologies for enhanced impact of their programming. Faculty members, staff and graduate students with an expanded global view can help to guide the direction with mentor-centric elements drawn from their experience.

Class Activity

Course activity through curriculum planning in engineering has been traditionally segregated by discipline but is moving towards a more liberal arts conceptual framework. Accreditation bodies are realizing the multiple perspective benefits offered by greater diversity in outcomes-oriented approaches as we further analyse what engineers do throughout society (Liebelt et al, 2018). Cross-disciplinarity and academic flexibility in curriculum design allows for structured education that can more easily fit into the fluid industrial landscape of the 21st century.

Club activity with student led research efforts are a natural fit for development of integrated societal datasets. In this case study the example given for integration of the student led research is for an introductory engineering course covering sensors, measurement and analysis. The course cultivates the process of experimental investigations in the context of engineering systems with students working in teams to look into the measurement of fundamental properties of the physical world and to design and fabricate simple electronic sensors that allow them to measure these properties in an engineering application. With the inclusion of the student led research, the courseware can be enhanced by examining a longitudinal study on the social impact their analysis will facilitate. Utilization of the student led research enhances the courseware through experiential learning with the ABET requirement of engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors ("ABET", 2018). Survey results to measure the skillsets gained from expeditionary experience of the discrete subset of club-engaged students versus their peers are underway.

In contrast to the student led research, coordination of an industrially supported project to match up with the associated courseware has additional constraints.

Industrial ties are hard to shape – there is no external control over company direction so manipulation of a dataset to an ascribed course objective can be difficult. For industrial research programs the information is often sensitive/confidential so analysis of the underlying fundamental properties may be obscured for student learning. There is commonly lack of facility support for co-ordination of the academic-industrial partnerships that need to be established over the long term to deploy assets from the company to comply with academic needs, and the semester system of university courses rarely overlap with the scope of any particular industrial project. While industrially co-ordinated projects have great experiential impact, the student led research can form the same real-world dataset but with a greater match to timing, scope and control.

University Resource Use

Success of external efforts to acquire research funding is assessed in a variety of ways globally but common to every assessment is the perceived value of the submitted programming. If the expansion of research funds can be shown to increase involvement in undergraduate led research efforts and integrated learning in the form of research insertion in undergraduate courseware then it is reasonable that this increased function would serve as a more attractive model per dollar spent. In addition to this expanse in programming benefit the project may also fall under additional training or development funding and as such be viable for an increase in grant scope that includes social and infrastructure development. Institution funding directed towards infrastructure development could also serve as a model for successful increase in club funding if social projects are integrated with planned university development such as in the presented case study.

The advantages on mixed pool university funding offsetting existing research and courseware resources with club activity, further activation of undergraduate involved research, and projected increases in breadth and success in research grant application all forecast advantages of this codesign strategy.

CONCLUSIONS

This work provides a framework for development of faculty led initiatives into student-led research that is a novel strategy for in-house expeditionary program planning that results in better trained students, more engaging club and course activity, and reduced university resource demand.

Student preparation through immersion of practical skill development in conjunction with their technical work gives them the confidence they can repeat this practice in the workplace. Training to recognize new directions and strategies for global change through engagement with 'grand challenges' or societal needs can be facilitated by faculty through club activity to further drive research integrated experiential learning. The student led research can form an industrially comparable real-world dataset but with a greater match to timing, scope and control in a university environment. This strategy could also lead to increases in breadth and success in research grant application in tapping other funding sources for social or infrastructure development. Elements of the approach relied on both student-led and faculty-guided expeditionary learning, with further evidence under exploration to measure specific enhancement in vocational skill development under this expansion of the expeditionary program definition.

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A STEM CLUB FOR LOW-INCOME YOUTH EXPLORES STRATEGIES FOR STRENGTHENING COMMUNITY RESPONSIVENESS IN INFORMAL SCIENCE EDUCATION

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ABSTRACT

This paper explores how informal science education providers can work towards community responsiveness. Due to the complex intersection of societal and cultural factors, children living in low-income communities are often marginalized from access to, and engagement with, science. Specifically, this paper examines how children's engagement with science education can be fostered in an experimental STEM club developed in, with, and for a low-income community. Alongside a notfor-profit science club provider, we used parameters determined by local educators and residents (including children) to co-create an after-school STEM club that ran for 7 months during the 2018/2019 academic year. Using qualitative methods of inquiry, we investigated the strategies, challenges and opportunities for the STEM club provider striving to respond to a specific community context. This paper focuses on semi-structured interviews with staffers that described their suggestions for the new STEM club (n=9) and reflections on club implementation (n=3). Data was analyzed using a constant comparative approach. Preliminary analysis has revealed three emergent themes: i) strategies for re-imagining informal science education spaces and places; ii) the lengthy and iterative nature of community-responsive work; and iii) opportunities for community-responsive informal science initiatives. These findings suggest not-for-profit organizations may benefit from adopting similar research informed methodologies to co-create experimental, iterative models in, for, and with community members, to develop and advance sustainable approaches to informal science education in low-income communities.

Keywords: *community-responsive programs, informal science education, science clubs, low-income communities, elementary school education*

INTRODUCTION AND LITERATURE OVERVIEW

Due to the intersection of societal and cultural factors, children living in low-income communities are often marginalized from access to, and engagement with, science (Dewitt et al., 2013). As science is embedded in the everyday lives and experiences of young people, it is a priority for contemporary, democratic societies to build opportunities for accessible and equitable science education (Dawson, 2014a). For any child, gaining access to effective science education and maintaining ongoing engagement with science are complicated issues that involve privilege and marginalization in formal settings such as schools (Calabrese-Barton, 2001) and in informal settings such as museums, clubs, and science centres (Dawson, 2014b). Moreover, demonstrating competence in science can enhance the way an individual is perceived and recognized as a 'science person' by others (Carlone & Johnson, 2007) and in society. A lack of external recognition can undermine a child's belief in their own competency, and their eventual engagement as a science participant.

Informal science education can provide marginalized audiences with alternative ways to engage with science on an ongoing basis (Bell et al., 2009). As a complement to school-based learning, informal science education settings can reach groups commonly underrepresented in science career pathways, including youth from low-income communities (Dorsen et al., 2006; Peters-Burton et al., 2014). Researchers have identified the value of out-of-school clubs in providing opportunities for the academic, personal, and social development of children (Durlak, Weissberg, & Pachan, 2010). Recent studies have also revealed that science clubs can offer opportunities for children and youth to use their own knowledge and ways of knowing and doing to address science issues that are relevant to their communities (Calabrese-Barton & Tan, 2010; Dawson, 2017; Streicher et al., 2014). Community-based research is gaining recognition in addressing social inequalities in Canada (Flicker et al., 2008); however, research centering community-responsiveness in the context of low-income communities and informal science education remains underexplored.

GOALS AND OBJECTIVES

This study was conducted through the collaboration of a university research team and a not-for-profit organization, the STEM Academy. The STEM Academy provides STEM clubs in low-income areas, run by facilitators with lived experiences of the communities in which they work. During the first year of a two-year study, we conducted research in existing STEM Academy clubs to distill features of the clubs' activities that support community inclusion. We also held interviews and focus group sessions in a low-income community where we proposed to establish a new STEM club to determine the desires and needs of community members regarding informal science education. This paper explores the second year of our study to examine the benefits and challenges of using an intentional community-responsive approach to informal science education in a low-income setting.

THEORETICAL FRAMEWORK

Community-based research approaches have gained strong momentum in health and social care fields (Flicker et al., 2008). Israel et al. (1998) extended the notion of community-centered research to situate community-based studies within a constructivist, critical-theory framework that emphasizes the "participation and influence of non-academic researchers in the process of creating knowledge" (p.177). This community-responsive research approach emphasizes collaboration, participation, and social justice agendas. The fundamental argument behind community-based and community responsive research approaches is that, through community involvement, initiatives can become accessible, and relevant to people (Minkler, 2005). The positive power dynamics at play can move individuals toward sustained personal and societal change. Key dimensions of research-informed community-based initiatives include:

- considering the community as a unit of identity, with its own strengths and resources (human and otherwise);
- valuing experiences of the community members involved;
- fostering community involvement at all levels of influence;
- facilitating equitable and collaborative partnerships;
- promoting co-learning and capacity building among all parties involved;
- emphasizing local relevance (Israel et al., 1998; Roche, 2008).

This approach balances community narratives against the researcher's understandings of relevant research literature and coordination of perspectives and interests presented by different community participants. In terms of its aims, community-based research "brings together community and academic expertise to explore and create opportunities for social action and social change" (Roche, 2008, p. 2). A key strength of this research perspective is that it facilitates the ability of researcher and community members to highlight and foreground experiences and opportunities that are often masked in more solution-based research approaches.

METHODOLOGY

In Vélez-lbáñez's (1988) seminal work describing the *funds of knowledge* concept, the researcher is cautioned to value and respond to knowledge bases and practices that exist within a community before envisaging and operationalizing ways forward. For this project, we employed a research approach that sought to gather the perspectives of community residents and youth workers, and existing STEM club participants (research Phase I) prior to introducing a STEM club into a new community (research Phase II) during the 2018/2019 academic year. Following Phase I of the project we co-identified four aspects of community responsiveness that would serve as our focus for Phase II (and the focus of this paper):

1. Exploring collaborations with other community organizations
2. Recognizing and working with community funds of knowledge
3. Exploring the diversity of children's interests
4. Supporting activities with, in and for the local community

These four areas of focus defined the parameters for exploring the following research question: *What are the strategies, challenges and opportunities for a STEM club provider striving to respond to a specific community context?*

For the purposes of this paper, our analysis foregrounds the perspectives of informal science education providers by focusing on semi-structured interviews with STEM Academy staffers that described their suggestions for the new STEM club (Phase I transcripts, n=9) and reflections on club implementation (Phase II transcripts, n=3). Each interview lasted between 30 and 80 minutes and was audio-recorded. Data was analyzed using a thematic analysis of the interview transcripts. Themes were derived using a constant comparative approach (Glaser, 1965) starting with codes that might be anticipated as informed by the four community-responsive areas of focus identified above.

RESULTS AND DISCUSSION

Our analysis shed light on the STEM Academy's drive to progress definitions of community-based work by supporting an approach that is responsive to community inclusion. In keeping with their operational model, certain characteristics of the STEM club program were maintained in the new club context:

i. Running 2-hour hands-on workshops on a weekly basis from October to April
ii. Capping club attendance at 20 children to facilitate group activities while allowing for personalized attention from club leaders during club activities
iii. Having workshops guided by program facilitators who had backgrounds in science at higher education level and first-hand experience of low-income community living
iv. Utilizing curriculum modules developed by STEM Academy staff (at least at the start of the academic year)
v. Emphasizing relationship-building, leadership, and social-emotional learning that are fundamental to the program's ethos

These features served as a foundation upon which a new club could be established.

Strategies for re-imagining informal science education spaces and places

The STEM Academy's usual model of informal science education involved running clubs on Saturday mornings, with the majority of clubs being situated within community housing recreation spaces. When conducting our background research in the area of the new STEM club, a number of community members had identified schools as safe spaces for children to come together for an informal club. The after-school timing, prior to parental pick-up, was also mentioned as a favorable scheduling strategy for community members. One STEM Academy staffer, Renee, also alluded the potential for establishing a tighter connection between formal and informal spaces of learning: *"if you can really engage families and engage these core people in the- in these kids' lives, that's what shifts conversation, that's what shifts dynamics. And that's what will ultimately help us to see change in the communities that we serve. Because school is one part of it, the same way our STEM clubs are one part of it"* (Renee, Phase I). Although the STEM Academy occasionally run clubs within schools, staff members noted that a clubs' success depended on 'buy-in' from the community, not just the support of the school. Phase I of the project purposefully attended to achieving school and community support, and the benefit was described by one staffer: *"buy-in that they got from having a seat at the table and a stake in being able to share what they thought and make suggestions and accommodations, that's something that we don't traditionally do"* (Bowser, Phase II). But with a change in setting came new challenges for staff to contend with:

> *It is right after school. So many things, you know just seeped into club and then we walk in and then certain kids would run up to us and say hey, like this happened today, this person may be in a mood today or something or you know that you want to stay away from a certain person and then seeing that transpire.* (Ex, Phase II).

Staff noted a difference in children's behaviour in an after-school setting compared with the Saturday clubs in that the children were all familiar with each other and events would take place during the school day which might extend into the club space. Staffers experimented with different methods of attending to the social dynamics of clubbers, including allowing free play before the club activities to mark a distinction between club and school spaces. Overall, the staff members were excited by the club's capacity for fostering social-emotional learning and they were not surprised to hear of the positive impact of the club on participants' behaviours in school. Jade suggested, *"even though we may think we only touched twenty kids, I think we touched a lot more than that in that school, just by, like, you know, seeing, like, what the kids were doing and hearing about it"* (Jade, Phase II).

The lengthy and iterative nature of community-responsive work

Club staff agreed that the first iteration of the club was a success as an experimental learning opportunity. Nevertheless, they recognised that it would take considerable time, and continued work, to attend to all of their initial aims. Of the goals they set out to achieve (as described in the methodology), staff members were most attentive to addressing the diversity of children's interest. This is an area that they saw as instantly rewarding for the children. New to the club model, was a strategy where the club year was split in two 'terms'. During the first term, staffers used a range of pre-planned modules that exposed children to the fields of science, technology, engineering, and mathematics; at the outset of the second term, staff surveyed children to gauge topics of particular interest and engagement. The club facilitators indicated that in future club iterations they could even envision *"getting their input from the start"* (Jade, Phase II) to maximize child-centeredness.

One invaluable opportunity for promoting community inclusion was the final showcase event where children were able to demonstrate a self-selected group project to community members: parents, teachers, and peers. Children were proud to show what they had learned and teachers and parents were impressed with the children's knowledge and confidence. Staffers suggested that, due to the extensive community engagement prior to the club's initiation, the school community (administrators, teachers, and families) excitedly anticipated the club opportunity for their children and used the showcase event to share their thoughts with the club staff. Jade was humbled by the parents' positive feedback:

> *The parents, like, were super proud of them. And, like, they came to me and they were like, 'Thank you so much! This has been great. You know, they come home, and, like, they tell me what they've done during the day.' And, like, getting their feedback was super important to me. Because they're with them every day and they know their children the best, right?* (Jade, Phase II).

Club staffers described their ambitions to increase the extent to which they might explore community funds of knowledge within the club setting but they recognized that more time and resources would be needed to accomplish these objectives. Nevertheless, the strong turnout for the showcase was an indication of parents' interest in future involvement. Several staff also indicated that they felt prepared to incorporate elements of 'place-based learning' with club participants to facilitate activities with, in and for the local community. Bowser described future plans for cold-weather outdoor exploration, citing, *"we didn't do any outdoor exploration, which we planned to […] but exploring the local community is something that could have happened, but […] we don't have winter modules"* (Bowser, Phase II).

Opportunities for community-responsive informal science initiatives
As with all community-based, community-responsive work, researchers and not-for-profit organizations are tasked with balancing the needs and influences of multiple stakeholders. Staffers recognized the place of communication in effective planning: *"communication is a big piece in everything, relaying information between the teachers and the principals and the parents, just so that everyone's on the same page and they all know what's going on in the program"* (Ex, Phase II). Although club staffers were unsure about how school administrators and staff would influence the club model, the teachers' demonstrated a hands-off approach and were grateful for the club, which was meeting a need of a school that was already stretched for resources. Families were similarly relieved to have an after-school option for their children in the 'safe' space of the school.

Balancing stakeholder's desires is a critical component of the success of non-profit community responsive organizations like the STEM Academy, particularly since some of those stakeholders are funders. Renee described the tensions present when funding and designing any new STEM club, *"I think it's just being careful to that, so we're not just chasing buzzwords […] but we always take it back to our community […] and what these kids really need. And what they may need the most from us may not necessarily be, I guess – what's sexy"* (Renee, Phase I). By engaging in communityresponsive research projects organizations are able to provide their funding networks with rigorous, in-depth feedback on club initiatives, such as supporting children's social-emotional learning. Bowser summarized the benefits of this research experience, *"this entire experiment gave us insight on how we can be doing things differently and achieve what we want to achieve or surpass what we want to achieve… it just opened up the doors in terms of giving us evidence-based opportunities on where [the STEM Academy] can go in terms of what does engagement look like"* (Bowser, Phase II). Even though research partnerships with universities are not always options for community-based organizations, we suggest that informal science providers like the STEM Academy can engage in community-responsive research of their own by soliciting ongoing feedback and input from the community members they are working with (e.g., school staff, students, families, community youth workers, and funders).

CONCLUSIONS AND IMPLICATIONS

In seeking to co-create an experimental community-located STEM club based on a pre-existing model, the STEM Academy have contributed to the development of ways in which community-based programming may be defined. By focusing on more fully embracing community responsiveness, they have illustrated how programs can be established and maintained based on the characteristics of a given community. By exploring ways of integrating informal science education into a more formal space (e.g., after school), in consultation with a low-income community, club staff appreciated a pronounced level of community 'buy-in', including working with a group of children who were already familiar with each other. While time and resources continue to be limiting factors in community-based work, this experimental club provided an opportunity for the STEM Academy to explore ways of creating settings where children, teachers, family members and peers can work together in successive cycles of science engagement. We have seen how some co-created goals were easier for club staff to implement than others. Attending to the various interests of children, was made a priority, and a new showcase event was initiated where families were brought into the educational space, extending the club further into the community. Although it was difficult for staff members to anticipate the expectations of multiple stakeholders, STEM Academy staff believe their efforts to improve opportunities for community feedback and communication will foster increased program sustainability.

Not-for-profit organizations may benefit from adopting similar research-informed methodologies. In co-creating experimental, iterative models with community members, and seeking ongoing community feedback, not-for-profits stand to gain new sustainable methods for informal science education in low-income communities.

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FOSTERING AND RESEARCHING STUDENT PERSISTENCE IN TVET IN THE GULF: MUTUAL ADAPTATION IN AN INTERCULTURAL SPACE

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ABSTRACT

Newly resource-rich countries in the Gulf region of the Middle East face a conundrum with respect to TVET/STEM: native technical capacity constrains their ambitions for sustainable social and economic growth. This case study examines the tensions a technical college international branch campus encountered in fostering, and also researching, Qatari student persistence on TVET educational pathways. Analysis of interviews of key personnel reveals that several localized factors impact student persistence and mediate the college's institutional outcomes: basic life skills, academic and technical preparedness, beliefs and expectations about learning, and life priorities (i.e. family, occupational prestige, expectations/rewards of technical careers). The findings suggest that transnational educational innovations must attend to localized conditions that mediate their effectiveness. It concludes that successful mutual adaptation – aimed at academic and technical apprenticeship and practiced by Qatari nationals and international educational personnel alike – is a necessary condition to shifting culture in ways that supports new educational and work traditions. This paper finishes with some surprising consequences and interesting implications for researchers working in complex intercultural spaces.

Keywords: *student persistence, TVET, STEM education, Middle East; intercultural studies, international education*

INTRODUCTION

Technical educational and occupational traditions emerge locally, evolve under complex influences, and become transmitted generation to generation over time. However, newly resource-rich countries in the Middle East face a conundrum: native technical capacity constrains their ambitions for sustainable social and economic growth. This case study (Stake, 1995) of a Canadian technical college in Qatar offers a shop-floor view of the complex, fluid, localized factors shaping a significant TVET innovation in the Gulf region. The innovation is a new Technician Certificate Program (TCP) designed to provide Qatari national high-school graduates pathways to become entry-level process operators or mechanical, instrumentation and electrical maintenance workers in the energy and industry sector. This empirical study examines tensions around issues of academic preparedness, technical preparedness and student school and career pathways through the lens of student persistence (Tinto, 1975).

LITERATURE REVIEW

The Issue of Student Persistence

Persistence is defined as a multifaceted phenomenon in which students hold firmly to their purpose, despite obstacles, in order to achieve their educational goals. Persistence does not necessarily mean that students will graduate from their programs and so it is not simply an antonym of attrition or retention (Reason, 2009). Tinto (2006) distinguishes between these similar terms, which are often used interchangeably:

> Leaving is not the mirror image of staying. Knowing why students leave does not tell us, at least not directly, why students persist. More importantly, it does not tell institutions, at least not directly, what they can do to help students stay and succeed. (p. 6)

Accordingly, attrition is defined as the gradual loss of enrollment experienced by the postsecondary institution due to the premature leaving of students, while retention is defined as the holding power of an educational program or institution (Johnson, 1991). Persistence is an individual phenomenon related to students and their educational pathways, whereas attrition and retention are organizational phenomena and typically involve measures to mitigate undesirable institutional outcomes (Reason, 2009).

Only a handful of studies address persistence in non-degree engineering technology programs (Christe & Feldhaus, 2013), which most closely relates to this study's context. James-Byrnes (1997) found that academic performance prior to and including the first semester of engineering technology accurately predicted persistence at the one-year mark. Holloway (1991) compared first- and final-year engineering and engineering technology students in terms of career maturity, selfesteem and vocational interests to reveal that engineering technology students were less connected to their career choice than their engineering counterparts. Finally, Christe (2015) found seven factors that shape student persistence in the first year: personal goals, classmate collaboration, faculty relationships, uneasy beginning, work effort, adaptability and campus involvement. This body of research suggests that academic preparation, understandings of their discipline, goal clarity, faculty support and learning styles potentially shape engineering technology student persistence. Christe and Feldhaus (2013) identified student persistence in engineering technology as poorly understood; they argued that engineering student persistence research is not simply transferrable, and called for more qualitative studies on student persistence in non-degree technical education.

THEORETICAL PERSPECTIVES

This study is guided by Terenzini and Reason's (2005) model of student leaving and persistence and Hirschy, Bremer, and Castellano's (2011) conceptual model for persistence in community colleges. Theoretical models of student persistence have been developed for over four decades since Spady (1970), Tinto and Cullen (1973) and Astin's (1975) groundbreaking theoretical work. Tinto's seminal model of persistence (Tinto, 1975) focuses on students leaving or staying at college as a process. He drew on Van Gennep's (1960) socio-anthropological theory of rites of passage, which describes individuals leaving one culture and becoming integrated into another via the distinct stages of separation, transition and integration. Tinto (1975) also drew on Durkheim's theory of suicide to frame persistence (Durkheim, Simpson, & Spaulding, 1952) in terms of social and academic integration. Tinto (1993) attempted to incorporate later theoretical developments into his original model, specifically the importance of background, attitudinal and environmental variables and student, peer and faculty interactions. Tinto (1993) is credited with treating persistence as a multi-faceted, longitudinal process of social and intellectual integration or non-integration into subcultures of a campus.

Terenzini and Reason's (2005) model of student leaving and persistence synthesized several models to comprehensively map the primary influences on student persistence: student precollege characteristics and experiences and individual student experiences within peer environments. Theirs is arguably the most comprehensive model, yet it remains a product of theoretical development based on four-year colleges. Hence, this study also draws on Hirschy et al.'s (2011) conceptual model for persistence in career-focused community colleges. This model adds the influences prominent in two-year colleges: program career integration (i.e. exposure to target work environment, apprenticeship, career-related work experience and socialization to professional norms) and interactions between college and local community and family environments.

RESEARCH DESIGN

This study employed a case-study approach (Stake, 1995) to understand the tensions the college has encountered in fostering technical pathways for Qatari nationals through the lens of student persistence. A total of 15 participants were recruited based on their breadth of knowledge and depth of involvement in the new Technician Certificate Program (TCP). A diversity of views and experiences about students' trajectories from admission to the end of their two-year TCP program were sought from instructors (English, mathematics, technical), counselors and administrators. Participants who agreed to take part in this study were interviewed face-to-face for 60 to 90 minutes. The purpose of the interview was to examine participants' perspectives on the nature of students' academic and technical preparedness, their transitions from K-12 into studying in English foundations and then into technical courses at a Western college, and the college's response to their evolving needs. The transcribed interviews were analyzed using grounded theory methods (Bryant & Charmaz, 2010).

RESULTS AND DISCUSSION

Multiple enduring themes were found to affect Qatari nationals' persistence in the Technician Certificate Program: basic life skills, academic and technical preparedness, beliefs and expectations about learning, and life priorities (family, occupational prestige, expectations and rewards of technical careers). Taken together, these paint a rich, multi-dimensional picture of student persistence in this context from the point of view of key college personnel.

Having Basic Life Skills

Basic life skills emerged as a significant issue that impacted TCP students' capacity to function in classrooms, particularly in the first months after starting college. A range of life skills normally expected of high-school graduates coming to college in other regions was reported to be absent in a significant percentage of Qatari students:

- A capacity to prepare themselves for school
- Fine motor/physical skills for organizing learning materials, accomplishing tasks
- Knowledge of classroom routines
- Ability to self-regulate
- Ability to collaborate with other students

Being academically and technically prepared

Academic and technical preparedness emerged as a significant issue that impacted TCP students' capacity to function in the program. Across the data set, instructors reported a lack of Englishlanguage preparedness. One instructor gave an anecdote about a student: 'He could not read, and consequently when we had any activities that involved reading of any sorts, his behaviour changed: he would act out. And I believe that was his way of diverting away from the activity. He could not read.' In addition to language ability, basic numeracy skills were reported to be lacking. A mathematics instructor reported: 'Even the adding and subtracting is weak – they're grabbing their calculators for even the most basic questions.' Another mathematics instructor observed, 'Their English levels were so low, they couldn't read the textbooks'. Similarly, technical instructors widely reported that most students lack even a basic knowledge of hand tools. One reported that 'they don't know how to hold a hammer the proper way. They may hold it with the stick end out or something'. A second instructor ascribed this to students' earlier experiences: 'They don't grow up with their parents, their fathers for example, fixing the house, or working on their cars or getting their hands dirty.'

Beliefs and expectations about learning: learning to learn, learning to be a student

Socialization into post-secondary education as an essential process for Qatari students to get an education at a Western-style campus. That is, somewhere between English foundations and technical (shop) courses, students need to learn how to learn; they need to learn how to be students. Participants summarized Qatari students' views of the college as 'having a lot of unwritten rules', being 'a very foreign structure' and having 'protocols that [students] are just not cut out to follow'. Analysis of episodes, anecdotes and perspectives across the data set captured a sense of these 'unwritten rules' as they manifest themselves in classrooms, counseling rooms and administrator offices. Qatari students and college instructors/administrators were found to harbor very different beliefs and expectations around what it means to be at school, to learn and to be a student (Table 1).

Table 1. Beliefs and expectations about school, learning, being a student.

Beliefs, expectations	Instructors	Students
School: Purpose, processes	Building knowledge, gaining skills. Attendance leads to studying, to learning, to passing	Completing prescribed tasks, navigating obstacles, passing tests, which leads to students being awarded a pass
Roles, responsibilities	Students are self-directed/responsible for their own learning, need to reflect on/ figure out what is relevant to them	Teachers/sponsors determine what students need to know. Students' reflections on/preferences about their learning are irrelevant
Knowledge	Knowledge develops in students. Students construct their own understandings, develop their skills	Students get knowledge from the teacher, memorize and display it back
Helping	Teachers/other students help students by helping them learn	Teachers/other students help students by giving them the answers
Relationship vs. task orientation	Classroom work/tasks are more important than social relations	Social relations are more important than classroom work/tasks
Passing	Students demonstrate their learning so that they can earn marks, pass	Getting marks/passing is a game of chance; teachers bestow marks on students, can pass students up

Life priorities: family, occupational prestige, expectations and rewards

Having basic life skills, being academically and technically prepared, and learning to learn and be students get Qatari nationals on a technical career pathway. Yet, several factors related to life priorities evidently shape whether they persist: family and occupational prestige. Qatari families were reported to significantly shape students' life priorities. One Arab counselor reported that, as per Islamic and Arabic values, family commitments come before education. Outside of school, TCP students may be de facto heads of their families, be responsible for driving family members to medical appointments, accompany family members on holiday, run camel farms, or live under a variety of circumstances. Their responsibilities are often the origin of the excused absences and lateness described in the previous section that intrude on their opportunities to learn and succeed.

Yet, family influence can also lead to students prioritizing school if education is held as valuable in its own right, for its prestige or its monetary benefits. Many families are well educated, which places expectations on sons. First-generation college students also abound at the college and garner status for their families, which can positively impact their persistence. Not all Qataris are affluent, and with promotions and rewards being linked to qualifications, wives and mothers have been reported to have a strong influence on their husbands' and sons' behavior at school. Indeed, persisting in school can be about students solving problems in other spheres of their lives rather than about being students pursuing a technical career through the TCP program. Some students keep their lucrative camel farms and businesses running with sponsors' generous salaries and harbor no intentions of working in the energy and industry sector. Occupational prestige is also recognized as one of the most influential predictors of expectations and labor market participation in Gulf countries. A cultural tendency to disdain work that is not considered noble has been noted in the region, which has significance for TVET (Wiseman, et al., 2014). Participants widely reported that students regard becoming a technician as a low-status pathway, something that contributes to the student persistence and attrition).

CONCLUSIONS

The discourse on student persistence has shifted from the integration of students into such norms to the adaptation of institutions to students' needs, particularly in culturally diverse contexts (Tierney, 2000). In this view, persistence is understood as being influenced by 'how well students' cultural attributes are valued, accommodated, and how differences between their cultures of origin and immersion are bridged' (Zepke & Leach, 2005 , p. 52). Accordingly, this study offers the term positive mutual adaptation to describe an institutional approach to educational innovation that seeks to bring the culture of standards, quality and accountability of a foreign campus and the local culture and context into correspondence in ways that generate new educational culture. Tensions emerge, and require negotiation, at the intersection of these two systems in the formal and informal contexts of campus, classroom, boardroom, workshop and plant. Positive mutual adaptation is a necessary condition to shifting the culture of Qatari nationals to embrace new educational culture. Toward this end, this study recommends institutions:

- Recognize gaps in basic life skills, academic/technical preparedness, and beliefs/expectations about learning
- Continually refine the foundational curriculum and build teaching capacity to address gaps, with specific attention to teaching students how to learn
- Account in curriculum and programming for the local context, specifically in modes of delivery in light of learner priorities based on external influences, such as the family
- Rebrand TVET and foster a culture of career integration through apprenticeship

- Manage career expectations by providing opportunities to discuss occupational responsibilities and progression through career guidance
- Factor positive mutual adaptation into short- and long-term planning for the institution

EPILOGUE

Conducting research in international educational contexts has unexpected consequences. This paper's original version – in print, 2018, International Journal of Training Research – was retracted after an initially successful debut at a UNESCO sponsored scholarly event at the Canadian college in Doha, Qatar. The paper was soon shared with Qatar's national oil and gas company, the Minister of the Interior, the Minister of Education, and the college's Board of Governors, caused a significant negative reaction. It was seen as critical of the Ministry of Education, viewed as judgmental of Qatari students, and interpreted as the authors' personal views rather than findings on college personnel's perceptions influences on student persistence. Without opportunities to debate such claims and after harrowing weeks of damage control directed by the college president, the authors retracted it to preserve themselves. They adopted a low profile in their desert compound until leaving Qatar three months later – at exactly the time Matthew Hedges, a UK doctoral student accues as a spy, spent months in solitary confinement in the UAE. The Canadian college remained intact with the *de facto* termination of the authors (we resigned). Business resumed at the college.

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"START WITH WHERE YOU ARE": THE VIEW OF INDIGENIZING STEM CURRICULUM FROM EDUCATIONAL OUTREACH

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ABSTRACT

As educational institutions in Canada respond to the Truth and Reconciliation Commission's 2015 "Calls-to-Action" by exploring what it means to "indigenize" curriculum, the process is complex and requires contributions from multiple angles of education, including informal education. This is particularly important for STEM education, where the exclusivity of westerncentric notions of science and technology must be re-evaluated to provide a more culturallyaware offering. The unique position of informal education programs like educational outreach provides a unique outlook that offers lessons that formal education can benefit from. To explore this unique position in indigenizing, we use a qualitative study with *Geering Up*, a STEM educational outreach program at the University of British Columbia, and members of K'omoks First Nation on nearby Vancouver Island. We conducted semi-structured interviews with 10 members of Geering Up and 4 members of K'omoks First Nation, and identified themes that ought to inform how educators and scholars consider the foundations of indigenizing curriculum and education in general, particularly the value of sharing. We explore its potential as the foundation of a broad framework for indigenizing curriculum in a way that scales from one community's perspective to multiple in a way that is respectful, and accounts for the significant time, energy, and human resource commitment involved in these practices.

Keywords: *informal education, educational outreach, indigenization, indigenizing curriculum*

"Start with where you are": The View of Indigenizing STEM Curriculum from Educational Outreach

Introduction

Canada at the turn of the 21st century is in the process of coming to grips with its colonial practices that persist today in the form of numerous social and psychological wounds affecting its indigenous peoples (Chrisjohn, McKay, & Smith, 2017; Chrisjohn, Young, & Maraun, 2003; Milne, 2016). In 2015, Canada's Truth and Reconciliation commission laid out its "Calls to Action", which defined various goals for decolonizing Canada, including in education. At their core, these seek to move away from purely western-centric educational content and towards a more equitable balance between western and indigenous ways-of-knowing.

However, the process of *indigenization*, however aspirational, is deeply complicated and even organizations with good intentions risk perpetuating colonizing practices through sloppy execution or lack of investment in understanding. This is particularly important for science, technology, engineering, and mathematics (STEM) education, as interest in these lucrative careers crosses cultural boundaries. We examine here one such STEM educational institution from an understudied angle: that of informal education through outreach. Their story has lessons to offer both formal and informal education, and broader initiatives that operate across multiple communities and institutions.

Literature Review

Colonization and Education in Canada

The long term effects of Canada's residential school system are so severe (Chrisjohn et al., 2017; Milne, 2016) so as to be considered by many to be a genocide (MacDonald & Hudson, 2012). Attempts to avoid furthering cultural genocide through education have led to a reassessment of educational practices, notably as explicit "Calls to Action" by the Truth and Reconciliation Commission of Canada, e.g. "developing culturally appropriate curricula" (The Truth and Reconciliation Commission of Canada, 2015). The education priorities capture a push to "indigenize" education, which seeks transformation via inclusion of "indigenous knowledges, voices, critiques, scholars students and materials", and support the plurality of Indigenous knowledges and practices (Pete, 2016). Institutions across Canada are in the process of figuring out what it means to "indigenize", including STEM education.

Indigenizing STEM Education

That being said, while Canadian institutions have focused on the inclusive aspects of indigenization, support for indigenous ways-of-knowing as part of the curriculum has been lacking, leaving us still exploring *what does indigenization look like* (Gaudry & Lorenz, 2018)? Indigenizing curriculum is a nuanced and negotiated process, and cannot be reduced to simply adding western and indigenous outlooks together (Hauser, Howlett, & Matthews, 2009; Nakata, 2007). There are complexities and power dynamics at play where cultures meet (Nakata, 2007), and indigenizing institutions must navigate these dynamics.

There have been initiatives globally to indigenize STEM curriculum, although much of the scholarship has focused on projects that work with a single community, with less focus on the possibility of many, such as Miller & Roehrig (2018) incorporating STEM curriculum into a traditional Ojibwe game called Snow Snakes (Gooneginebig in Ojibwe) with the White Earth Ojibwe community in the United States. STEM education has also worked with indigenous communities within city centers rather than within their own communities, e.g. (Bang, Marin, Faber, & Suzukovich, 2013).

Lessons from indigenizing STEM (and education in general) have given us various recommendations, including: the value of circles of sharing and social relationships between students and instructors (Ragoonaden & Mueller, 2017); the importance of indigenization being community-driven, building an inclusive curriculum, prioritizing ontological pluralism, and institutional reflexivity (Hauser et al., 2009); and the aforementioned move beyond mere inclusion towards reconciliation and decolonization (Gaudry & Lorenz, 2018). Additionally, the importance of proper mindset has been stressed (Hatcher, Bartlett, Marshall, & Marshall, 2009; Kapyrka & Dockstator, 2014). We are at the point in indigenizing education where scholars and education professionals are working to understand what indigenization looks like, and experiences must be drawn from all angles where educational services are offered.

Research Objectives

Informal education has not had as much attention in indigenizing STEM education scholarship, e.g. educational outreach. Outreach has a unique relationship with indigenous communities, given broad geographic coverage and intermittent contact with communities. Although situated within a broader educational apparatus, they are nonetheless unique in their position, and have important lessons to share for educational practices more broadly. This is especially true when outreach organizations undertake indigenization: working with many communities consolidates many ideas on indigenization, supporting the development of frameworks informed by their cultural encounters.

Therefore, our first objective is to describe how both STEM education outreach employees and indigenous First Nations community members conceptualize the role of the organization in indigenizing STEM curriculum within outreach within the context of the relationship between indigenous communities and western academic institutions. This calls to mind hopes and challenges of indigenizing curriculum. Then, drawing on this descriptive analysis, we explore what informal education like outreach can offer efforts to indigenize STEM.

Research Design

Research Framework

We use an evaluative case study design, which allows us to investigate multiple social units in order to understand the overall phenomenon (Merriam, 1998, p. 41). We focus on the educational outreach program: Geering Up Engineering Outreach at the University of British Columbia (UBC). Geering Up offers STEM educational outreach to schools and communities in Vancouver and broader British Columbia. Their outreach ranges from educational workshops at local and remote communities to week-long camps offered to indigenous and rural K-12 students throughout the province. Crucially, they are working more closely with their partner First Nations communities to indigenize their practices. This study focuses on the indigenous outreach team with Geering Up, specializing in outreach to participating indigenous and/or rural communities and schools.

We also work with K'omoks First Nation on Vancouver Island, located just outside of Comox BC. This small First Nations community of approximately 220 members (Government of Canada, 2016) has a standing relationship with Geering Up for STEM summer camps. We work with the education coordinator to oversee the research process and assist in recruiting participants.

Data Collection and Analysis

We use a qualitative methodology consisting of semi-structured interviews with members of the STEM educational outreach program and community members from K'omoks First Nation. Each interview takes approximately 1.5 to 2 hours. We use a purposive sampling procedure to select interview participants from Geering Up's indigenous outreach team. This resulted in the researcher conducting 10 semi-structured interviews. With K'omoks First Nation, we use a snowball sampling procedure based on building a relationship first and foremost with the nation's education coordinator, who serves as the primary point of contact between K'omoks First Nation and Geering Up. This resulted in 4 semi-structured interviews. Additionally, members of the community were given the opportunity to elect whether they were to be anonymized for the purpose of presentation and publication.

The researcher transcribed the audio of the interviews. Each interview transcript was analyzed using qualitative thematic analysis.

Findings

Inclusion and Representation

Awareness of underrepresentation of people of indigenous identity in STEM fields was perceived as a primary value of outreach's goal. Increasing indigenous representation in STEM was described by both Geering Up and members of K'omoks First Nation as a process of 'seeing oneself' as a scientist or engineer. Said Charlene Everson, education coordinator for K'omoks First Nation:

> …that's the thing with indigenous kids, and that's the whole goal with indigenous education in general, is making indigenous kids see themselves in sciences, see themselves in healthcare, see themselves in these things, and by highlighting their strengths.

This however was connected to anxieties about race on the part of Geering Up staff, where staffers sometimes struggled with the fact that they themselves were not indigenous: …we look different, we look different from everyone there, and that's not good. I want the kids to be able to see themselves in us, and I think that's easier if their ancestry is at least a little bit closer.

Lack of indigenous instructors in the Geering Up staff was perceived as an obstacle to the goal of helping children to 'seeing oneself' in STEM.

The Human and Cultural Capital Connection

Meeting the demands of indigenizing curriculum is a time and energy intensive process, reliant upon significant effort from actors on both sides of the equation, community and educational institution. The contribution of elders and knowledge keepers was reinforced by community members:

> "Interviewing people, elders, knowledge keepers, and do some vetting. And bring in an elder or knowledge keeper who can start it up. Preferably the beginning of each group, I would have someone come in and ground the knowledge."

This, however, is difficult to implement in small communities, as elders and knowledge keepers are often both a) limited in number, and b) limited in availability:

> "I know for K'omoks, there's very limited amount of people... [Elder] really is one of the only people with a lot of that cultural knowledge in our town, in our community."

Furthermore, Geering Up employees regarded the prospect of a full-time community outreach staffer whose sole job is working with communities on relationships towards this end as an ideal, indicating the need for extensive effort to be contributed to indigenizing curriculum.

> "I would love it if we [could have] someone like [outreach assistant], which I guess we now have, but yeah, like someone whose job it is to be our cultural liaison, and that's like their sole job, of getting in touch with the community."

Although outreach organizations are exposed to many different communities, contexts, and ideas, working with many different communities simultaneously and sequentially makes it difficult to put in the time and energy required to indigenize curriculum. Therefore, traditional indigenizing frameworks that rely on lengthy time and energy investment are a challenge to implement and to sustain when they don't come in with structures to manage the time and energy commitment of staffers, elders, knowledge keepers, and community members.

The Prominence of Resource Sharing

Building lessons that coordinate STEM and indigenous cultural outlooks was considered difficult, and this is where the emphasis on sharing was particularly felt. Sharing is seen as a seeding the beginning of this process, and 'starting where you're from', given UBC's place on unceded Musqueam territory:

> "Even if you […] came in and had […] stuff that was all Salish, Musqueam, Squamish people, technology that you used in the program […] it's those kinds of things and I think that once you get started […] They start off with one project, and next thing you know they have all of these ideas for stuff. And I think it's the same with this. You just have to spark people's imagination, and just start. Start with where you are."

The value of sharing was not just considered to be between First Nations communities through Geering Up, but also with the mainstream, formal school district as well:

> "what if you […] helped develop something and then we were able to bring it into the school and use it as a tool to teach the district about K'omoks people, by showing that technology, and having a whole science thing based around it that would benefit not just our students where they could see themselves in their education, which is the whole point of indigenous education, but where the rest of the community could use it too. Our community at large, not just K'omoks First Nation, but the district."

Even though Geering Up employees were well aware of the follies of building panindigeneity into their practices, indigenous community members emphasized that indigenizing education is a process that is shared by multiple First Nations communities, and that there's significant benefit in sharing lessons and ideas about how their own outlooks and STEM education can be equitably represented.

Discussion

The Unique Offerings of Educational Outreach

What is evident in conceptualizing informal educational organizations like Geering Up is that their attempts to indigenize their STEM educational offerings are subject to many of the same challenges that would affect formal education, in particular the constraints of time and energy and its connection with human and cultural capital towards indigenizing curriculum. However, exposure to many different communities, which may be considered weakness towards indigenization, accords Geering Up with a unique position: that of being a nexus of resources between multiple First Nations' communities and educational institutions.

Given the challenges with developing indigenized STEM lessons, entities that serve as a nexus of resources are of great value, and can lessen required time commitment on members of the community, as well as serve as the spark by which lessons and ideas can be created. This also speaks to the value of allowing educational organizations to "start with where [they] are", and where human and cultural capital may be its most accessible: although indigenized STEM lessons themselves may not necessarily translate by virtue of their cultural source, their existence serves as a beacon for communities to explore, with the educational outreach program, its own actualization of indigenized STEM.

Towards a Sharing Framework of STEM Indigenization

As a potential nexus of resources, the prominence of *sharing* comes to mind. Ideas for curriculum indigenization that are developed in one community, i.e. "start with where you are" can seed discussions with other nations, prompting opportunities to actualize how STEM curriculum indigenization can look for other nations. Indigenizing STEM lessons is not always immediately obvious (one participant from K'omoks First Nation expressed the oddity of "indigenizing math"), so it can be a time and energy intensive process. Outreach based sharing can spark these conversations and make them easier by virtue of example, but in doing so manage the required time and energy commitment asked of knowledge keepers and elders. The value of this idea was developed primarily by the education coordinator of K'omoks First Nation, based on her own experiences with education within her community, so exploration of this idea and its advantages ought to be credited there.

The ultimate goal is a critical mass of indigenized STEM lessons, borne from networking indigenized curriculum between First Nations communities. Avoiding pan-indigeneity becomes a priority, and this ought to be guarded against by a) emphasizing the source of a lesson, and b) acquiring advance permission from the community leaders or representatives to teach such a lesson in their community. Furthermore, lessons can be transmitted to mainstream formal educational settings, especially since outreach organizations like Geering Up commonly interact with formal school boards and instructors (case in point: one of the participants from the community is a school teacher).

The place of Geering Up at the centre of many entities produces an opportunity to develop a framework for assisting educational organizations and communities in producing indigenized STEM curricula, and thereby meeting some of the most conceptually difficult Calls to Action in the TRC's 2015 report. While significant value has been had in projects that build relationships and lessons with singular nations and communities (e.g. Miller & Roehrig, 2018), broader-scale initiatives like what is suggested in the TRC's Calls to Action require broader scale approaches and frameworks, and these start from identifying the foundations that those approaches and frameworks will require.

Relationships as Foundational

Finally, the basis of this indigenizing framework depends on the quality of the relationship built between institutions and nations, evident in the challenge of time and energy in indigenization efforts and resource sharing. The quality of the relationship will determine engagement in the education process that enhances the human capital availability, as well as the quality of resources that are shared across any framework. In this way, no framework can exist without development of a trustful relationship. Relationships must also be persistent: oral and collaborative knowledge built over the course of a relationship can be at risk due to staff turnover, an issue facing both informal and formal education alike. While scholars, indigenous and western alike, have stressed the importance of good and persistent relationships (e.g. HaigBrown & Dannenmann, 2002), the importance of research and mindfulness must continue to be stressed, and that simple practices like gift-giving be incorporated into western-indigenous engagement.

Conclusion

Indigenizing education and curriculum within it is essential to Canada's push to decolonize. However, without proper implementation of indigenization, these Calls to Action are little more than aspirational. This requires buy-in and initiatives from all forms of education, formal and informal. This brief look-into the operations of a STEM educational outreach program working to indigenize carries lessons for formal education that can prove essential in connecting targeted, one-to-one relationships between institutions and nations, to many-to-many, broader scale relationships between multiple institutions and multiple nations. By emphasizing the foundational element of sharing through the resource nexus that is organizations like Geering Up Educational Outreach, we hope to help move the push to indigenize to a broad scale, national level, collective endeavor.

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UNDERSTANDING STEM IDENTITY USING THE HIGH SCHOOL LONGITUDINAL STUDY FROM THE U.S. NATIONAL CENTER FOR EDUCATION STATISTICS

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ABSTRACT

This study examines the relationship between STEM identity in high school and postsecondary indicators as a way to inform efforts that address challenges in STEM interest, learning, and participation of groups underrepresented in STEM. STEM identity is described as the way in which individuals understand themselves within and receive recognition from the STEM community. This study augments the current knowledge base on STEM identity by using (a) the STEM identity composite score in the High School Longitudinal Study (HSLS) of the U.S. National Center for Education Statistics (NCES), (b) a series of postsecondary indicators, and (c) student demographics. The data allow us to determine whether differences in STEM identity exist across student populations, whether a relationship can be found between STEM identity and postsecondary indicators, or whether students with non-STEM majors possess measurable STEM identity. Results indicate significant differences can be detected in STEM identity based on personal characteristics. STEM identity also is a significant predictor of postsecondary indicators, with some personal characteristics moderating that relationship. STEM majors report greater levels of STEM identity, but a non-trivial percentage of non-STEM majors report moderate to high levels as well. This suggests a well of untapped potential may exist for filling the STEM pipeline.

Keywords: *STEM identity, postsecondary indicators*

INTRODUCTION

This study examined the relationship between STEM identity in high school and postsecondary indicators as a way to inform efforts that address challenges in STEM interest, learning, and participation of groups underrepresented in STEM. STEM identity can be described as the way in which individuals understand themselves within and receive recognition from the STEM community. This study augments the current knowledge base on STEM identity by using (a) the STEM identity composite score in the High School Longitudinal Study (HSLS) of the U.S. National Center for Education Statistics (NCES), (b) a series of postsecondary indicators, and (c) student demographics. The data allow us to determine whether differences in STEM identity exist across student populations, whether a relationship can be found between STEM identity and postsecondary indicators, or whether students with non-STEM majors possess measurable STEM identity.

THEORETICAL OR CONCEPTUAL FRAMEWORK FOR THE RESEARCH

Frameworks build upon a foundation of established knowledge, offer logical explanations for the relationships observed, and reveal new understandings of a phenomenon—in this case, the ways in which STEM identity is contextualized within self, the internal environment, and the external environment. Four components comprise Collins' (2018) contextual model of Black Student STEM Identity (BSSI): STEM reflective identity, STEM competence/ability, STEM values/interest, and STEM assimilation. The model was developed from Whiting's (2006) Black Male Scholar Identity Model and Ford's (2013) Female Achievement Model for Excellence, which indicate identity is complex, developmental, and multidimensional. The Collins model assumes an asset-based approach to STEM talent development for underrepresented groups. The BSSI Model represents four basic, interconnected questions internalized by Black students that influence their STEM identity: (1) Do I belong in STEM (reflective identity)?; (2) Can I succeed in a STEM field (competence/ability)?; (3) Do I want to succeed in a STEM field (value/interest)?; and (4) What must I do to succeed in a STEM field (assimilation)? These questions are situated within their internal environment (home, community, and cultural space), as well as their external environment (school, work, and career space).

BRIEF REVIEW OF RELEVANT LITERATURE

Broadening participation in STEM fields is of paramount importance to the scientific and educational communities. In 2016, a 10-year high was seen with 35% of freshmen intending to pursue a STEM major, which is a marked increase from less than 10% in 2008 (National Science Foundation [NSF], 2018). Almost 16% intended to pursue a major in the biological and agricultural sciences; 11% in engineering; 6% in mathematics, statistics, or computer science; and 3% in the physical sciences. While women earn about half of the bachelor's degrees in biological and agricultural sciences, the bachelor's degrees awarded to women in mathematics, statistics, and computer science have been declining since 2000. Meanwhile, from 2000-2015 the number of STEM degrees earned by White students has increased, but their share declined from 71% to 61%; Hispanic degree recipients increased from 7% to 13%, Asians 9% to 10%, African Americans remained at 9%, and American Indians and Alaskan Natives decreased from 0.7% to 0.5%. Overall, doctorate-granting institutions with very high research activity award the most STEM degrees in the United States, but the largest proportion of racial and ethnic minorities receive their STEM degrees at minority-serving institutions (NSF, 2018). These numbers have a reverberating effect in the workforce. For example, while racial and ethnic minorities account for 32% of the American population, only 10.2% of employed engineers and 6.3% of all engineering faculty identify as such (National Action Council for Minorities in Engineering, 2014).

These STEM actualities create economic constraints, particularly deficiencies in the human capital necessary to be competitive in the field in the 21st century. This will continue until those underrepresented in STEM are more effectively engaged in the discipline (NSF, 2018). These groups include women, underrepresented racial and ethnic minorities, individuals with disabilities, English language learners, and those from lower socioeconomic backgrounds. To better understand ways to increase participation in the disciplines, measurement of STEM identity and related interventions to increase STEM identity have grown in popularity.

Much of the STEM identity research has been devoted to student interviews, with a strong focus on racial and ethnic minority student experiences (Rodriguez et al., 2019), as well as institutional-level surveys (Seyranian et al., 2018). Findings from STEM identity research indicate this concept is measurable (McDonald et al., 2019), and discernable differences can be found across student groups. Women and racial and ethnic minority students often report a lack of access to socialization opportunities in their disciplines, in addition to being subjected to subtle biases (Rodriguez et al., 2019). These gender and racial/ethnic experiences complicate their STEM identity and place them at a disadvantage in academia in multiple ways, such as in distribution of resources, mentoring opportunities, and persistence in their major. As a result, these issues contribute to lower retention and completion rates in comparison to their White male counterparts.

Some prior efforts at measuring STEM identity have been based on survey research, with three general findings. First, students' STEM identities differ by gender and race/ethnicity. Hazari et al. (2013) found the weakest STEM identity was reported by females (particularly Hispanic females), with males in all race/ethnicity groups expressing the strongest STEM identity. Second, STEM identity is strongly correlated with choosing STEM career pathways (Hazari et al., 2010; Hazari et al., 2013). Third, and perhaps surprisingly, even STEM career-minded students report low STEM identity (Hazari et al., 2013). Almost all of these survey studies relied on large samples from a broad range of backgrounds. But none were longitudinal or compared STEM majors to non-STEM majors in how they are described below. While a growing value has been attached to STEM identity research, no study has been found that used nationwide data to determine whether differences exist across student populations, whether a relationship can be found between STEM identity and postsecondary outcomes, or whether non-STEM students possess measurable STEM identity.

RESEARCH QUESTIONS

The research was guided by the following questions:

1. Is there a significant difference in STEM identity based on gender, disability status, race/ethnicity, English language learner status, and socioeconomic status?

2. Is there a significant relationship between STEM identity and college enrollment, college persistence, and declaring a STEM major?

3. Is there a significant difference in STEM identity between STEM majors and non-STEM majors?

4. What percentage of non-STEM majors possesses a STEM identity?

METHODOLOGY

Data were drawn from HSLS, which was a particularly relevant dataset for at least four reasons. First, it contains questions specific to STEM identity. Second, the dataset is now old enough to include postsecondary data. Third, the data are longitudinal, whereas other STEM identity research is predominantly cross-sectional. Fourth, STEM was a particular focus of HSLS because it includes questions about STEM indicators omitted in other databases.

The substantive variables in the analysis include the following.

STEM identity in high school: a composite variable constructed from eight scales in the base year and first follow-up—math identity, utility, self-efficacy, and interest; and science identity, utility, self-efficacy, and interest.

Postsecondary indicators: whether a student enrolls in college, remains in college, and declares a STEM major.

Student characteristics measured in high school: gender, disability status, race/ethnicity, English language learner status, and socioeconomic status.

Control variables measured in high school: mean high school math/science teachers' perceptions of the math/science professional learning community, mean high school math/science teachers' selfefficacy, mean high school math/science teachers' perceptions of math/science teachers' expectations, mean high school math/science teachers' certification, urbanicity, region, school type, school principals' perception of school climate, students' mean math/science GPA, and students' combined credits earned in math/science.

The overall sample size was approximately 23,500, although some analyses used smaller sample sizes. For example, questions about declared major were approximately 13,000, as they only included those who enrolled in college.

DATA ANALYSIS

24. Is there a significant difference in STEM identity based on gender, disability status, race/ethnicity, English language learner status, and socioeconomic status?

$Y = \beta_0 + \beta_1$(gender) + β_2(disability status) + β_3(race/ethnicity) + β_4(English language learner status) + β_5(socioeconomic status) + X + e

OLS regression, where Y = STEM identity and X = index of control variables (as defined previously)

2. Is there a significant relationship between STEM identity and college enrollment, college persistence, and declaring a STEM major?

Prob(Y = 1) = $\beta_0 + \beta_1$(STEM identity) + β_2(STEM identity*gender) + β_3(STEM identity *disability status) + β_4(STEM identity*race/ethnicity) + β_5(STEM identity*English language learner status) + β_6(STEM identity*socioeconomic status) + X

Logistic regression, where Y = college enrollment, college persistence, or declaring a STEM major and X = index of control variables. This question employed two models. The first used only STEM identity and control variables. The second included the interactions to analyze the extent to which the relationships between STEM identity and the postsecondary indicators differ based on the various student characteristics.

3. Is there a significant difference in STEM identity between STEM majors and non-STEM majors?

$Y = \beta_0 + \beta_1$(STEM major) + $X + \Theta$ + e

OLS regression, where Y = STEM identity score, STEM major = whether student has declared a STEM major, X = index of control variables, Θ = index of student characteristic variables

24. What percentage of non-STEM majors possesses a STEM identity?

This question was answered by using the identity score to calculate percentages of non-STEM majors with a STEM identity equal to or greater than the mean STEM identity score of STEM majors.

Percentages were disaggregated by gender, disability status, race/ethnicity, English language learner status, and socioeconomic status.

RESULTS

Results indicate significant differences in STEM identity based on personal characteristics. Greater levels of STEM identity were significantly associated with students with special needs (β = .153) and being a male (β = .096). STEM identity acts as a significant predictor of postsecondary indicators. STEM identity is positively related to college enrollment (β = .563), which is moderated by being white (β = -.331) and being an English language learner (β =-1.529). STEM identity is positively related to persisting in college (β = .228), which is moderated by being an English Language Learner (β = -.949). In addition, STEM identity is positively related to declaring a STEM major (β = .790), which is moderated by being female (β = .544) and SES (β = .372).

Relative to the relationship between STEM identity and STEM/non-STEM major, results indicate STEM majors report greater levels of STEM identity in high school (β = .266). When STEM identity is measured as z-scores, the overall (unconditional) sample mean is .01, with non-STEM majors mean = -.044 and STEM majors mean = .429. This not surprising, although a non-trivial percentage of non-STEM majors—19%—report levels of STEM identity at or above the mean for STEM majors. This suggests a well of untapped potential may exist for filling the STEM pipeline. And when these percentages are disaggregated by student characteristics (see Table 1), some noteworthy differences are present.

Table 1
Percentage of non-STEM Majors with STEM Identity at or Above the Mean for STEM Majors

Student Characteristic	Percentage
Male	21.6
Female	16.6
Special needs	19.4
No special needs	16.5
Not ELL	19.2
ELL	17.1
White	18.0
Person of color	20.0
SES quartile 1	14.4
SES quartile 2	17.4
SES quartile 3	19.0
SES quartile 4	24.0

CONCLUSIONS AND STUDY SIGNIFICANCE

Study results suggest initiatives to increase college-going, persistence, and choice of STEM as a major should address fostering STEM identity among school-aged children. Unlike resourceintensive programs designed to increase participation in STEM, encouraging STEM identity does not necessarily require highly structured and expensive programs. STEM identity is measured here with questions such as, “You see yourself as a science person” and “Others see you as a science person.” Teachers can encourage these attitudes through consistent and positive interactions with students.

The results also appear to contradict extant STEM identity literature that opines students of color may hold lower levels of STEM identity. Rather, white students were found with lower levels of STEM identity, which suggests applying deficit thinking to students of color is counterproductive. Finally, the non-trivial percentages of non-STEM majors with STEM identity suggests a possible role for STEM disidentification theory (Filer, 2009) to influence the way in which the relationship between STEM identity and filling the STEM pipeline is viewed.

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STEM ENROLLMENT OF SECOND-GENERATION IMMIGRANT STUDENTS WITH HIGH-SKILLED PARENTS

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ABSTRACT

Israel is a multicultural society that has experienced waves of Jewish immigration since its foundation in 1948. Most of the Jewish population in Israel are either immigrants or their offspring. STEM-related careers often open doors to economic upward mobility and financial independence. This research examines between-group differences in Israeli high school STEM enrollment between five groups of *Israeli-born Jews*. Four of these groups comprise secondgeneration immigrant students from North America (NA), South America (SA), France, and the Former Soviet Union (FSU), with high-skilled background parents. The fifth group comprises non-immediate-immigrant background students. The study's conceptual framework combines expanded Segmented Assimilation Theory and Bourdieu's concepts of habitus and cultural capital. NA second-generation immigrants were characterized by the highest family educational and economic levels, while the FSU second-generation immigrants had the highest percentage of high-skilled parents, albeit with the lowest economic background. This research used Ministry of Education databases for all grade-12 students in the Jewish sector, who earned a high school matriculation certification during 2014-2017 (N=173,636). The study found that the non-immigrant background students did not have an advantage in STEM enrollment in high school as compared to the second-generation immigrants. Moreover, the FSU students had the highest percentage of STEM enrollment. Our findings suggest that both Segmented Assimilation Theory and Bourdieusian concepts of habitus and cultural capital should be considered to account for the STEM enrollment of immigrant children. This study's practical implications may inform and equip educational policy and intervention programs aimed at increasing school STEM enrollment.

Keywords: *segmented assimilation theory, cultural capital, science habitus, STEM enrollment***,** *STEM educational achievements, second-generation immigrants, high-skilled immigrants*

INTRODUCTION

In order to address contemporary economic, political, and environmental challenges, modern societies have to ensure that the next generation of students is ready to engage in post-secondary science, technology, engineering, and mathematics (STEM) education. High financial rewards in many STEM-related occupations are especially attractive to immigrants, as these professions can facilitate their occupational and economic mobility in the target country (Riegle-Crumb, King, Grodsky, & Muller, 2012). A number of previous studies have found that student enrollment in science courses at advanced levels in high school is one of the best predictors of their future entrance into the STEM fields (Chachashvili-Bolotin, Milner-Bolotin, & Lissitsa, 2016; Wang & Degol, 2013). In Israel, in order to pursue STEM occupations, as well as STEM-related tertiary education, enrollment in advanced secondary science and mathematics courses is required. In the Israeli context, physics is perceived as the most difficult and demanding science subject and the students who choose to take it are considered to be the most able science-oriented students (Lissitsa & ChachashviliBolotin, 2019). Therefore in this paper, the combination of advanced secondary mathematics and physics courses is labeled as a STEM track.

The aim of the present study is to examine between-group differences in enrollment in secondary school STEM track among second-generation (S-G) immigrant students with high-skilled parental backgrounds. To reach this goal, we approached the analysis from two angles: the expanded Segmented Assimilation Theory (Portes & Rumbaut, 2006) and Bourdieu's concept of "cultural capital" (Bourdieu, 1986). Israel provides an attractive setting for this study. Since 1990s, the Israeli Jewish population has increased by more than 20 percent, thanks to the multiple waves of immigration of highly educated immigrants. These immigrants came mainly from the Former Soviet Union (FSU), North America (NA), South America (SA), and France (Israel Central Bureau of Statistics, 2017). Despite the high education level of these immigrant groups, their economic and occupational profiles, as well as cultural characteristics differed both within and between them and the Israeli Jews, whose parents were born in Israel (Amit, 2010; Amit & Bar-Lev, 2015; Chachashvili-Bolotin & Lissitsa, 2018; Chachashvili-Bolotin et al., 2016). We will refer to the latter group as a non-immigrantbackground group to distinguish them from the second-generation immigrants. NA immigrants were characterized by the highest educational and economic levels compared to the other groups. FSU immigrants had the highest percentage of high-skilled scientific and technical personnel, but the lowest economic background of the five groups.

METHOD

The Education System in Israel is divided into two sectors: a Jewish and an Arab sector. In the Jewish sector, the main language of instruction is Hebrew, while in the Arab sector, the main language of instruction is Arabic. Therefore, Jewish students choose to study in the Jewish sector, whereas most Arab students study in the Arab sector. Since this research aims to examine the differences between five Jewish groups, this study is situated in the Jewish sector. This research used Ministry of Education databases that included relevant information about all students in the two types of Jewish sector schools: state and state-religious. The database we used included students who finished their secondary education with a matriculation certificate during 2014-2017. Our final dataset included 173,636 students. We applied the Generalized Linear Mixed Models to carry out the analyses.

PRELIMINARY FINDINGS

While the analysis is still ongoing, we have some preliminary findings. So far, there are three main findings. First, non-immigrant background students did not have an advantage in STEM-track enrollment compared to the second-generation immigrant groups. Second, NA second-generation immigrant students did not exhibit the highest STEM-track enrollment. Third, the highest STEMtrack enrollment was found among the FSU second-generation immigrant group.

Controlling for parental education and school variables did not diminish the initial advantage of the FSU second-generation immigrants. Moreover, controlling for school and student variables revealed significant disadvantage of NA and SA second-generation immigrant students compared to nonimmigrant background students. Finally, controlling for school and student variables did not yield the difference in STEM-track enrollment between the second-generation French students and nonimmigrant background students.

PRELIMINARY DISCUSSION

Considering that STEM-track enrollment is an indicator of high educational achievement, the findings for second-generation students from NA, SA, and France are in line with classic Segmented Assimilation Theory (Portes & Rumbaut, 2001), which reported a "consistent and strong" association between parental socioeconomic status and second-generation educational outcomes.

The findings among the FSU immigrants may be explained by the Bourdieu's concept of "cultural capital" as the knowledge, skills, and behaviors transmitted to an individual within their socio-cultural context. As it was mentioned before, the FSU immigrants had the highest percent of STEM-related occupations. Consequently, their children might have inherited the science habitus and science cultural capital from their parents. This family environment could have motivated the children to choose the STEM track. However, one cannot ignore the fact that at the same time the FSU immigrants were the most economically disadvantaged group. Thus, future economic security might have also been the motivator behind their choices of STEM-related careers. Therefore, future STEMrelated career paths enabled FSU students to utilize familial cultural capital and to ensure future economic security.

PRELIMINARY CONCLUSIONS

STEM courses in secondary schools play a crucial role in students' decision making regarding their post-secondary career choices. Therefore, the current study aimed at examining STEM enrollment of secondary school students in the Israeli context. The most important finding of the current study regarding this issue is that the highest socio-economic family background is insufficient to sustain the highest students' STEM track enrollment. We also found that students from groups with higher percent of science habitus families were more likely to enroll in the STEM track. However, second generation immigrant students whose parents were high-skilled immigrants did not have an advantage in enrolling in STEM track as compared to the non-immigrant background students. Therefore, both the socio-economic family background and the family STEM-related cultural capital should be considered as important factors in students' decisions to enroll in STEM track courses. In other words, both Expanded Segmented Assimilation Theory (Portes & Rumbaut, 2001, 2006), that emphasizes the role of the socio-economic status, and Bourdieu's concepts of habitus and cultural capital (Bourdieu, 1986) should be taken into account for understanding the reasons behind student STEM track enrollment (Chachashvili-Bolotin, Lissitsa, & Milner-Bolotin, 2019).

PRACTICAL IMPLICATIONS

Governments and science educators all over the world have expressed concerns that STEM participation needs to be increased and broadened for the reasons of both national economic competitiveness and social justice (ensuring that STEM fields are open to all) (Archer, Dawson, Seakins, & Wong, 2016). In Israel, like in many other western countries, the Ministry of Education targeted disadvantaged socio-economic groups for expanding the enrollment in the high school STEM track courses. At the same time, the Ministry assumed that the students from the high socioeconomic family backgrounds do not need encouragement for enrolling in STEM track at secondary schools. Therefore, in the case of Israel, the second-generation immigrants from high-skilled parental background were not designated as such a target group by the Ministry. This decision had important and often unintended social implications that were uncovered in our study – the unrealized STEM potential of a significant segment of the population.

Our preliminary findings indicate that STEM enrollment for these immigrant students was similar to or even higher than the non-immigrant background students. In other words, these immigrant groups succeeded in spite of the lack of support from the Ministry of Education. While the Ministry of Education supported disadvantaged groups, the children of high-skilled immigrants should not be ignored, as they might have significant unrealized potential. Their STEM academic potential may be realized with relatively low funding by cultivating students' science habitus. School-based STEM enrichment activities and social environments can be used to inform adolescents about STEM-related occupational areas, especially those lacking a science habitus (Ayalon & Mcdossi, 2016; Chen & Carroll, 2005; Katherine P. Dabney et al., 2012; K. P. Dabney, Tai, & Scott, 2015; Engle, Bermeo, & O'Brien, 2006; Liao, McKenna, & Milner-Bolotin, 2017; Mann, Legewie, & DiPrete, 2015; Milner-Bolotin & Johnson, 2017; Milner-Bolotin & Milner, 2017; Stephens, Hamedani, & Destin, 2014). In this way, the science habitus can be inculcated among different groups without a direct reliance on family science background of the students (Milner-Bolotin, 2011; Milner-Bolotin & Johnson, 2017). In line with our findings, we recommend educational administrators and policymakers to pay extra attention to school-based STEM outreach activities aimed at cultivating students' science habitus. There is ample research literature on how these school-based STEM outreach activities can be implemented (Milner-Bolotin & Marotto, 2018). Therefore, our study calls on the administrators, educators, and policy makers who want to support student STEM track enrollment to pay attention to the students from diverse socio-economic family backgrounds.

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ANIMATING THE INQUIRY PROCESS ON CLIMATE CHANGE THROUGH LEARNING OF MATHEMATICAL AND COMMUNICATIVE LITERACIES

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ABSTRACT

The ‘M’ (mathematics) in STEM is often perceived as the most challenging part as it is not easy to connect the teaching of core mathematics concepts to inquiry, team work, communication and design processes. In this design-based research, we observe how Grade 10 students work in teams to use Desmos (a mathematics graphing application) activities that draw on mathematical ideas of relationships, functions, and causality and how they express these ideas in connection with the inquiry of a contentious social scientific issue, climate change. With pre- and post-intervention tasks we document change in students’ performance in reasoning and argumentation on social scientific issues requiring application of mathematics and communicative literacies. Focus group interviews are also conducted to get students’ feedback on their learning experiences.

Keywords: *techno-mathematics literacies, communicative literacies, climate change, Desmos*

INTRODUCTION

STEM education seeks to integrate science, technology, engineering and mathematics together for both coherence and unification between the different disciplines. This educational initiative emerged partly from criticism that these subjects, which have a lot in common, are frequently being taught in isolation from each other. However, it has been 94riticized that the M in STEM is not high-quality mathematics (English, 2016). In addition, mathematics topics are assumed to be addressed and learned within the scope of the other disciplines; the 18th century mathematician Gauss, in fact, described mathematics as a basis for all sciences. This assumption can draw attention away from the explicit teaching of mathematics. When mathematics is framed as a fundamental core of the sciences, it makes sense that teachers may simply believe that mathematics learning may just happen. In this paper, we outline a study that seeks to raise the attention and quality of mathematics but yet still values and highlights the sciences. We do this by integrating a web-based digital application called Desmos which is designed to integrate mathematical analysis alongside visual and socio-textual interactivity (Desmos is described in more detail below). Our study also draws out the science component of STEM by exploring the socio-scientific issue of climate change, a topic relevant and current but also potentially inaccessible in that it is difficult for students to engage with climate change data on a personal meaningful level. We believe that using Desmos to explore climate change data, students will be explicitly developing techno-mathematical literacy as well as communicative literacies (e.g. developing well-reasoned and data-based arguments in verbal and multimodal communication with the public).

Research Gaps/ Weak Links in STEM Education

The literature on STEM education focuses predominantly on cognitive constructivism, hands-on problem-based/inquiry-based activities, model/artifact building, and slants towards science learning. However, mathematic literacy is central to STEM education. We suggest that one of the aims of STEM education is to develop our future generation’s capacity to analyse and reason with data and develop evidence-based explanation and argumentation as competent contributors and critical participants in public, democratic debates on highly contentious social scientific issues such as climate change, genetic engineering, or food crises (English, 2015).

Mathematics teaching is, however, often cerebral and neglects the emotional aspects and embodied nature of human interests. In addition, science teaching, while stressing hands-on inquiry processes, often falls short of helping students to develop both the core of mathematical literacy and the kind of communicative competencies to formulate data-based explanation and argumentation in a clear and accessible language to the general public to engage in constructive debate on imminent issues. Below we summarize what we perceive to be the weak links in STEM education:

(1) Weak link between mathematical literacy and science literacy

While the rhetoric of STEM education includes mathematics, there is still paucity of research on how the teaching of mathematical literacy and science literacy can be integrated in actual curriculums and pedagogies that pay due weight to both (Shaughnessy 2013; English 2016; Maass et al., 2019). Mathematics is often seen as a discipline that calculates or solves problems, so that when science and mathematics are integrated, science is seen as the discipline that sets up a real-life model and mathematics is seen as the discipline that does all the computation needed within that model. In this way, mathematics is subordinated to the discipline of science. Another challenge that causes tension between science and mathematics teaching and learning is the underlying enculturated ways of doing in each discipline. When Boote (1998) compared highschool word problems in physics and in mathematics classrooms, it was clear that when students were solving problems in the different classrooms, the norms and values were significantly different, causing students to invoke different literacies and methods of meaning making in the different classes.

(2) Weak link between mathematical/science literacies and 21st Century communicative literacies

The specialized languages of mathematics and science have been constructed by internal communication among the disciplinary elite and are often ill-suited for participating in public conversations on controversial issues. However, although there is a wide gap between these specialized disciplinary languages, a clear, accessible language can be used to express data-based reasoning to the general public on key issues of both local and global concerns. 21st Century literacies include such communicative, multimodal and critical literacies (Morrell, 2012). The STEM education research literature is still relatively silent on concrete curricular and pedagogical approaches on how to facilitate integrated learning of mathematical, science, and 21st Century communicative literacies for constructive participation in democratic deliberation and debate on contentious social scientific issues. In British Columbia, Canada, the mathematics curriculum hints at these literacies (BC Ministry of Education, 2015) but there is no clear articulation of how these literacies should be developed or taught. There is ample description in public discourse of the untenability of the future and the inability to predict what competencies will be important but this simply hints at the need to develop a mathematical approach that extends beyond the general knowledge to "get by" in society. Mathematical literacy involves an ability to articulate the necessary variables in a situation, articulating why these variables are the important ones, and negotiating with others through discussion how and why the mathematization of these variables will be an appropriate approach. This is 21st century education: awareness, articulation of importance, critical negotiation, and willingness to refine the formulation of a scientific data/evidence-based argument accessible to the general public.

TECHNO-MATHEMATICS LITERACY

Pseudo-mathematics refers to data representations like tables, numbers and graphs (Noss et al., 2007). It is called pseudo-mathematics because although there is potential for mathematical analysis, there is no guarantee that genuine mathematics thinking or analysis will occur. For example, if a student sees a temperature chart for a specific area plotted over the last century, there is no assurance that the student will apply any mathematical analysis, such as extrapolating or differentiating, on this data. A more advanced approach is needed to explore the underlying relationships inherent in data. A mix of techno-mathematics literacy and social interactivity/communicative literacy is our proposal for this study. Techno-mathematics literacy offers a way in for students to explore and interact with the underlying relationships while social interactivity/communicative literacy allows for meaning making through democratic, dialogic discussion, explanation and warranting. Mathematics in this way can lead and guide STEM activity by focusing specifically on developing mathematical argumentation, mathematical language through discussion and modelling mathematics in contextualized experiences. We plan to combine these literacies through the application Desmos.

Desmos

Desmos is an online web-based calculator that has calculating, graphing and geometric functionalities. Desmos was originally developed in 2011 to make graphing more stable, reliable, and accessible and was created online making it fully accessible on various platforms. Desmos has previously-made and vetted activities that present a mathematical idea through a set of slides. The slides (approximately 8-20) are constructed to help students build up knowledge through the use of a variety of interactive communications. One form of communicative interactivity that is common in Desmos comes in the form of a question. For example, a Demos slide might pose the following prompt: 'How long did it take you to get to school today?' The interactivity is carried forward when each student's response is presented on the next slide alongside their classmates responses. In this way, the dataset in Desmos is created from all the responses of students. It is not a disconnected set of data but links up each individual student in two ways: 1) they contribute to the data. That is, their information is literally a part of the dataset; and 2) they are motivated to reflect on the data set because the data is something they can relate to (how far they are from home). Through this interactivity, the data set becomes a mathematical object for students to engage with. In response to the example question described above, a scatterplot of distance versus time is graphed and students are expected to create a mathematical regression. Desmos is a predominantly meta-mathematical platform that focuses less on content and more on actions like predicting, refining, inferencing based on provided interactive data. The mathematical content is subordinated to the broader scope of the sequence and or development of a big idea. We suggest that Desmos draws on the big picture of mathematics focusing on critical thinking and social personal responsibility that is found in the British Columbia curriculum. Our goal is to have students create their own Desmos slideshow on the topic of climate change. Building an activity demands students to curate and present values and learning about climate change. The idea is that by considering the progression of a Desmos activity students assess their own knowledge and learn about themselves. We use climate change as a topic not only because it is relevant to the students, but we believe the social interactivity of Desmos and specifically the metacognitive framing required to design and build a Desmos activity will help students bridge the link between disembodied data of climate change and the daily experience of students. We seek to explore students' communication acts during a climate change project in Desmos.

CLIMATE CHANGE

One of the challenges of supporting students to think deeply about climate change is the need to reconcile the disembodied facts of climate change data with the experience of students in everyday life (Jasanoff, 2010). In one's own experience, it is hard to 'feel' climate change happening but in mathematizing climate change (creating a mathematical object in Desmos for example) students can interact with it in a personal way. We believe calculation is not enough, as educators we need to allow students to create a narrative. We believe Desmos is a digital technology that provides an opportunity to create that narrative.

The overall focus on this research is to understand better how students weave the facts of climate change into meaningful patterns so that they can discover and understand some of the underlying mathematical relationships inherent in the data.

RESEARCH QUESTIONS

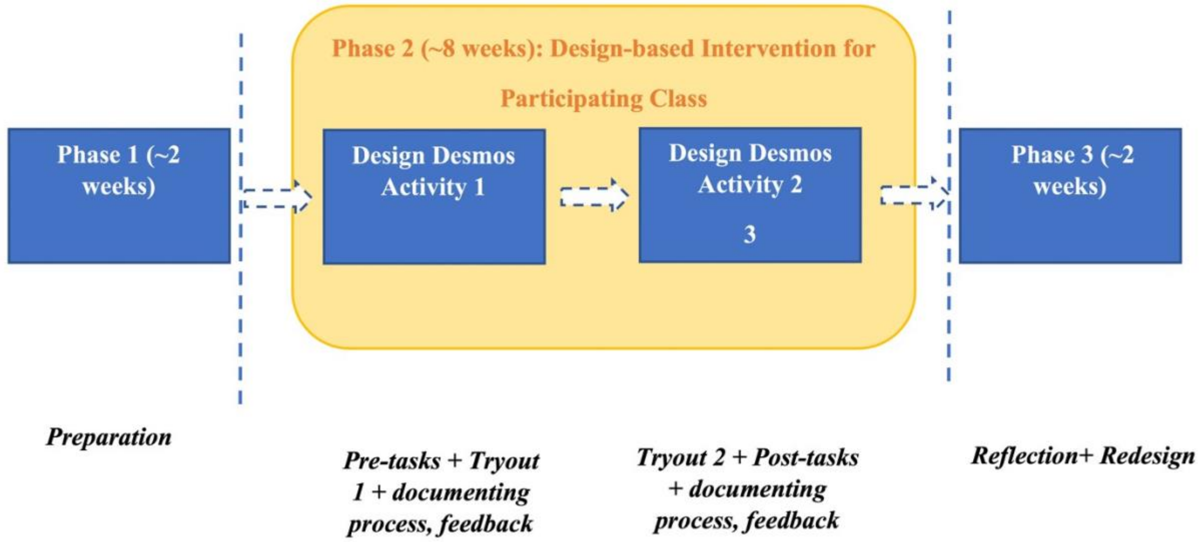
1. How do students' interaction with Desmos activities draw on mathematical ideas of relationships, functions, and causality? What is the nature, scope and impact of the techno-mathematical literacies that develop through their use of Desmos?
2. What communicative (meaning making) features in Desmos are explicitly drawn on when students engage in an activity that mathematitizes an climate change issue?

METHODS

This study will be conducted in a grade 10 mathematics classroom in a school on the west coast of Canada. Foundations and Pre-Calculus mathematics 10 (FPC 10) is a requirement for graduation. Although there are alternate courses to fulfill this mathematics requirement, most students take it. In grade 10 students are 15-16 years old. Two classrooms will be observed, one will explore the topic of climate change using Desmos, the other will approach the topic without digital technology. The purpose of this is to contrast the mathematical literacy that develops in each class. FPC 10 was chosen because in its curriculum there is a component of statistical analysis which aligns with the focus on climate change data analysis. In addition, students have just learned linear and quadratic functions so they will have been introduced to coordinate systems as well as different types of functions.

Classes will be videotaped to capture the dialogue that occurs. In addition, Desmos will capture data from all interactions with the software so that it can be analyzed as well. The focus in this analysis will be on the student's articulation of general ideas regarding the mathematical analysis of data. The research design follows a 3-phase plan typical of design-based research (DBR) (See Figures 1). Brown (1992) first introduced the concept of design experiments. DBR is especially suited for research that aims at developing innovative curricular design and pedagogical practices in a complex, real contexts, rather than a controlled environment. It focuses on collaboration between researchers and research participants and documents the experiences and perspectives of students, teachers and researchers in the research process. This approach was first introduced in educational psychology as a critical response to the traditional experimental psychological approach, which tends to investigate the effect caused by a variable under a controlled environment (Collins, 1999). Broadly defined, "design-based research is not so much an approach as it is a series of approaches, with the intent of producing new theories, artefacts, and practices that account for and potentially impact learning and teaching in naturalistic setting" (Barab and Squire, 2004, p. 2).

Figure 1: The Three Phases of Design-based Research (Duration of each phase can be flexible, depending on the feasibility and curricular plan of the particiapting class, teacher and school)



With pre- and post-intervention tasks we document change in students' performance in reasoning and argumentation on social scientific issues requiring application of mathematics and communicative literacies. Focus group interviews are also conducted to get students' feedback on their learning experiences. The pre- and post-intervention tests will consist of reasoning/argumentative tasks contextualized in the topical area of climate change and will require the application of mathematical and communicative literacies.

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EXPLORATORY STUDYOF THE HYPOTHETICAL LEARNING TRAJECTORY OF CHINESE STUDENTS' SPEED CONCEPT

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ABSTRACT

The development of the concept of speed has long been concerned (Piaget, 1970; Thompson, 1994) since the concept itself is actually a quite complicated and important concept that involves both physic and mathematics fields. The concept of speed is usually arranged separately in Chinese basic education, which causes low efficient learning and teaching. To explore the learning trajectories of Chinese students' concept of speed, constructivist qualitative teaching experiment is used in this study. Firstly, we design the learning tool based on the principles of STEM education. Then four fifth-grade students of different mathematics levels are selected to participate in the teaching experiment. Ongoing analysis and retrospective analysis are used to analyse the data. We find that there are four stages of Chinese children constructing their speed model: the pre-concept of speed, the preliminary concept of speed, the participatory concept of speed and the anticipatory concept of speed. This study also shows that the interactive software designed based on principles of STEM and the communication between partners improve students' conceptual understanding of the concept of speed.

Keywords: *speed, learning trajectory, qualitative teaching experiment*

INTRODUCTION

The comprehension of speed concept has long been concerned (Piaget, 1970; Thompson, 1994), since the concept itself is actually a quite complicated and important concept that involves both physic and mathematics fields. On one hand, based on its physical characteristics, speed can be attributed as an intensive quantity, which cannot be measured directly and is dependent on the rate of the other two extensive quantities, time and distance, which can be obtained by directly measurement. On the other hand, from mathematical perspective, the interrelationship between speed, time and distance is regarding measurement, proportionality, ratio, rate, fraction and function (Thompson, 1994). In Chinese mathematics curriculum, the speed and its relationships with time and distance are considered as one of the most important reality models of multiplication (Shi, 2013) and students encounter this concept as early as in their third grade with the focus of using its formula to calculate and solve the related multiplicative problems. Although the memorization of the formula increases the efficiency of calculating, what is hidden behind students' recitation is unknown. Furthermore, instead of complementing the understanding of the relationship within these three quantities by organizing some activities suited for students to construct the concept, what present in Chinese science curriculum standards and textbooks now is far behind the content in mathematics. It only requires fourth and fifth grades students to know the way of measuring time and distance, the meaning of the speed and the range speed of some transportations in daily life (PEP, 2017). This disconnection causes the real low efficiency in teaching and has no benefits for students to construct the concept.

Recently, with the prospect of STEM education, the core concept is frequently mentioned. As an instructional approach, STEM integration has attracted greater attention. Different categorizes, approaches or principles have been proposed. Despite varied procedures of categorizing, little attention has been given to students' learning process, especially in the non-western context.

Ultimately, the aim of STEM integration is to expose students to meaningful learning experiences that enrich their deep understanding in the STEM discipline topics. Therefore, it is imperative to first explore how do students construct the concept and what are their common misconceptions, and then to depict their learning trajectories. In this exploratory study, we use qualitative constructivist teaching experiment (Steffe & Thompson, 2000) to mainly focus on students' mental action and progress on understanding the relationship between speed, time and distance, and further propose some suggestions on adjusting the arrangement of this content.

LITERATURE REVIEW

Most studies on children understanding of the concept of speed focus on the order of children's conceptions of speed, time and distance and their corresponding age. Piaget (1970) and Cross & Pitekethly (1988) propose that speed is the last concept that mastered by children, in contrast, some other researchers find that time is the most difficult one (Siegler & Richard, 1979; Acredolo & Schmid, 1981). Jin et al. (2018) review the previous studies, and summarize that there are four stages of the children's learning of the concept of speed: the stage of judging speed according to the stopping point; the stage of transforming from the stopping point to considering other factors; the stage of direct proportion and reversal proportion, and the stage of mastery of the relations of three quantities. But most of these studies are conducted in western countries, and the researchers care more about the key stage of their development of the basic concept of speed, and few studies explore students' constructing process of speed.

Since the late 20th century, the external pressures from the globalization have compelled many countries, including China, to reform their organizational and epistemological framing of curriculum policy (Yates & Young, 2010). Currently, the nationwide used compulsory mathematics and elementary science curriculum standards, which were published in 2011 and 2017 respectively, are the basis for the textbooks' compilation. The equation "distance = speed ×time" is considered to be one of the most important reality multiplicative models in mathematics and is widely used in calculating contexts, such as equation, fraction and ratio. Before the curriculum reform in 2001, the subject related to science was called "*Nature*", which was implemented in primary school aiming at enlightening children's scientific interests. At that time, the guideline and textbooks of science were not systematic (Duan & Liu,2019). Since the curriculum reform in 2001, "*Nature*" has been changed to "*Science*", and the contents in Science is broadened to four core concepts which are Science of material, Science of life, Science of earth and universe, and Science of the technology and engineering (Ministry of Education, 2017). The content of speed belongs to the Science of material, which basically consists of three major parts: describing objects' position, understanding the concept of speed and knowing the different forms of mechanical movement. Table 1 presents the arrangement of speed-related content of Chinese mathematics and science textbooks.

Table 1 The arrangement of the content of Speed in Chinese primary school textbooks

	Version of People's Education Press (PEP) (2013 for M, 2017 for S)	Version 2 (Beijing Normal University Press, 2012 for M; Education Science Press, 2017 for S)
Mathematics (M)	**Grade 2**: direction and position; measurement; duration **Grade 3**: using line segment to represent distance; calculating the distance by multiplication **Grade 4**: proposing the concept and formula of speed **Grade 5**: including the movement of two objectives	**Grade 1**: position **Grade 2**: measurement **Grade 3**: calculating the distance by multiplication **Grade 4**: calculating the speed and including single round trip **Grade 5**: including the movement of two objectives
Science (S)	**Grade 5**: focusing on the relationship between tension and speed by writing down the strength of tension and the time	**Grade 4**: direction and position; using map; design experiments to compare speed, time and distance.

As is shown in Table 1, in the third grade mathematics class, students are required to calculate the distance and use the line segment to present the movement, and in forth grade, students need to learn the formula. While in science class, it is not until fourth or fifth grade that the concept of speed appears, and it only refers to designing experiment to understand the relationship between time, distance and speed, which students have already learned in math. This inconsistency of sequence arrangement in these two subjects causes low efficiency in teaching and impedes students' construction of the concept. So, it is necessary to integrate related content on speed to improve students' learning.

In this study, we adopt the original definition of hypothetical learning trajectory (HLT) proposed by Simon's (1995), "... made up of three components: the learning goal that defines the direction, the learning activities, and the hypothetical learning process, which is a prediction of how the students' thinking and understanding will evolve in the context of the learning activities" (p. 136). We give priority to their transition process from less to more advanced, which is called shift study (Tzur 2019), that means we emphasize the specification of conceptual transformations involved in progressing from less to more advanced markers. Constructivist teaching experiment is used to capture students' performance in different tasks and depict the preliminary trajectory in learning this concept.

RESEARCH DESIGN

Constructivist qualitative teaching experiment is used in this study. Firstly, we develop a software according to the core concept of movement and the principle of problem-centered interdisciplinary integration. Then, in the teaching experiment, through interaction with students, we try to explore and analyze students' developing process of their thinking.

Software Design

Design objectives: To give students opportunities to experience movement (fast and low), the differences among time, speed and distance and help students build the relations between formula and real-life situation.

Design principles: Visual presentation of the movement of objects; testing students' concepts at any time; students' involvement in the situation.

Design contents: There are two basic situations, Single situation (single-object and single-way) and Composite situation (double-way situation). In composite situation, there are two sub-composite situations. Composite situation I (CI) is single-object double way and Composite situation II (CII) is two objects double-way situation. These three situations cover the content of speed in Chinese primary school and the difficulty levels increase accordingly.

Software description: At first, we revise the learning software game “Turtle-rabbit race” developed by Thompson (1994). The new software’s name is “the little postman” (refer to Figure 1). Most tasks in this software are designed according to the “mailing” situation — turtle and rabbit send mails between the mail stations and the animal home. Through operating the software, students can observe the movement of the animals, measure time and distance, and construct the relations between the speed, time and distance.

The design ideas are as follows. Firstly, in order to design two objects to reciprocate at the same time, the software sets the same speed throughout the round trip for the rabbit, but the turtle can set the two different speeds of leaving and returning to the post office respectively. So, besides ensuring the basic situation, the software also provides space for exploring more difficult problems. Secondly, compared to Thompson's original research software, which can only move 100 cm in a single pass, the distance value in the "little postman" software can be selected between "10-700", but need to be an integer multiple of ten. This can help students practice with different levels of speed. Thirdly, students can move the rabbit and the turtles separately in this software, and also allow the two animals move at the same time, and pause at any time during the exercise to facilitate observation and give time for teacher-researcher to prompt questions. This design ensures the difficulty of different problems and facilitates student learning. Fourthly, the software has the option of checking whether to display the moving distance of the object. Combined with the clock timing in the upper right corner, it can help students to establish the relationship between speed, time and distance during the intuitive experience. Finally, when the “Show Line Segment” item is checked, the destination and the start point will be connected by the line, and the line will be segmented every “10” unit. This is helpful for children to understand the abstract line segment representation.

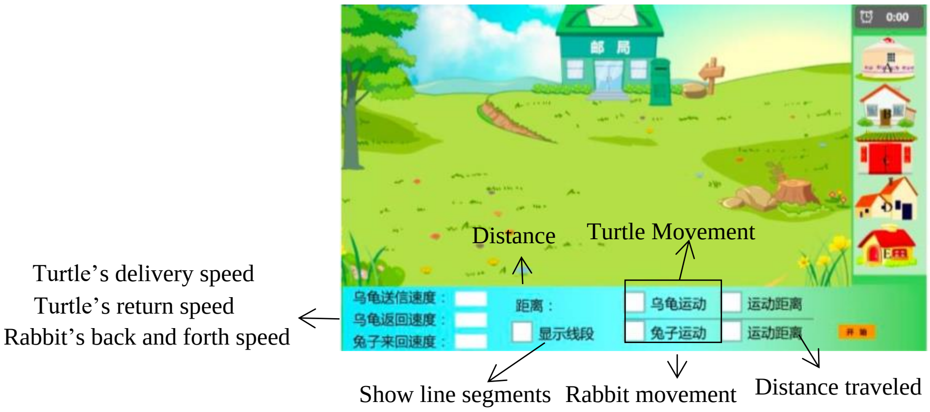

Figure 1 The interface of software of “the little postman”

Constructivist Teaching Experiment

Four fifth-grade students from a private school are selected as participants. Students A and B (middle level in mathematics) are in one group, and Students C and D (low mathematical level) in the other group. There are two reasons for us to select fifth grade students as participants. The first one is that they already have learned the concept of speed in their school education, so our purpose is not teaching them new concept, but identifying their levels of developing the concept. The second reason is that all of them still have difficulties when they encounter the problems about speed, except student B could solve one-object single-way tasks. Therefore, these fifth-grade students with learning disability in mathematics give us the opportunities to present and explore their levels and constructing process of complicated conception of speed with different pace.

Altogether, we taught the four students17 times, once a week after their class, from April to September 2018. The first and second authors are the teacher-researchers, whose roles are the leaders of making plans, teaching students and analyzing the data. And other two graduate students attend all the teaching episodes, take videos, and make notes, and discuss teaching plans. At last, we do ongoing analysis and retrospective analysis in group.

RESULT AND DISCUSSION

Through interacting with students, we summarized two of our major findings.
Firstly, we find that there are at least four distinctive stages in mastering the concept of speed. Level I is the "pre-concept of speed" and there are three main characteristics in this stage. In Level I, students may confuse the quantities, use formula mechanically, use numerical values instead of quantity to express, or use informal phrase, such as, "how fast they move" to replace the term of speed. Level II can be named as the "preliminary understanding stage of concept of speed". And in stage of Level II, students can distinguish each quantity and comprehend their meanings. They can also solve one single movement problem in one-way trip as well as present the movement through the line segment, that is, they know what is missing and how to figure out the third value. However, when added the interfere variables, students become confused again. It is until Level III that student can solve the round-trip tasks of one single object and present the motion of the object in line graph correctly and independently. Level IV can be seen as the anticipatory stage for concept of speed, as they can not only distinguish the meaning of each quantity in round-trip tasks of two objects but can also use abstract symbols to present the movement of the two objectives as well as their relationships. The table below presents the episodes we extracted at each level. Before we started the research, student A, C, D were all at the first level, while student B was basically at the third level, and after the research, student B reached the anticipatory stage, while the other three students were promoted to Level III.

Table 2 The Level of Students' Understanding of the Speed and the Typical Behavior

Stage	Performance
Level I	T: OK. Would you tell me what does "15" represent in this question? A: Seconds. T: But what do seconds refer to? Speed? Distance? Or… A: Speed. Umm… After thinking for a while, students A pointed at "15" and said: It is the time. [Find the speed in a one-way trip] Student D calculated the answer of multiplication, then subtracted before she gave researcher the dividing results. T: What do these calculations represent for, and why did you delete them? D: Well, I think it should be the division, but I am not sure, so I try other methods.

Level II	[one-way distance (220) and double time (10) for rabbit. Students were asked to calculate the speed] [description of student A's calculation] Student A first tried "220 ÷ 2", then thought for a while and revised it to "220 ÷ 10". After hearing the researcher repeated the question, he listed "220 ÷ 5", but wrote it off in the half and listed 220 ÷ 2=110 and then wrote 110÷ 5=22 (seconds). After hearing student B' answer 44, A quickly changed his answer by listed 22 + 22 = 44 seconds
Level III	[given the turtle the speed for both deliver the letter (20cm/s) and come back to post office (30cm/s) as well as the distance from between post office and destination 360cm. The requirement is they must come back to post office together] Student C: My answer is 30, I just added the speed of turtle and rabbit. Researcher: But which one is the speed of rabbit? Student C hesitated for a while and explained: This is what I thought. Add them together. This is 30, and this is also 30, not the same. They must be the same. If they are not the same, this 30, this 31 is wrong. Anyway, in the end, they are the same.
Level IV	[using the symbol to present the motivation. Extraction of the conversation] Student B: Well, you use the S_d divide the V_r and you get the time, umm… but you have to multiply it by 2. Because, it has to be the back and forth. Then, you must know the time for turtle to deliver the letter.

Secondly, by interacting with students, we identify many possible factors that may affect students. Among them, the "hands-on" manipulatives, specifically the software, can really boost students understanding. The function of the manipulatives has long been addressed, including use for visualization (Cope, 2015) and their use as an isomorphic representation system for "abstract" (Post, 1981). Recently, Simon et al. (2018) addressed the computer software as the activities for students to reflect and abstract. Similarly, in our research, when all students are confused in CII situations (known the distance and the double way speeds of turtles, to find the speed of rabbit, and condition is that they set off and arrive at the same time) and insist that the speed of rabbit should be the mean of forth and back speeds of turtle, the software is used to show the moving process at the speed they got. After seeing their movements, students realize the necessity to find the same quantity (time) instead of calculating speed directly.

CONCLUSION AND SIGNIFICANCE OF THE STUDY

To summarize, the hypothetical learning trajectory and their behaviors' characteristics we explored in this study can be used as a guidebook for teacher to diagnose students' development and design relative tasks. Although this is just an exploratory study, and the results are definitely needed to be further tested and modified, the current results do reflect students' weak understanding on speed. Despite the fact that these students begin to learn speed at very young age, they can only memorize the formula and unable to explain or use it to solve problems. Besides, the successful use of the software emphasizes the importance of using the hands-on activities in learning the abstract concepts. As a pretty abstract concept, speed cannot be directly delivered as a multiplicative model. It should be designed as a reinvention process (Freudenthal, 2006), in which students discover their relationships and construct their own understanding, and this is also the key point where science can be integrated into. By rearranging the contents in primary school, teachers can start the learning process by more simple tasks based on the software, such as fixing the speed and adjusting the distance, and let students predict the time and then generalize the pattern.

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THE IMPACT OF TEACHING AN INTEGRATED STEM CURRICULUM ON PRESCHOOL TEACHERS' KNOWLEDGE, PRACTICE, AND SELF-EFFICACY

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ABSTRACT

Despite the promising evidence that introducing STEM/engineering concepts and practices during the early childhood (EC) years supports children's cognitive development and positive attitudes toward learning and inquiry, there is very little STEM or engineering instruction within pre-kindergarten classrooms. One reason for the lack of STEM instruction is teachers' low self-efficacy regarding the teaching of STEM, which is due in part to a lack of preparation and available curricula. The current study examined the impact of teaching a year-long, standards-aligned, integrated STEM curriculum in preschool classrooms on teachers' knowledge, pedagogical skills, and self-efficacy. The study was designed as an underpowered randomized control trial (RCT) and was conducted in 16 Head Start classrooms (8 intervention; 8 control), with 40 participating teachers. Results suggest significantly greater knowledge and use of STEM instructional practices in the intervention group compared to the control group, and improved self-efficacy regarding the teaching of STEM. Data from teachers' interviews and open-ended feedback supported these findings. Thus, we believe that teaching STEM in preschool classrooms is both possible and a valuable learning experience for teachers and students. With instructional support in the form of professional development and resources, the experience of teaching problem-solving to young children empowers teachers to try more STEM-related activities with their students.

Keywords: *integrated STEM, early childhood, teachers' knowledge, teachers' self-efficacy, mixed methods*

INTRODUCTION

Policymakers, educators, and researchers consider STEM literacy and expertise to be critical human capital competencies for the 21st century. However, research points to persistent gaps from as early as kindergarten with regard to access, opportunities, and performance in K-12 STEM education, where female, racial minority, and students from high-poverty backgrounds lag behind their White male and Asian counterparts (Gonzalez & Kuenzi, 2012; Morgan, Farkas, Hillemeier, & Maczuga, 2016; U.S. Department of Education, 2016).

Despite the promising evidence that introducing STEM/engineering concepts and practices during the early childhood (EC) years supports children's cognitive development and positive attitudes toward learning and inquiry (Eshach, 2006; Evangelou, 2010; Katz, 2010; Van Meeteren & Zan, 2010), there is very little STEM or engineering instruction within pre-kindergarten classrooms (Diamond, Justice, Siegler, & Snyder, 2013; Ginsburg, Lee, & Boyd, 2008). One reason for the lack of STEM instruction is teachers' low self-efficacy regarding the teaching of STEM, which is due in part to the lack of preparation and shortage of EC STEM curricula (Bagiati, Yoon, Evangelou, & Ngambeki, 2010; Brenneman, 2011; Greenfield et al., 2009). Recently, several published reports called for investment in EC STEM research, curricula, and high-quality professional development (PD) programs for teachers (McClure et al., 2017; Sarama et al., 2018). Seven years after the release of K-12 science standards that include engineering practices (NGSS Lead States, 2013), there is still a great need for a research-based and standards-aligned STEM curriculum that empowers EC teachers to engage their young learners in STEM experiences that support the development of problem solving and analytic skills. In the current study, we ask:

What is the impact of teaching Seeds of STEM, a problem-based, STEM curriculum on preschool teachers' STEM knowledge, pedagogy/practice, and self-efficacy with regard to teaching STEM?

BACKGROUND

The lack of STEM teaching during early childhood is well documented (Greenfield et al., 2009; Cho, Kim, & Choi, 2003; Brenneman, 2011). Reasons include teachers feeling underprepared to teach STEM concepts to young children, their incomplete understanding of academic domains associated with STEM, and the lack of time for planning and preparation (Bagiati, Yoon, Evangelou, & Ngambeki, 2010; Greenfiled et al., 2009). A national assessment for prekindergarten quality instruction reports that on average, teachers score high on the emotional support they provide to children, but score low on the measures of instructional support, such as concept development and language modeling (Pianta, La Paro, & Hamre, 2008). Many prekindergarten classrooms across the U.S. fail to challenge their children during the critical years of skill and cognitive development. This is especially pressing for classrooms and programs serving children from low-income families, who may lack the resources to participate in academically enriched environments outside of the school. Studies have shown that PD programs relieve some of these concerns, especially those related to the perception of STEM in early childhood level and self-competence (Roehrig, Dubosarsky, Mason, Carlson, & Murphy, 2011).

About the intervention

To address this dire need for early childhood STEM education, the authors obtained funding from the US Department of Education (IES, #R305A150571) to develop and test an integrated STEM curriculum for preschool classrooms, called *Seeds of STEM*. The overarching goal of the intervention is to **help children develop and improve their problem-solving skills**. The intervention includes two components: (1) The **curriculum and classroom kit**, and (2) **teacher professional development program**.

1. *The curriculum and classroom kit*. *Seeds of STEM* is a year-long problem-based STEM curriculum, developed in alignment with four sets of standards: The Next Generation Science Standards (kindergarten), the Common Core standards for Mathematics (Kindergarten), the Massachusetts Science, Technology, and Engineering (STE) frameworks (Pre-K and kindergarten), and the Head Start's Early Learning Outcomes Framework (ELOF). The curriculum was developed by researchers from Worcester Polytechnic Institute (WPI), the College of the Holy Cross, and teachers from the Worcester Child Development Head Start Program. The development was guided by an advisory board that included engineers, experts in EC education, experts in teacher PD, and researchers with expertise in study design and STEM stereotypes. Prior to development, the research team established a framework for high-quality EC STEM experience (Dubosarsky, John, Anggoro,

Wunnava, & Celik, 2018). The development process followed a rigorous iterative process of development, testing, and revision, in which 40 teachers (in nearly 20 classrooms) provided feedback after teaching each one of the curricular units in their classrooms (John, Sibuma, Wunnava, Anggoro, & Dubosarsky, 2018).

Seeds of STEM includes **eight units**. Each unit integrates **science** and **engineering** and provides authentic **math** opportunities. During the first part of each unit, children unpack the relevant science concepts through experimentation, games, stories, and self-directed activities, while the second part of each unit includes an **authentic problem** related to the science concepts.

The problem is introduced to the children by the curriculum's main character, Problem Panda. For example, during a unit about ice and water, Problem Panda asks the children to help him get a ring out of a block of ice. The children help Panda solve each unit's problem by following the Engineering Design Process (EDP). With guidance from the teacher, the children **define and research the problem**, **brainstorm** possible solutions, **sort** the solutions into testable/non-testable in a classroom setting, **plan** a selected solution, **create** the solution, test it against the criteria for successful solutions, **revise** the solutions, and **share** the final solutions with Problem Panda and a classroom guest. Throughout the process the children share their work (ideas, plans, prototypes) with their peers.

2. *Teacher Professional Development (PD)*. The *Seeds of STEM* intervention includes a twoday PD workshop intended to train and empower EC educators to lead high-quality STEM experiences in their classrooms. Due to national data on the lack of STEM knowledge and low self-efficacy regarding the teaching of STEM (McClure et al., 2017), the PD introduces teachers to the framework of high-quality STEM and the problem-solving process, and guides teachers in unpacking each curriculum unit. The training is co-facilitated by an expert PD provider and a *Seeds of STEM* developer teacher, who shares with participants her own experience teaching the curriculum in the classroom.

METHODOLOGY

The study was designed as an underpowered randomized controlled trial (RCT), involving 16 preschool classrooms that included 40 teachers and about 280 children.

Participants

Forty teachers (21 intervention, 19 control) took part in the study. Seventy-three percent of teachers reported White/Caucasian (not Hispanic) as their ethnicity, 18% Hispanic/Latina, 5% Black/African-American, 2.5% multi-racial/multi-ethnic, and 2.5% other. The children at these sites were 2.9-5 years old, with over 60% belonging to a minority group. The average age, education, and experience of participating teachers was equivalent in both groups.

Study design

Using teacher pre-study survey data, the 16 classrooms were randomly assigned into intervention and control conditions, to ensure matching of participants based on teachers' outcomes (self-efficacy, knowledge, and practice) and demographics (age, years of experience, education level). Intervention group teachers (N=21) were provided with the curriculum (including all required materials) and training, and were asked to teach all 8 units of the curriculum. These teachers were also asked to videotape all curricular activities. Teachers in the control group (N=19) continued with "business as usual" regarding the teaching of STEM. These teachers were given the last unit as an assessment but did not receive any training. Control teachers were asked to follow the unit "as is" and videotape the activities they implement. A post-study survey with all teachers was conducted once instruction was complete, followed by interviews with nine teachers. Teacher data were analyzed using quantitative (for knowledge, self-efficacy, and reported practice survey data) and qualitative (for data from interviews and open-ended question) methods. Qualitative data were analyzed using an emergent, thematic approach, and coded for reflections about changes to knowledge, teaching practices, and self-efficacy.

Measures

The research team used multiple measures to gauge the impact of teaching the curriculum on teachers' knowledge, practice, and self-efficacy. Since no valid measure could be found to match the population of preschool teachers, the research team developed and adapted available measures. To measure teachers' knowledge of STEM and the engineering design process the team developed a questionnaire with 7 open-ended questions. The items ask teachers to explain their understanding of STEM and engineering, to draw and label the problem-solving process, to provide an example of a high-quality STEM activity they have done in their classroom, and to define 10 problem solving-related vocabulary words, in the context of preschool STEM activities. Responses were scored by a trained research assistant using a grading rubric established by the research team, with reliability established by a second rater (interrater reliability = .875). The point values awarded for each item were summed to create the total score, ranging from 0 (no knowledge) to 8 (very knowledgeable). Cronbach's alpha values were .81 and .82 at pre and posttest.

To evaluate teachers' self-efficacy with regard to teaching STEM, the research team used the *Personal Teaching Self-Efficacy in STEM*, an 11-item survey from the *T-STEM* (Friday Institute for Education Innovation, 2012). Scores were based on the mean responses to the items, ranging from 1 (low self-efficacy) to 5 (high self-efficacy). Cronbach's alpha values were .81 and .92 at pre and post-test.

Teachers' self-report on their practice was gauged using the *STEM Instruction 2* scale, adapted from *Teacher Efficacy and Attitudes Towards STEM Survey* (T-STEM; Friday Institute for Educational Innovation, 2012). The scale was adapted to include items that assess the frequency in which the teacher encouraged certain STEM behaviors (e.g., "During the time you spend in the Pre-K classroom, how frequently do you encourage children to do each of the following in your work with them?"). For each scale, scores were the mean response to the items, ranging from 1 (instructional practice never used) to 5 (instructional practice used very often). Cronbach's alpha was .93 for pre- and post-study surveys.

RESULTS AND DISCUSSION

In order to calculate effect sizes, we utilize a hierarchical linear model which accounts for the nesting of teachers in schools. The outcomes are predicted based on pre-test scores and an indicator of treatment status. Overall, compared to teachers in the control group, intervention teachers (who taught the entire *Seeds of STEM* curriculum and received PD training) have significantly higher levels of knowledge, self-efficacy, and reported practices at the end of the study. Table 1 provides a summary of effect-sizes for each one of the measures.

Table 1: Study Effect Sizes

	Intervention		Control		Effect size (p-value)
	Pre	Post	Pre	Post	
Knowledge Assessment of STEM and the EDP*	1.49 (.96)	3.54 (1.17)	1.63 (.83)	2.81 (.86)	1.35 (.001)***
Personal Teaching SelfEfficacy in STEM	3.12 (.44)	3.96 (.45)	3.42 (.59)	3.71 (.63)	0.995 (.035)*
STEM Instruction 2 (adapted T-STEM)*	2.61 (.64)	2.96 (.56)	2.81 (.62)	2.57 (.57)	1.29 (.007)**

* p ≤.05; ** p ≤.01; *** p ≤.001

Teachers' knowledge

Teachers from the intervention group scored significantly higher on the project-created knowledge assessment compared to control teachers at posttest (effect size 1.35, p=.001).

Qualitative analyses found that the teachers learned more than just the curriculum. They learned about problem-solving in general, and reported using this knowledge in other contexts. Intervention group teachers learned about new ways of teaching and presenting materials to children. The curriculum showed the teachers how much the children can learn and how to keep them engaged while doing so. One teacher reported: *"I feel like it has made me a better teacher and have a better understanding of the Problem Solving Process personally."* Another reflected, "*It's like the whole new higher thinking, more complex concepts for me. So I was learning right along with the kids, which was cool*."

Teachers' self-efficacy regarding the teaching of STEM

Teachers from the intervention group significantly enhanced their self-efficacy as measured by the *Personal Teaching Self-Efficacy in STEM* survey, compared to control teachers at posttest (effect size 0.995, p=.035)

Qualitative analyses found that the curriculum challenged the teachers in a new way that helped build their confidence in teaching STEM and problem-solving. Teachers reported feeling more prepared in teaching the curriculum to children in the future. They admitted to it being challenging and overwhelming at first, but afterwards they found it rewarding. One teacher stated,
"I feel that my students have gained so much this year by being part of this program and I will continue teaching Seeds of STEM in years to come." Another teacher shared her thoughts about teaching the curriculum again, "*I'm excited to reteach it, honestly. And I know more now too, so I'll be more prepared this time than I was last time*." A third teacher commented on the developing confidence by saying "*I feel like you might be overwhelmed at first, but it's okay. Because not only are you going to see a difference in your students, but you're also gonna see a difference in you, your room, and just how you approach things—that more on a can-do attitude".*

Teaching practice

There was a statistically significant difference in teachers' reported practice between the intervention and control group (effect size 1.29, p=.007).

Qualitative analyses showed that the teachers found it best to set high expectations and allow the children a chance to understand the problem-solving process and problem-solve on their own. Repetitions also helped children internalize the problem-solving process. More specifically, teachers improved their pedagogy by asking *why* and *how* questions when the children identify the problem and come up with possible solutions. Letting the children explore solutions "even if you know it won't work" are effective strategies. Lastly, analyses showed that intervention teachers have transferred the problem-solving pedagogy to everyday teaching, with many reporting using the problem-solving vocabulary and process during social/emotional situations. One teacher reported, *"It changed my approach to problem solving with the children. It made me realize how much they can contribute and participate in everyday problems if I change how I present them, and also step back and let them take control of their own ideas."* Another said, *"I think, as a teacher, I would be more willing to challenge the kids and see what they could learn".*

Discussion

The study found that teaching a standards-aligned, integrated STEM curriculum helped improve preschool teachers' knowledge, self-efficacy, and practice. In terms of knowledge, teachers understood the problem-solving process and how to use it in guiding children through STEM problems. This impacted teachers' practice as well, as many reported that they used the engineering design process visual aid to address social/emotional problems in the classroom.

Teachers' expectations of their children's abilities have changed as well. Several teachers commented about being "happily surprised" when the children in their classroom started using the problem-solving vocabulary and followed the problem-solving pedagogy (e.g., following the steps of the problem-solving process to address a social problem). This repeated feedback demonstrated the need for an extensive curriculum that builds children's vocabulary through repetitions. One or two stand-alone activities may not be sufficient for teachers to notice a change and therefore adopt the new pedagogy.

In addition, teachers found the PD program helpful for learning the STEM pedagogy. Control teachers that received one unit without preparation or guidance expressed their need for guidance.

PD could also be used to address implementation challenges and help build teachers' expectations regarding the pace of STEM learning in their classrooms.

CONCLUSIONS

Significance

With the development of national standards for high-quality STEM and renewed focus on problem solving skills (NGSS Lead States, 2013), there is a great need for high-quality standardsaligned curriculum for preschool classrooms. The National Institute for Early Education Research named teacher professional development as the highest-need area among 10 preschool quality standards (Friedman-Krauss et al., 2019). In order to improve STEM in early childhood, researchers note parents' and teachers' anxiety and low-confidence with regard to STEM topics, and recommend engaging them in interactive STEM learning environments (McClure et al., 2017). The *Seeds of STEM* intervention addresses the needs identified by the research – it is aligned with standards, focused on practices, and includes an interactive PD training that engages, excites, and empowers teachers to adopt a STEM pedagogy in their classrooms.

This study adds to the body of research on early childhood STEM from the perspective of the teachers, and shows that being engaged in teaching a high-quality STEM curriculum does indeed help the facilitator of the curriculum gain knowledge, pedagogical skills, and confidence in teaching STEM to young children.

Limitations

The main limitation of the study is its small scale. Although meaningful, the study would have to be scaled up, testing the curriculum with a larger population of teachers. A second limitation is the lack of validated measures to study preschool teachers' STEM knowledge, practice, and self-efficacy. Due to this gap, the research team had to adapt or develop new measures. This study demonstrates the need for the development and validation of STEM research tools for the population of preschool teachers. This understudied group plays a critical role in the development of children's STEM and problem-solving skills and therefore more research on best practices for teaching STEM would benefit our society.

Next steps

The research team is in the process of analyzing student data from the study, as well as designing a scale-up study, in which the Seeds of STEM intervention will be tested in dozens of classrooms.

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DIFFERENTIATED INSTRUCTION IN SCIENCE CLASSROOMS: THE POTENTIAL ROLE OF TECHNOLOGY

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ABSTRACT

This paper presents a literature review about differentiated instruction (DI) with a focus on its applications in science secondary classes. It provides an overview about the following aspects: positive student outcomes of DI, applications of DI in science classes, and the integration of technology in DI. A total of 37 articles, book chapters, and dissertations were included in this review. According to the reviewed literature, DI helps students achieve better and enhances their attitude towards learning. Moreover, the proficient integration of technology facilitates DI for teachers and benefits the students. While there's an adequate research on DI in general, the literature review shows that there is a need for further research on the applications of DI in science secondary classes and specifically on the effective use of technology in this process. Teachers can use this review as a summary of the various aspects of DI, as it highlights the importance of this strategy and provides them with practical and diverse ways to differentiate their instruction. Curriculum designers can refer to the reported DI strategies when developing subjects' curricula to help teachers differentiate their instruction. Teacher education programs and school administrators can integrate and develop the reported strategies to enhance preservice and in-service teachers' expertise in this domain. Finally, researchers may consider developing research programs addressing the noted gaps in the literature.

Keywords: *differentiated instruction, technology-enhanced differentiated instruction, science education, technology-enhanced teaching, teaching strategies, secondary classes*

INTRODUCTION

Context and Background

Classrooms in North America (Canada & USA) are becoming increasingly well known for their heterogeneous composition; diverse cultural, socio-economic, and racial backgrounds. This is mainly due to the increase in the number of immigrants. For instance, according to Statistics Canada (2017), two in five Canadian children had an immigrant background in 2016, meaning they are foreign-born or had at least one foreign-born parent. This ethnic, racial, social, and cultural diversity is also accompanied by a linguistic diversity. Statistics Canada (2017) confirms this claim by showing that the percentage of immigrants with English or French as a mother tongue decreased from 71.2% in 1921 to 27.5% in 2016. All these classroom complexities increase given the variation in students' levels of achievement, interests, and learning profiles (Tomlinson, 1999). Differentiated instruction (DI) has the potential to address these differences (George, 2005).

On the other hand, the COVID-19 pandemic has caused the shift to distance teaching with a huge emphasis on technology in online teaching. Yet, science, technology, engineering, and mathematics (STEM) teachers in Canada have reported many challenges that affected their online teaching practices. Specifically, they indicated difficulty differentiating their instruction and attending to various students' needs in online settings (DeCoito & Estaiteyeh, in press).

Acknowledging the importance of DI as a teaching approach and the latest increased reliance on technology in teaching, this paper reviews the literature on DI in science classrooms with an emphasis on the potential role of technology in differentiating instruction.

DI Definition and Positive Outcomes

DI is a constructivist-based teaching approach that aims to achieve learning for all students of diverse socio-cultural backgrounds, abilities and interests (Valiande & Tarman, 2011). It is an approach to teaching in which teachers proactively modify curricula, teaching methods, resources, learning activities, and student products to address the diverse needs of students and maximize their learning opportunities. DI focuses on four interrelated dimensions: the *content* students learn, the *process* of student learning, students' *products* that demonstrate their learning, and the *environment* in which students learn (Tomlinson, 1999).

Research has shown that DI has positive impacts on student outcomes. DI enhances student achievement as it makes the content more relevant to students aided by the use of multiple representations (written, spoken, visual) (e.g., Tobin & Tippet, 2014). Moreover, DI results in better student motivation and attitudes toward science compared to traditional instruction as DI is more creative and matches their interests and learning styles (e.g., Chamberlin & Powers, 2010). Additionally, DI is associated with more autonomous yet cooperative learning, facilitating the exchange of cultural and social values in a supportive learning community (e.g., Goodnough, 2010).

RESEARCH DESIGN

Literature Review Objectives

A lot of research has been done on DI. Yet, the applications of DI in science subjects are not extensively researched. Accordingly, this paper aims to review the literature done on DI with a focus on secondary science classrooms. It attempts to answer the following research questions: 1) What are the reported applications of DI in science secondary classrooms? 2) How can technology be integrated in differentiated science classes? And 3) What is the impact of technology enhanced DI on student outcomes? In addition, this paper will identify the gaps in the existent literature and recommend questions for further research.

Literature Review Methodology

Four Databases were searched using Western University Libraries. The databases are: Education Database, Education Source, ERIC, and JSTOR. The search for the phrase "differentiated instruction" (with quotation marks) in the title field yielded the following results on December 20, 2018: 29 articles in Education Database, 147 articles in Education Source, 97 articles in ERIC, and 32 articles in JSTOR. The search for the phrase "differentiating instruction" (with quotation marks) in the title field yielded the following results on December 20, 2018: 26 articles in Education Database, 53 articles in Education Source, 20 articles in ERIC, and 8 articles in JSTOR. Furthermore, to explore the aspect of technology in DI especially after the COVID-19 pandemic when this topic has become more pressing, an additional search was performed in May 2021. Using Western University Libraries, the search for "differentiated* instruction" and technology (with asterisks and quotation marks) in the title field yielded 34 articles and in the subject field yielded 33 articles. During the search, I was keeping two categories of articles: general articles that apply to various subjects across different classes, and articles that are specific to science instruction in secondary classes. As a result, a total of 37 articles, book chapters, and dissertations were included.

RESULTS AND DISCUSSION

Applications of DI in Science Secondary Classes

Different science curricula encourage the use of DI as a teaching strategy. In the USA, the New Generation Science Standards “NGSS” highlight the importance of DI in providing accommodations for students with disabilities and in promoting science learning for gifted and talented students as well (NGSS Lead States, 2013). In Canada, specifically in Ontario, the science curriculum for Grades 9 and 10 lists DI as one of the suggested instructional approaches to enhance students’ learning (Ontario Ministry of Education, 2008).

Despite that, few studies investigated DI in science classes from teachers’ perspectives. For example, Graaf et al. (2018) tried to develop cost-effective procedures (heuristics) to support Biology teachers in redesigning their lessons in a differentiated manner. The five involved teachers used the heuristics, implemented DI in their lessons, and valued their differentiated lessons more than their regular ones. Moreover, the majority (66%) of their students valued the lessons positively. Maeng and Bell (2015) showed that teachers tried to and were able to implement a variety of differentiation strategies in their classrooms with varying proficiency. Watson and Knight (2012) focused on the assessment aspect, and showed that the continuous formative assessment and feedback facilitated and complemented DI in an enquiry-based laboratory course in college.

Technology-Enhanced DI in Science Classes

Research findings mostly emphasize the importance of teachers integrating technology to support science instruction (Cha & Ahn, 2020; Maeng, 2017). Yet, the concept of combining DI with technology is relatively new and insufficiently explored in science secondary classes. This section will detail the findings on practical technology-enhanced DI tools, their impact on students, and teachers’ perspectives in this regard.

Practical tools. Integrating technology is helpful to teachers as it facilitates their differentiation strategies in secondary science classes (Heilbronner, 2013; Maeng, 2017) and elementary science classes (Boelens et al., 2018; Cha & Ahn, 2020; Valiande and Tarman, 2011). Both Maeng (2017) and Heilbronner (2013) provide practical ways for teachers to create and deliver DI in biology lessons. New technologies can support the “content” differentiation by modifying the instructional pace sparing time to work with gifted and/or struggling students (Heilbronner, 2013; Karatza, 2019; Maeng, 2017). Moreover, Milman et al. (2014) report how elementary classes’ teachers can use iPads to offer various choices of the same content for students to engage with, and to integrate content from various subjects in an interdisciplinary approach.

Technology can also facilitate the “process” differentiation by presenting the content in various modes using multimedia, and by supporting students individually and in groups (Karatza, 2019; Scalise, 2009). For example, computer-supported teaching enables more DI in science elementary classes through visual representations and interactions, enhancing diverse learners' scientific understanding and inquiry (Zheng et al., 2014). Zervoudakis et al. (2020) report how technology such as clustering algorithms can be used to help teachers form heterogenous groups based on a detailed analysis of student differences in skill level, and psychosocial and cognitive profiles. In harmony, technology can help in creating student centers, communicating electronically with students, creating models, and using databases to inform instructional decisions (Benjamin, 2014). Siegle (2014) specifically explains how teachers can use technology in DI through the flipped classroom strategy which is more effective with high achievers. With respect to multimodal representations, electronic technologies can facilitate DI by including more media that enhance interaction and offer more choices for students (Scalise, 2009). Technology can be an asset for teachers as they can use blogging, vodcasts, podcasts (Colombo & Colombo, 2007), in addition to content creation tools such as Glogster, Animoto, Jingproject, and infographics (De Lay, 2010).

With respect to the “product” differentiation, technology allows teachers to monitor more closely their students’ work and offers several ways for students to express their understanding (Heilbronner, 2013; Karatza, 2019; Maeng, 2017). Tahiri et al. (2017) propose the use of differentiated Massive Open Online Courses (MOOCs) in which the courses are structured according to learners’ preferences. This would support the instructor in decision-making and ensure that every learner is performing well. Also, interactivity and flexibility are important in assessment. Several tools can provide adaptive testing systems which permit customizable content and learning pathways, such as Khan Academy and CK-12 (Kassissieh & Tillinghast, 2014). Adaptive learning systems and learning analytics can support teachers in DI by providing up-to-date information about students’ progress (Dietrich et al., 2021; Keuning & van Geel, 2021). This is of particular importance in formative assessment (Bellman et al., 2014), as technology can help teachers collect more data and allow students to improve their responses on assessment (Scalise, 2009).

Impact of technology-enhanced DI on student outcomes. Technology-enhanced DI has the potential to enhance students’ outcomes. Following a study with 115 students in their second-year biology class in the Netherlands, Haelermans et al. (2015) concluded the presence of a significant effect of digital differentiation on student’s achievement. Another intervention was tested by Zheng et al. (2014) in a grade 5 class in California, USA. Students, who used computers and interactive software to learn science concepts, showed an improved academic performance and concept understanding (especially at-risk learners) as well as a positive attitude towards STEM. Collins (2018) affirms that technology has supported the individual needs of students, which has also contributed to their positive feelings towards such learning strategies. Similar findings are reported by Olsen (2007) indicating that special education students who have used computer-mediated instructional approaches demonstrated more conceptual growth and better content learning in a middle school science class than those who have not used such approaches. Similarly, Shepherd and Alpert (2015) maintain that DI was particularly helpful for deaf students as it enabled multimodal expressions for students, which improved their retention, interest, and motivation. Yet, these findings are inconclusive. For instance, in a study with 111 high school biology students, Casey (2018) reports that computer-based instruction did not have a significant impact on high achievers, while low achievers benefited more from teacher-led instruction rather than technology-enahnced DI. Similalry, a DI learning design for online teaching did not affect university students’ achievement although it improved their self-efficacy and attitudes (Dietrich et al., 2021).

Teachers’ perspectives. Teachers believe that there is still a long way to go for optimizing the use of technology to support DI (Cha & Ahn, 2020; Valiande & Tarman, 2011). Boelens et al. (2018) explored instructors' strategies for and beliefs about DI in blended learning. The findings revealed inconsistencies among instructors in using technological tools to match students' needs. Nicolino (2007) reported that only 53% of K-6 teachers from seven schools in New York have stated that they were knowledgeable in providing DI to their students through instructional technology. In line with this, Karatza (2019) reported that teachers have seen this integration as a demanding process. Regarding the three dimensions of DI, Karatza (2019) noted that teachers have used technological tools to differentiate their instruction mainly by content, secondly by process, and lastly by product. Correspondingly, since technology-enhanced DI is a relatively new concept, teachers need to be trained to attain a new skillset required to utilize such systems (Hinkle, 2020; Keuning & van Geel, 2021). Thus, several studies emphasize the importance of teacher training and professional support in enhancing teachers’ attitudes and self-efficacy to technology-enhanced DI (Boelens et al., 2018; Karatza, 2019; Millen & Gable, 2016). Such training shall aim at further developing teachers’ technological, pedagogical, and content knowledge (TPACK) for them to grow from immediate, to expert, to full master level proficiency (Bellman et al., 2014). Communities of practice were proven to be of great assistance in this regard (Friesen, 2007).

CONCLUSIONS

With respect to the applications of DI in science classes, the literature review showed that research is extensive in primary and middle schools, but not secondary classes. Also, studies were mostly done on DI in languages and mathematics rather than science subjects. Science teachers in secondary classes need more practical tools that would facilitate their teaching. Further research is specifically needed to explore "content" and "product" differentiation as these are more challenging to teachers, especially when standardized curricula and tests are mandated. Moreover, secondary science teachers' attitudes toward, knowledge in, and implementation of DI need further exploration since their role is critical in this process. From students' perspective, more research is needed on student achievement taking into consideration aspects other than grades and standardized test results. This includes scientific literacy, practical skills, experimental design, analysis, higher order thinking, and the level of collaboration versus individualization in a differentiated classroom.

On the other hand, the integration of technology with DI is promising. Yet, the research in this domain is still limited and inconclusive. Technology seems to facilitate the work of teachers in differentiating instruction, and help students benefit as evident in their better achievement and enhanced attitude towards learning in technology-enhanced DI. With the rapid advancement and increased diversity of available technological solutions, and the recent emphasis on online teaching, there is a need to explore the impact of technology-enhanced DI on the aforementioned student outcomes. Moreover, teachers need more practical examples on how to integrate technology in DI. Hence, further research can investigate if and how teachers are making use of the available electronic resources to differentiate their teaching practices, and the challenges and successes they encounter. Finally, future research can explore the effectiveness of professional development programs for in-service teachers and training of pre-service teachers in enhancing their readiness to implement technology-enhanced DI in their classes.

SIGNIFICANCE AND IMPLICATIONS

This study provides a summary of a big body of literature pertaining DI for both researchers and practitioners. For researchers specifically, this review highlights the gaps in the literature, calling for a further exploration of certain topics. Such investigations would consider new perspectives and thereby advance the current knowledge. On the other hand, teachers can use this review as a summary of the various aspects of DI, as it highlights the importance of this strategy and provides practical and diverse ways to differentiate the instruction. The paper also recommends new ways of implementing DI by integrating it with technological tools. Curriculum designers may need to consider the various aspects of DI when developing subjects' curricula. Curricula must be flexible so that teachers can implement DI techniques more easily. Written curricula may also include examples of the suggested strategies and relevant resources that would help teachers differentiate their instruction. Finally, teacher education programs and in-service professional development programs can integrate and develop the reported strategies to enhance pre-service and in-service teachers' expertise in DI generally and technology-enhanced DI specifically.

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ENHANCING MATHS TEACHERS' PEDAGOGY IN SPECIAL SCHOOLS IN QUEENSLAND AUSTRALIA

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ABSTRACT

This paper reports on a project in one special school in Queensland Australia. The intention of the project was to improve the teaching and learning of mathematics to students from Preparatory to Year 12. The overarching concern of the project was the reported limited learning experiences provided to students, with maths learning reduced to a focus primarily on number. An action research/appreciative inquiry (AI) approach was used in the project to examine how teachers teach mathematics to the students. AI has been identified as a reconfiguration of action research within organisational settings such as schools. It closely interconnects with Timberley's Inquiry Cycle which was used in the project. The project also drew on the Most Significant Change Technique. Findings indicate more work is needed to capture the actual achievement of students. There is strong evidence to suggest that teachers (not all) lack sufficient numeracy and mathematics content knowledge. There is a need for special education teachers to have a repertoire of instructional strategies that they can use to assist students. The adoption of a professional learning community is commendable, however, when decisions, planning and resource making are left to a limited few or one member, it is difficult to see the benefits of such a community.

Keywords: *mathematics, special education, pedagogical content knowledge, professional learning community*

INTRODUCTION

This paper reports on a project at one special school in Queensland Australia. This project is more frequently referred to as the Triple M project. In what follows is a brief background to the project, the project problem, an explanation of the project, appreciative inquiry research and the program activities and outcomes as at July 2019.

Background to the project

The three-year project presented in this paper was informed by the final recommendations from the YuMi Deadly Maths Special Schools project completed in June 2016. Informal and formal discussions were held with the Principal and ad hoc conversations with project participants in the final round of workshops of the original project. It proposed to build on from the initial project that focused on the training of participating teachers with how to teach mathematics to students with intellectual disabilities, to extent and enhance teachers' maths pedagogy and continue to build sustainable success for students.

PROJECT PROBLEM

Whilst there was a very strong commitment from participating Principals and teachers with supporting students in the original project, the findings identified a need for teachers to continue to build and enhance their repertoire of maths instructional strategies to assist students with successful learning of mathematics. It is this finding that the current project discussed in this paper will address.

The combination of wide-ranging deficits in foundational knowledge about mathematics, experiences and skills and the pressure to increase student achievement, places students with disability at greater risk for failure unless their teachers provide specifically designed instruction and resources.

RESEARCH UNDERPINNING THE PROJECT

The project is guided by the research pertaining to school improvements in mathematics education for special schools. In what follows discussions are provided about multi-sensory teaching and learning, pedagogical content knowledge and the inquiry cycle of professional development.

Multi-sensory teaching and learning

Many students who experience learning difficulties can benefit from multi-sensory or multi-modal teaching practices (Witzel, Riccomini & Schneider, 2008). Multi-sensory and multi-modal teaching and learning can best be described as visual, auditory, kinaesthetic and tactile pedagogical practices which incorporate different ways of learning. Teachers can desist from limiting the learning possibilities of their students by endeavouring to use all of the senses when engaged in the teaching of mathematics. Rather than simply using reading or listening strategies to teach students, teachers should aim to use all of the senses to support active and interactive student learning. Bedard (2002) states there are three distinctive learning styles: auditory, visual, and tactile. Each student has his or her own unique learning preference style or way of processing and retaining information. When teachers use strategies for all learning styles, individual students are able to learn through their strongest modality (p.13).

Taljaard (2016) suggests that, 'we all interact with the world around us with our five senses, but we process the information received in our distinct ways' (p.47). As with any teaching facility, children who are being educated in special education schools are not all at the same educational level when it comes to what they know and what they understand about mathematics. Using multimodal and multi-sensory instruction can more fully engage students' development of conceptual understandings of mathematics ideas, equipment and materials. This will, however, be contingent on a teacher's pedagogical content knowledge.

Pedagogical content knowledge

There continues to be a strong consensus in teacher education literature that going beyond the dispensing of content, i.e., giving a test or grade, is the challenge for this century. Its resolution will depend on schools' and teachers' abilities to develop knowledge that supports and enhances more strategic learning and understanding of how to teach and organise schools in ways that respond to students' diverse approaches to learning (Darling-Hammond, 2016, p. 85). Whilst teacher content knowledge is crucially important for improving teaching and learning, historically there has been a tendency to focus on such content, with scant attention paid to how teachers must understand the content of the subjects they teach (Loewenberg Ball, Thames, & Phelps, 2008). More recent findings show that content knowledge continues to be inert in classrooms unless it is accompanied by a rich repertoire of knowledge and skills related directly to the curriculum, instruction and student learning (Darling-Hammond, 2016). Shulman (2005) refers to pedagogical content knowledge as highly quality instruction that requires sophisticated pedagogical content knowledge. The appeal of this knowledge is that it bridges the content knowledge and the practice of teaching.

Timperley inquiry cycle

Whilst a focus on professional learning communities is critical to rich and insightful teaching and learning in classrooms, there is much debate about how teachers can be professionally supported with developing their pedagogical content knowledge so that it leads to more effective teaching practice. A synthesis of research that focused on teacher professional development (Timperley, 2011) identified that teacher engagement in professional learning can have a substantial impact on student learning. The synthesis also found that one-off professional learning events with external experts who presented prescribed practices to teachers were ineffectual and had limited impact on student outcomes. Where student gains were identified, a number of elements were strongly related to these gains. Referred to as a *Cycle of Inquiry*, (Timperley, 2011) consistently found that elements such as "grounding learning in immediate problems of practice, deepening relevant pedagogical content and assessment knowledge, and engaging existing theories of practice on which to base ongoing inquiry process" (p. 5) all contributed to teachers becoming collectively and individually the drivers for acquiring the knowledge require for effective teaching and learning.

METHODOLOGY

An action research/appreciative inquiry (AI) approach was used in the project to examine how teachers taught mathematics to the students (Ford & Ashford, 2000; Hammond, 1996). AI has been identified as a reconfiguration of action research within organisational settings such as schools. It is described as a strategic planning model, participatory, and a system-wide approach that seeks to discover what works based on solutions that exist currently within organisations such as schools. It closely interconnects with Timberley's Inquiry Cycle discussed earlier. The project also drew on Most Significant Change Technique (Davies & Dart, 2005). This approach promotes considerations of how people are brought together as a collective in a group context to participate in organisational learning and change, knowledge sharing and making sense of impact.

The project combined mixed model (quantitative and qualitative questions) and mixed method (quantitative and qualitative stages in the design) approaches (Johnson & Onwuegbuzie, 2004) in an explanatory design. It involved three studies (Table 1) that used multiple data collection methods and analysis. Study 2 and 3 are the focus of this paper.

Table 1. Overview of Studies

Component	Description
Study 1: Design and development of evaluation (Feb 2018-2019)	The 10 steps of Most Significant Change (MSC) model to monitor and evaluate the fidelity of the PLC design and implementation: a) defining domains of change, b) define feedback and reporting loops and, c) data instrument design using Concerns Based Adoption Model (CBAM).
Study 2: Data collection, analysis and monitoring (Feb 2018-2019)	The Concerns based Adoption model to conduct online surveys, conduct a social network analysis to identify how networks are operationalised in the PLCs and,
Study 3:	Professional learning workshops, visits to classrooms and resource development.

The Stages of Concern About an Innovation (George, Hall & Stiegelbauer, 2006) was developed as one of three diagnostic dimensions for the Concerns-Based Adoption Model (CBAM), a framework for measuring implementation and for facilitating change in the school. The Stages of Concern Questionnaire (SoCQ) provided a way for the project leader, administrators and PLC team to assess teacher concerns about strategies, programs or materials introduced in the school. An important caveat is necessary here. The SoCQ was conducted with a small sample and once only. It is not ethical to generalise beyond this limitation. Further, other forms of data need to be considered in conjunction with the results of the SoCQ.

Study 2: The concerns-based adoption model to conduct online surveys

The Seven Stages of Concern About an Innovation are called stages because usually there is a developmental movement through them, for example, the user of an innovation may experience a certain type of concern rather intensely, and then as that concern subsides, another type of concern may emerge (George, Hall & Stiegelbauer, 2006). The Stages progress from little to no concern, to personal or self-concerns, to concerns about the task of adopting the innovation, and finally to concerns about the impact of the innovation. The SoCQ is a tool for determining where an individual is in the stages. According to George, Hall & Stiegelbauer (2006, p. 8) the emergence and resolution of concerns about innovations appear to be developmental, in that earlier concerns must first be resolved (lowered in intensity) before later concerns can emerge (increased in intensity). Figure 1 provides a profile of concerns of the participant group *(n=6)*. In doing so, it provides relative intensity of each stage for the PLC team.

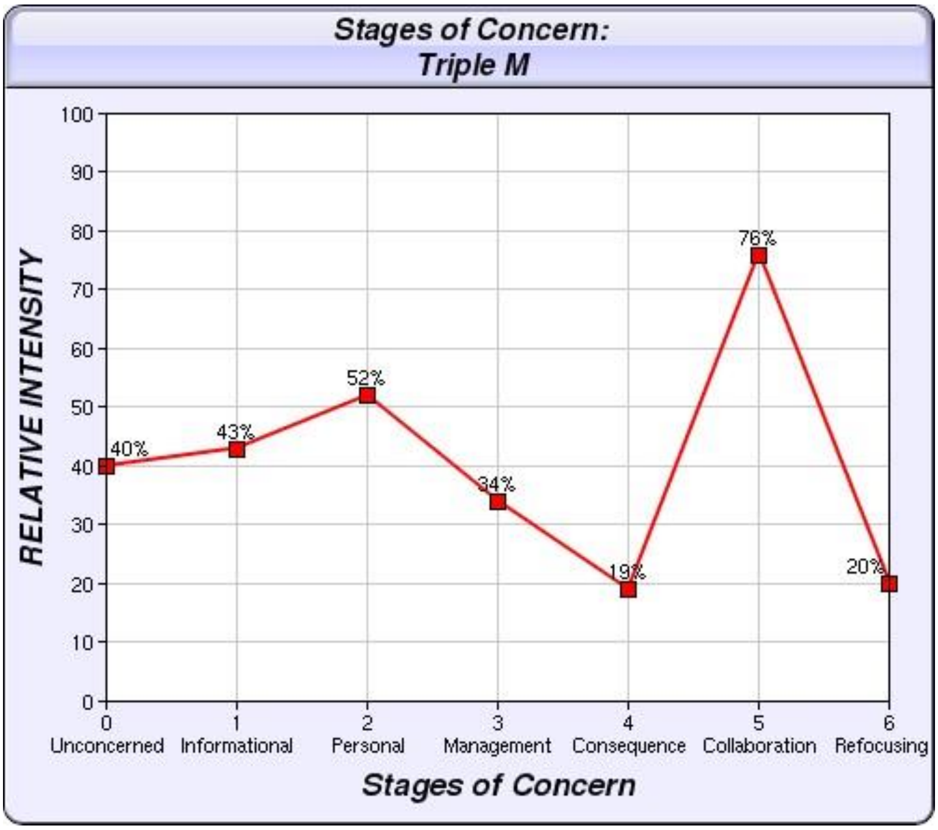

Figure 1. Stages of Concern - Triple M

Stage 0 score suggests that the team overall does have some concern for the project innovation but is somewhat more concerned about other things. A typical high score at this stage (hypothesised score of 82%) suggests that a nonuser's concerns are normally high on Stages 0, 1, and 2 and lowest on Stages 4, 5 and 6. Because Stages 1 and 2 are higher, it can be inferred that the team is interested in learning more about the project. The team does not have significant management concerns, signified by low intensity on Stage 3 and is not intensely concerned about the innovation's consequences for students but collaborating with others is high. The low tailing-off Stage 6 score suggests that the team does not have other ideas that would be potentially competitive with the innovation. The overall profile of the team suggests and reflects interested, not terribly overly concerned, positively disposed.

The relationship between Stage 1 and Stage 2 scores are important. A negative one-two split occurs when the Stage 2 score is higher than the Stage 1 score. These scores depict the team as having various degrees of doubt and potential resistance to the project. When Stage 2 concerns override Stage 1 concerns, the concerns about an innovation's effect on personal position or job security usually are greater than the desire to learn more about the project innovation. Experience suggests that when general, nonthreatening attempts are made to discuss an innovation with a person or team with this profile, the high Stage 2 concerns are intensified, and the Stage 1 concerns are further reduced. An individual or team with this kind of profile will not be able to consider an innovation objectively until her or his personal Stage 2 concerns are reduced.

Stage 5 provides information about how interested team members are in working with colleagues in coordinating the project. This concern is typical of people, such as team leaders, who spend a considerable amount of time coordinating the work of others. In contrast, high Stage 5 concerns tend to score lower in Stage 4, as is shown in the table below. These scores indicate a lack of concerns about the direct effects of the project on students. A breakdown of the individual team member responses could shed further light to determine whether they are team leaders, administrators or full-time classroom teachers. In any case, with the high Stage 5 score, the team's most intense concerns about the project are about coordinating with others in using it.

Stage 6 provides additional information about the attitude of the team towards to project innovation. When Stage 6 concerns tail off or down, the team does not have ideas that would potentially compete with the project. When Stage 6 tails up, it can be inferred that the team has ideas that they see as having more merit than the proposed innovation. Any tailing-up of Stage 6 concerns is a warning that the team may be resistant to the project. The Stage 6 tailing-down is detectable in terms of the overall concerns of the team.

Study 3: Professional learning workshops, classroom visits, resource development outcomes

The following activities were conducted with the school and teacher participants: a) professional learning workshops and reflections, b) in class lesson modelling to classroom teacher and with students, c) co- lesson modelling with classroom teacher and with students, d) observing teacher conduct focused lesson with students and e) reflection with teachers and PLC team. Resource development will now be discussed.

Multi-sensory Learning and Resource Development

Multisensory Learning (MSL) assists children to learn through the use of more than one sense. Considerable literature has been written about MSL and its benefits for the education of children (Aaron, 2017). Resource development plays a critical role in the project. More specifically resources were designed, created, trialled and modified to ensure that all children engaged actively in the teaching and learning process. Thus far in the project, several resources have been created by the PLC team and the project leader and team. Table two provides an example of this work.

Table 2. Resource development

Maths topic	Resource developed	Supporting image
Fractions: whole, half, quarter, eighth	Foam boards with sensory elements attached and connecting with real life experiences, e.g., pizzas and sandwiches. Planning template and ALD boards.	 

DISCUSSION AND CONCLUSION

This project has been positioned to strengthen the evidence pertaining to the teaching and learning of mathematics to students with intellectual disabiliy. Currently, there is limited research about students with intellectual disability, numeracy, multi-sensory and multimodal forms of learning mathematics and numeracy interconnect with improving instructional pedagogy. Intervention studies of mathematics have focused on explicit instruction and concrete, abstract sequences of instruction (Wizel, et al., 2008), but the literature is largely silent on the prior and existing knowledge and experiences of students with disability and how teachers can build on from that knowledge and experience and why this process is crucial to students' development and teachers' instructional strategies which includes appropriate resources.. As a consequence of the project there are several implications for consideration.

There is strong evidence to suggest that teachers (not all) lack sufficient numeracy and mathematics content knowledge. Whilst there is a strong commitment from teachers to support students with learning numeracy/mathematics, unfortunately, their preparation and capacity to teach it is of current concern. There is a need for special education teachers to have a repertoire of instructional strategies that they can use to assist students. By adopting a strong collaborative approach, it is likely that teachers will benefit from a focus on interpreting experiences during the implementation and maintenance phases of the program. The adoption of a professional learning community is commendable, however, when decisions, planning and resource making are left to a limited few or one member, it is difficult to see the benefits of such a community.

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LEARNING ANALYTICS AS A TOOL OF PROGRESSIVISM: WHAT WOULD JOHN DEWEY SAY ABOUT LEARNING ANALYTICS?

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ABSTRACT

This short abstract focuses on Learning Analytics seen through the lens of ideological considerations, in particular progressivism following John Dewey's thoughts. As the social-romantic ideology this short paper is student-centered and inquires what Learning Analytics can do for the learner, because the field itself is still controversial and will ever be. While some scholars consider Learning Analytics to be harmful (Dringus, 2011) this short abstract will deliver arguments how Learning Analytics may be the key for progressive learning. To shape the future of Learning Analytics, one has to understand the past. The idea of progressive education might be a key for how Learning Analytics can be advanced and how its development over the next ten years and beyond might be guided. Learning Analytics interrelated with progressive education might bear the potential to impact education, especially in higher institutions in the field of personalised and adaptive learning. Related to STEM education, which learning theories might rely on behaviourism and are labelled "perhaps dangerous" (Wolfmeyer & Lupinacci, 2017, p. 1), the following arguments might offer interesting insights.

Keywords: *learning analytics, theoretical framework, ideologies in education, progressivism, socialromantic, learning theories*

METHODOLOGY

Theoretical abstract

This short paper focusing on John Dewey's book 'Experience & Education' (Dewey, 1938), which builds the foundation for progressive theory in education. Considering Dewey's thoughts about student-faced education lead to the following arguments presented in the next paragraphs. A literature review surveying studies, which summarize the impact of Learning Analytics in higher education institutions was conducted. The results were aligned with progressive principles and are presented in the following paragraph. Being aware of the scope of this paper the following arguments are just a glance and a possible view on the vast field of Learning Analytics. However, one should be reminded that "there is anecdotal evidence that some of the most successful projects to date have been in the US for-profit sector, where it can be easier to achieve change than in more traditional institutions. However, these findings remain unpublished due to the fact that they are seen as commercially sensitive." (Sclater & Mullan, 2017)

LEARNING ANALYTICS AS A TOOL OF PROGRESSIVISM

Stream of arguments

According to several authors "the combination of embedded administrative and academic technologies, big data, powerful analytical tools, and sophisticated data-mining techniques is poised to spark a revolution in how education is delivered— and in how the efficacy of that education is measured." (ECAR, 2015, p. 1). The argument should be challenged. The revolution itself should not arise out of technological opportunities. The methodological use of these new tools, relying on educational tradition, might spark the innovation. Furthermore, there is no need for a revolution and Learning Analytics may pursue and contribute to the evolution of progressive education rooted in a social-romantic ideology. STEM education roots in behaviorism (Skinner, 1974) basing on the assumption that human behavior can be predictable and controllable, forging a strongly objectivist epistemological position. Some critics might perceive this approach as "narrow myopic rationalist thinking" (Cole & O'Riley, 2017, p. 26), however STEM education is fertile ground for the application of Learning Analytics, which "is the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs." (SOLAR, 2011). The idea that STEM education has to move away from a purely behavioral learning theory promoting a cognitive development is not new (Case & Bereiter, 1984). However, the opportunity of relying on Learning Analytics applications, which provide real-time data is fairly new, as some examples demonstrate (Chen et al., 2019).

All above mentioned arguments about learning theories are abstract principles and as Dewey says: "All principles by themselves are abstract. They become concrete only in the consequences which result from their application." (Dewey, 1938, p. 20). Based on this Learning Analytics should be seen as the application in education of the previous stated concepts of 'big data' and 'sophisticated datamining techniques'. This is the first strength of Learning Analytics, which aligns with a progressive idea. According to Davis, Chen, Jivet, Hauff, & Houben (2016) Learning Analytics offers the potential "to ease the translation from data to actionable knowledge". Touching on the field of datavisualization Heer & Agrawala (2008) advocate for this to be an "effective sense-making tool".

Interrelationship of past, present and future

Another progressive principle Learning Analytics caters to is the sense-making of the past. Dewey asks: "How shall the young become acquainted with the past in such a way that the acquaintance is a potent agent in appreciation of the living present?" (Dewey, 1938, p. 23). Learning Analytics can answer this request. Tools like Degree compass or pathway analysis in general (see Denley & Oblinger, 2012) offer an approach for students to realize the present context they are situated in. Making meaning of the personal past and paths of the students before them helps to act upon the present. Student-facing dashboards drawing from Learning Analytics proof to be helpful, when it comes to the progressive urge to make meaning out of the past to master the present. Because "applied to the educational context, a student dashboard is ''an interactive, historical personalized, and analytical monitoring display that reflects students' learning patterns, status, performance and interactions'' (Park & Jo, 2015)" (Roberts, 2017). The topic of course-pathways in a higher institutional context embodies a further principle of progressive education, which might benefit from Learning Analytics. Dewey states out that "the cause for our preference is not the same thing as the reason why we should prefer it." (Dewey, 1938, p. 34). That said student's course selection shouldn't be determined be a gut-feeling or an assumption of advisors. Evidence-based decision making assisted by a tool like Degree Compass which "determines which courses are needed for the student to graduate" (ECAR, 2015, p.4) follows the spirit of progressive education. But one has to be cautious here because "when preparation is made the controlling end, then the potentialities of the present are scarified to a suppositious future. When this happens, the actual preparation for the future is missed or distorted." (Dewey, 1938, p. 49). Using the present as a mere preparation for the future relying on predictive models or shutting down the student's opportunity to explore might work against the spirit of a progressive education. “All this means that attentive care must be devoted to the conditions which give each present experience a worth-while meaning.” (Dewey, 1938, p. 49). However, Learning Analytics bears the potential to close the gap between past, present and future by providing pathway recommendations, current learning opportunities and predictions. According to Roberts (2017) students value features, which emphasize “learning opportunities, comparative information and tools”. He points out several studies, which confirm this assumption (Heath & Leinonen, 2016; McPherson, Tong, Fatt, & Liu, 2016). The mentioned features might proof themselves valuable for progressive education, which is concerned about the relationship of the past, present and future. Learning Analytics also consists of the controversial field of predictive analytics. “Machine-learning data-mining techniques, as well as big data storage and processing capabilities, has allowed us to go beyond conventional reporting about the past and move into an era where we can predict, with reasonable accuracy, everything from future student learning outcomes (e.g., a student’s final grade in a course) to whether a specific student will obtain a degree or continue in a given program.” (ECAR, 2015, p.2). Even several authors render this approach questionable (Dringus, 2011), in its core the idea speaks to the desire to unify past, present and future.

Freedom of intelligence

“The only freedom that is of enduring importance is freedom of intelligence, that is to say freedom of observation and of judgment exercised in behalf of purposes that are intrinsically worthwhile.” (Dewey, 1938, p. 61)

Learning Analytics caters to the above quoted principle of observation, rendering the learning process more transparent turning it into an observable field. According to Roberts (2017), who focuses on dashboards in particular, “perceived academic control is positively associated with academic motivation, self-regulated learning (You & Kang, 2014), academic achievement and retention (Perry, Hladkyj, Pekrun, & Pelletier, 2001)”. Furthermore, “it appeared that when students became aware of their risk level, they tended to alter their behaviour, with resulting improvements to their performance.” (Arnold, 2010). These arguments proof that Learning Analytics emphasizes freedom of observation enabling students to judge and make use of their freedom of intelligence. Opportunities which stay rather obscure without the illuminating component of Learning Analytics. The above stated idea relates to the fact that according to Dewey (1938, p. 64) “thinking is thus a postponement of immediate action, while it effects internal control of impulse through a union of observation and memory, this union being the heart of reflection.” Student-faced Learning Analytics exposing students to learning-behaviour data is more likely to engage them in reflection. Dewey also addresses the responsibility of the teacher “to be intelligently aware of the capacities, needs, and past experiences of those under instruction” (Dewey, 1938, p. 72). At this point Learning Analytics might become handy again from a progressive point of view because discretization (Dougherty, Kohavi, & Sahami, 1995), the grouping of students due to learning objects (Mor & Minguillon, 2004) or the categorizing of learners focusing on skills and other characteristics (Hamalainen, Suhonen, Sutinen, & Toivonen, 2004) are all features which Learning Analytics can perform catering to the above stated progressive demand. However, “policies framed simply upon the ground of knowledge of the present cut off from the past is the counterpart of heedless carelessness in individual conduct.” (Dewey, 1938, p. 78). Again, it should be pointed out that Learning Analytics can overcome this gap of present-pastfuture contradiction.

Real-time data

Another strong argument which is forged by the ECAR-Analytics Working Group (2015, p.10) stresses out the idea of standardized-test's static data and acknowledges learning as a continuous process while recognizing the history of Learning Analytical approaches:

"Since well before learning analytics came on the scene, higher education has been using static learning data—data that do not typically change during a course—to predict how students might perform toward their academic goals (e.g., scores on the SAT and other standardized tests such as placement exams). Although the increasing availability of dynamic learning activity data has improved the accuracy of such predictions, the inclusion of more traditional static learner data remains important, given the longstanding correlations that have been established between these data and student success."

The idea of dynamic data assessed and delivered through an Learning Analytics framework is fertile ground for Dewey's (1938, p. 79) idea to plant "in the learner an active quest for information and for production of new ideas. The new facts and new ideas thus obtained become the ground for further experiences in which new problems are presented."

The learner's active quest for information about his own behavior is supported by several Learning Analytic tools. "Learning Tracker widget that provides MOOC learners with timely and goal-oriented (i.e. towards passing the course) feedback in a manner that encourages reflection and self-regulation. (Davis et al., 2016).

Summarizing some of Dewey's demands of a progressive education it turns out that even a socialromantic ideology is in favor of evidence-based decision making. No doubt, it has to be debated what counts as evidence and how it is used "but as an ideal the active process of organizing facts and ideas is an ever-present educational process. No experience is educative that does not tend both to knowledge of more facts and entertaining of more ideas and to a better, a more orderly, arrangement of them." (Dewey, 1938, p. 82). However, the display of student-facing dashboards, degree compasses and predictive models are only one step on the stairway of the educational endeavor. Learning Analytics should not end with delivering data. "Intellectual organization is not an end in itself but is the means by which social relations, distinctively human ties and bonds, may be understood and more intelligently ordered." (Dewey, 1938, p. 83). The data back-end facing the learner is just the beginning. It is a call to action, an ignition to embark on an educational journey.

Critic

Despite all the potential Learning Analytics might also bear a menacing danger opposing the progressive spirit:

"Failure to give constant attention to development of the intellectual content of experiences and to obtain ever-increasing organization of facts and ideas may in the end merely strengthen the tendency toward a reactionary return to intellectual and moral authoritarianism." (Dewey, 1938, p. 86). At this point reality kicks in and experts (Slade & Prinsloo, 2013) warn: "Learning analytics as moral practice functions as a counternarrative to using student data in service of neoliberal consumer-driven market ideologies". Acknowledging the fact that Learning Analytics has to function within the framework of higher education institutes and does not operate in a theoretical vacuum renders some of the previous arguments in favor of Learning Analytics useless. Especially, when one inquires Learning Analytics through the lens of an institution or instructor. No doubt, when Learning Analytics becomes Institutional Analytics the progressive education of the learner might be at harm prioritizing economic factors. Furthermore "in terms of personalized alerts increasing self-consciousness, and in particular the public self-consciousness, of students. Public self-consciousness refers to the awareness of another's perspective, and in relation to learning analytics refers to students' perceptions that teaching staff are 'watching' them. High public self-consciousness has been associated with greater sensitivity to rejection (Fenigstein, Scheier, & Buss, 1975). Further, heightened self-consciousness through surveillance has been experimentally demonstrated to result in decreased performance, or 'choking under pressure' (Baumeister, 1984)." (Roberts, 2017).

Conclusion

Concluding the stream of arguments why Learning Analytics fits into a social-romantic framework one should be reminded of the fact that learning is a continuous endeavor aiming for the student's growth through experience, continuity and direction. Acknowledging that "every experience is a moving force" (Dewey, 1938, p. 38) the purpose of progressive education is the reconstruction of experiences, turning every experience into an educative one through the power of reflection. Can Learning Analytics assist in this endeavor from a student's point of perspective? I hope this theoretical abstract proofed that Learning Analytics might bear the potential to be a crucial part in the evolution of progressive education that fosters reflection.

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BLENDING EAST AND WEST: TEACHING COLLEGE-LEVEL ENVIRONMENTAL SCIENCE IN EASTERN CHINA TO CHINESE ENGLISH LANGUAGE LEARNERS

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ABSTRACT

The research problem was that Chinese undergraduate students in Hebei Province, China, taking an environmental science course taught only in English, had insufficient English language skills, such that only about 50% of the course could be completed in the normal 60-hour academic period. The research question was: *'How might instruction in introductory environmental science concepts be effectively designed and delivered in English to Chinese undergraduate students who are learning English as a second language?'* The purpose was to identify and develop a 'toolbox' of teaching and learning tools and practices that could be applied when environmental science and English are simultaneously being taught to students in China and elsewhere. The results of this research could be useful for (a) helping instructors to effectively design and deliver their instructional messages to such students, and (b) helping students to learn often difficult technical content in an enjoyable and effective manner. The study involved 34 Chinese undergraduate students. The researchers used a qualitative research approach, applying elements of both action research and ethnography. Data collected included observation data, survey data, visual data, and extant data. The main conclusions were that English proficiency seems to be the number one factor for academic success or failure among international students when learning complex technical content, and there are a variety of helpful teaching and learning strategies available to support such students.

Keywords: *environmental science, China, experiential learning, motivation, English language learner*

INTRODUCTION

Research problem

During the month of June, in the years 2017, 2018, and 2019, the researchers travelled to eastern China to teach four-week undergraduate courses to Chinese students—one researcher teaching an introductory environmental science at Hebei College, in Hebei Province. The course was taught solely in English.

Students taking the course were expected to have some mastery of the English language. The research problem was that students came to the environmental science course with insufficient English language skills, such that only about 50% of the course could be completed in the normal 60-hour academic period allocated for the course.

Background to the problem

The environmental science course described here is part of an inter-college partnership program between Hebei College—located in Hebei Province, China—and a State University of New York (SUNY) college—located in central New York State. The students who participate in the program must complete three years of study at Hebei College, and then travel to the SUNY college to complete a further two years of study, after which they will be awarded a Bachelor's degree from the SUNY college. The China-based courses typically run three to four hours per day, five days per week, and are delivered in the English language only. A Chinese translator is typically available in the classroom to help translate difficult course material into Chinese.

During the regular academic year, the students in this program received 240 hours of ESL instruction from Chinese ESL instructors at Hebei College. Despite this effort, however, most of the students were inadequately prepared for an English-only classroom. Many students struggled significantly with their English reading, writing, speaking, and oral comprehension.

Purpose of the research

There are a variety of teaching and learning strategies available that can help to remedy the research problem, and better prepare foreign students to learn in English, such that they could succeed in an English-only academic environment. The purpose of the research was to identify and try out such strategies, including how they might best be implemented in an environmental science course. The main intended outcome was to develop a 'toolbox' of such methods and tools that could be applied in the simultaneous teaching of environmental science and English—to students in China and elsewhere.

Research question

The research question was as follows: *'How might instruction in introductory environmental science concepts be effectively designed and delivered in English to Chinese undergraduate students who are learning English as a second language?'*

Rationale for the study

There are at least two reasons why this research might be useful:

(1) North American STEM college instructors are often faced with students whose native language is not English. The results of this research could be useful for (a) helping such instructors to effectively design and deliver their instructional messages to such students, and (b) helping such students to learn often difficult technical content in an enjoyable and effective manner.

(2) It is common practice nowadays for college partnerships to be designed, developed and implemented between North American universities and universities from other regions of the globe, including China. The results of this study could be helpful in designing, implementing, and maintaining effective and mutually-satisfying partnerships.

LITERATURE REVIEW / THEORETICAL FRAMEWORK

The following literature helped to guide this research:

Learner motivation

A significant challenge in many K-12 and college teaching environments nowadays is creating and maintaining student engagement and motivation. John Keller (1987) provided some interesting ideas for promoting learner engagement and motivation with his '*ARCS Model of Motivational*

Design'. According to Keller, there are four essential aspects of learner motivation: (1) *Attention*, (2) *Relevance*, (3) *Confidence*, and (4) *Satisfaction*.

Fortunately, environmental science lends itself well to all four of Keller's ARCS Model components. For example, student attention, confidence, and satisfaction might be obtained by making the learning hands-on as much as possible. Relevance might be obtained by addressing topics that affect students' day-to-day lives.

Theory of multiple intelligences

Howard Gardner (2011) postulated that there are at least eight or more different *'intelligences'* or ways of thinking, perceiving, learning, and problem solving. These include the following intelligences: (1) *linguistic* (i.e., 'language smart'), (2) *logical-mathematical* (i.e., 'math smart'), (3) *visual-spatial* (i.e., 'visual smart'), (4) *bodily-kinesthetic* (i.e., 'body smart'), (5) *musical* (i.e., 'music smart'), (6) *interpersonal* (i.e., 'people smart'), (7) *intrapersonal* (i.e., 'self smart'), and (8) *naturalist* (i.e., 'nature smart'). With proper instructional design, all eight intelligences can be addressed in the teaching and learning of environmental science.

Constructivist theory

According to constructivist theory, the learner is not a passive recipient of knowledge but, rather, actively 'constructs' their own meaning by building on their previous knowledge and experience, and adding to their mental schema (UCD Teaching and Learning, 2017). Also, learning is a social process: Groups of people can construct knowledge collaboratively. The teaching of environmental science—with opportunities for multiple representations of reality, real-world examples, and group-based, collaborative learning—lends itself well to constructivist-style learning.

Experiential, hands-on learning

According to Rogers (1986), students often fail to see the larger picture when they are required to simply learn facts. Such learning "involves the mind only. It does not involve feelings or personal meanings; it has no relevance for the whole person… At the other end of the continuum, [there are] significant, meaningful, experiential learning experiences, which are not easily forgotten" (Rogers, 1986, p.101). Learning environmental science can become relevant, meaningful, and engaging if learners' needs and interests are taken into account when designing instruction.

Scaffolding theory

With his *Scaffolding Theory'*, Lev Vygotsky (1934) postulated the existence of a learner's *'Zone of Proximal Development (ZPD)'*. Scaffolds can help a learner to accomplish tasks that he or she might not otherwise be able to complete on their own. A qualified instructor—through proper instructional design and careful instructional delivery that includes built-in scaffolds—can help students to (a) improve their knowledge of basics concepts of environmental science, and (b) improve their English language skills.

Prism Model for teaching culturally and linguistically diverse (CLD) students

In their '*Prism Model',* Herrera and Murry (2016) described the four dimensions of the culturally and linguistically diverse (CLD) student: (1) sociocultural, (2) cognitive, (3) academic, and (4) linguistic (Herrera & Murry, 2016, p.11). They also provided various teaching and learning strategies that can be applied to help students such as the Chinese students in the environmental science course described here.

RESEARCH METHODOLOGY / DESIGN

Research sample and its characteristics

The study took place during the month of June in the years 2017, 2018, and 2019. The research sample was three groups of students (10 students in 2017, 17 students in 2018, and 7 students in 2019) in a first-year undergraduate environmental science course at Hebei College, which is similar to a U.S. community college. The students were approximately 18-20 years of age, with approximately 75% of the students being male, and 25% female.

As with students in the U.S., the Chinese students all possessed—and were strongly attached to—a smart phone. This was both a help and a hindrance. On the one hand, students were able to translate difficult English academic terms using their smart phones. On the other hand, the smart phone can become a permanent crutch, as students tended to rely heavily on their smart phones—to the detriment of their English language skills.

In terms of teaching and learning styles, the students at Hebei College are products of the Chinese educational system, which often focuses on (a) rote memorization of facts and procedures; (b) students often learning alone non-collaboratively; and (c) lecture-based, teacher-centered classrooms. This is in sharp contrast to North American classrooms, where a diverse range of approaches are typically utilized.

Research approach and methodology

In carrying out the research, the researchers used a qualitative research approach, applying elements of both action research and ethnography. As action research, the researchers were seeking solutions to the aforementioned research problem, and were active participants in solving the problem. As ethnography, the researchers spent considerable time teaching, observing, and interacting with the students—both in the classroom, as well as in other locales before and after class.

Action research component: Iterative instructional design

In working to solve the instructional problem being addressed, the researchers made extensive use of instructional design methods and tools to iteratively design and re-design the instruction—from one course edition to the next—so as to (a) better meet the needs of the students, and (b) keep up with current trends and findings in the field of environmental science.

From the outset of the project, the researchers made the decision to keep lecturing to a minimum and make use of hands-on lab activities as much as possible. As such, a variety of relevant environmental topics were identified, and lab activities were created around these topics.

Course design in 2017 (first edition)

In the first edition of the course (i.e., 2017), the instructional plan included the use of PowerPoint slides and various handouts to present background information on the topics being addressed. A series of approximately 600 slides was created (i.e., 150 slides per week, or 30 slides per day), including a mix of text-based slides, and slides primarily containing visual images (photos, charts, graphs, etc.). Class time was equally divided between lecture and hands-on lab activities, with six labs in all completed.

Course design in 2018 (second edition)

In the second edition of the course (i.e., 2018), the PowerPoint slides were reduced to approximately 20 slides per day; much of the text on the slides was reduced or removed; and more visual content was included on the slides. More class time was spent on lab activities (nine labs in all). Also, a mid-term exam was given to the students that included a mix of multiple choice and fill-in-the-blank questions—20 questions in all.

Course design in 2019 (third edition)

In the third edition of the course (i.e., 2019), the PowerPoint slides were reduced even further to approximately 10-15 slides per day. The lab manual was enhanced to include the theoretical information needed to understand and complete the lab activities. Lecture/PowerPoint time was further reduced, and the lab activities were increased to 12 labs—up from 9 labs the previous year. In addition, a variety of learning strategies that addressed simultaneous learning of content and language were embedded into the course design (Herrera & Murry, 2016). This included: (a) embedding both content and language learning objectives into each lab activity, and (b) adding *'vocabulary squares'* (a popular English teaching tool) to each lab activity, so as to help the students more easily learn important environmental science vocabulary terms.

Also, in the third edition, the students were allowed and encouraged to use their native language as a resource—thereby creating a bilingual-style classroom. As Herrera and Murry (2016) pointed out, "when teachers encourage students to first process information in the language in which they are most familiar, students are able to utilize their existing…knowledge to enhance their concept development" (p.52). As Cummins (1981, as cited in Herrera & Murry, 2016) explained, there can be facilitating effects of the first language due to a *'common underlying proficiency'* so that "prior knowledge and academic skills in one language are transferable to learning and performance in another" (p.108).

Other instructional design strategies implemented

In all three editions of the course, the following additional learning strategies were implemented:

(a) Students were placed into cooperative learning groups (i.e., pairs or triads) to carry out the assigned lab activities.

(b) Various research-based ESL teaching strategies were applied, such as "giving more practical examples, sharing slides with students, providing notes before class, offering more time to complete tests/exams, and [allowing] dictionary use in class and during tests/exams" (MacGregor & Folinazzo, 2018, pp.320-321).

(c) Students' personal experiences were tied into lessons as much as possible, so as to promote student engagement (Herrera & Murry, 2016).

(d) The speed of the instructor's *'teacher talk'* was monitored and regulated, as "speaking more slowly [can] be helpful" (MacGregor & Folinazzo, 2018, p.320).
(e) Various visual games—such as PowerPoint-based *Jeopardy* and *Catch Phrase*—were used to help students learn various technical terms.
(f) Music was appropriately applied in the classroom to help address students' *'musical intelligence'* (Gardner, 2011), and their social/affective needs and interests.
(g) Humor was appropriately applied in the classroom to create "a more relaxed, motivating, and safer classroom atmosphere" (Fadel & Al-Bargi, 2018, p.279).

Data collection and analysis

Data collected included: (a) observation data (such as students' language abilities, students' classroom behaviours, etc.); (b) survey data in the form of students' learning summaries which they completed at the end of each course; (c) visual data in the form of photographs taken during various classes and lab activities; and (d) extant data, such as students' completed lab reports, etc. Data was analysed via visual inspection, data review, and reflective discussions with other instructors.

RESULTS AND DISCUSSION

Mastery of environmental science concepts

All students in all three course groups successfully passed the course, with class averages of 85% in 2017, 90% in 2018, and 94% in 2019. In the researcher's opinion, during the three years of the project, all students displayed sufficient cognitive ability and motivation to be able to understand and learn the course content, and to master the course learning objectives.
Unfortunately, however, because the students' English language abilities were relatively low, students consistently struggled to understand and learn the content. In all three editions of the course, only about half of the course content normally covered in a North American college introductory-level environmental science course could be covered.

The use of hands-on lab activities consistently proved to be motivating and engaging for the students, and helped them to master course content, including the learning of new vocabulary terms. This was confirmed by much of the research data collected, including observations made during the labs, and written comments contained in students' end-of-course 'learning summaries'. The use of cooperative learning groups (i.e., pairs and triads) also proved to be very helpful to the students—in learning course content, in completing lab activities, and in improving their English language skills.

Mastery of English language skills

In the researchers' opinion, by the end of the course, very few students (i.e., zero students in 2017, only one student in 2018, and only one student in 2019) had sufficient English language proficiency to be able to pass the TOEFL English language proficiency test.

Due to the relatively low English language ability among most of the students, much of the printed text displayed in course materials and presentations was challenging to the students unless they were given sufficient time to translate the information using their smart phone translation software.

One strategy that worked well in helping the students to better understand the course content was to (1) first present the PowerPoint slides and lab instructions in English, and then (2) ask a student (or the class translator), who was more proficient in English, to translate into Chinese any particularly complex technical terms and/or lab instructions that other students in the course might have difficulty with. This strategy conformed to the concept of a bilingual-style classroom.

CONCLUSIONS

Being proficient in English seems to be the number one factor for academic success or failure when considering the academic potential of international students. As such, considerable effort must be made up front to first promote the mastery of the English language before exposing students to complex technical content, such as environmental science. There are a variety of teaching and learning strategies that can be helpful in this endeavour.

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REVERSE THE WIND: HOW STEM HIGHER EDUCATION PRACTICES IN EASTERN CHINA COMPARE WITH HIGHER EDUCATION PRACTICES IN THE U.S.

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ABSTRACT

The research problem is that teaching, learning, and general societal norms, practices, and conditions in China can differ significantly from those found in the U.S. The research question was: *'What are some important differences between Chinese colleges and U.S. colleges—that could impact students' ability to learn effectively and/or foreign instructors' ability to teach effectively?* The results could be helpful in designing, implementing, and maintaining effective and mutually-satisfying college partnerships—and in helping both students and faculty be successful in such partnerships. The study involved 112 Chinese undergraduate students in two different STEM courses at two different colleges. The researchers used a qualitative research approach, applying elements of ethnographic methodology. Data collected included observation data, survey data, and visual data. Data was analysed in a qualitative manner, via visual inspection, data review, and reflective discussions with other instructors. The main conclusion was that there are a variety of distinct and important differences in teaching and learning norms, practices, and conditions between Chinese colleges and North American colleges. In developing college partnerships in the future, it may be productive to pay attention to such differences, so as to create optimal teaching and learning conditions that can maximize student and faculty success.

Keywords: *China, STEM, learning environment, educational practice, teaching practice, student motivation*

INTRODUCTION

Research problem

During the month of June, in the years 2017, 2018, and 2019, the researchers (both U.S. professors) travelled to eastern China to teach four-week undergraduate STEM courses to Chinese students—one researcher teaching an introductory environmental science at Hebei College, in Hebei Province—the other researcher teaching a course in database concepts at Qingdao College in Shandong Province. These courses were taught solely in English.

The research problem is that teaching, learning, and general societal norms, practices, and conditions in China can differ significantly from those found in the U.S.—potentially hindering both Chinese students and foreign instructors alike.

Background to the problem

The courses that were taught are part of an inter-college partnership program between the Chinese colleges and a State University of New York (SUNY) college (located in Central New York State). The program aims to provide Chinese students with STEM vocational courses not currently offered in their country, as well as the option to eventually transfer class credits toward a degree at the SUNY college.

Those students who opt to participate in the program must complete three years of study at their Chinese home college, and then travel to the SUNY college to complete a further two years of study, after which they will be awarded a Bachelor's degree from the SUNY college.

Purpose of the research

The purpose of the research was to identify and describe some relevant teaching, learning, and general societal norms, practices, and conditions in China that might affect both Chinese students seeking to study in the U.S., and foreign instructors traveling to China to teach there.

Research question

The research question being addressed was as follows: *What are some important differences between Chinese colleges (their operation, their teaching and learning practices, and their external environments), and U.S. colleges—that could impact (positively or negatively) students' ability to learn effectively and/or foreign instructors' ability to teach effectively?*

Rationale for the study

It is common practice nowadays for college partnerships to be implemented between North American universities and universities from around the world, including China. Many of these partnerships are STEM-related. The results of this research could be useful in designing, implementing, and maintaining effective and mutually-satisfying college partnerships—and in helping both students and faculty be successful in such partnerships.

LITERATURE REVIEW / THEORETICAL FRAMEWORK

The following educational theories and models helped to guide this research:

Learner motivation

In an age of smart phones and social media, a significant challenge in many college teaching environments nowadays is creating and maintaining student engagement and motivation. John Keller (1987) provided some interesting ideas for promoting learner engagement and motivation with his '*ARCS Model of Motivational Design'*. According to Keller, there are four essential aspects of learner motivation: (1) *Attention,* (2) *Relevance*, (3) *Confidence,* and (4) *Satisfaction*.

Constructivist theory

According to constructivist theory, the learner is not a passive recipient of knowledge. Rather, students actively 'construct' their own meaning by building on their previous knowledge and experience, and adding to their mental schema (UCD Teaching and Learning, 2017). With this teaching/learning model, teachers are not the sole possessors of knowledge, but are co-learners and learning guides.

Learning is also a social process: Groups of people can construct knowledge collaboratively, thereby creating a culture of shared artifacts that can have shared meanings.

Freedom to learn

As Albert Einstein eloquently stated, “it is in fact nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in need of freedom; without this, it goes to wrack and ruin without fail” (Einstein (n.d.), cited in Rogers, 1969, p.iv).

According to Rogers (1969), the most effective learning environment is one where the instructor is encouraged and supported to act more like a ‘facilitator’ than a ‘teacher’—and has

> “a willingness to be a person, to be and live the feelings and thoughts of the moment. When this realness includes a prizing, a caring, a trust and respect for the learner, the climate for learning is enhanced. When it includes a sensitive and accurate empathetic listening, then indeed a freeing climate, stimulative of self-initiated learning and growth, exists. The student is *trusted* to develop” (p.126).

Rogers’ (1969) suggested approach to teaching and learning implies minimum control by the instructor and maximum freedom for the student.

Impact of environment on creativity

Learning and creativity can often go hand-in-hand, and factors in one’s social and psychological environment can promote or inhibit creativity and learning. Burnside, Amabile and Gryskiewicz (1988) identified various barriers to creativity, including: (a) organizational barriers (inappropriate reward systems, lack of cooperation, etc.), (b) lack of freedom in making decisions about what to do and/or how to do it, (c) perceived apathy, (d) poor supervision, (d) inappropriate evaluation system, (e) insufficient resources, (f) insufficient time, and (g) emphasis on the status quo. For example, Kim (2005) found that the Confucian principles underlying much of Asian society promote rote learning, hierarchical relationships, and conformity.

Burnside et al. (1988) also identified a variety of stimulants to creativity: (a) organizational encouragement, (b) supervisory encouragement, (c) supportive work groups, (d) freedom to decide what to do and/or how to do it, (e) good supervision, (f) sufficient resources, (g) challenging work, and (h) perceived enthusiasm. It seems reasonable that all of these factors—both barriers and stimulants—can be present (or absent) in almost any college learning environment nowadays.

RESEARCH METHODOLOGY / DESIGN

Research sample and their characteristics

The study described here took place during the month of June in the years 2017, 2018, and 2019. The sample was a convenience sample of five groups of STEM students: (a) at Hebei College: 34 environmental science students (10 in 2017, 17 in 2018, and 7 in 2019), and 40 AutoCAD programming students (in 2019); and (b) at Qingdao College: 38 database concepts students (in 2019). Both Hebei College and Qindao College are technical colleges, somewhat akin to a community college in the U.S. The students were approximately 18-20 years of age, with approximately 75% of the students being male, and 25% female.

In terms of preferred teaching and learning styles, the students are products of the Chinese educational system, where teaching and learning norms can include: rote memorization of facts and procedures; students often working alone; and lecture-based, teacher-centered classrooms. This is in sharp contrast to the North American educational model, which typically promotes interactive, student-centered classrooms; frequent use of discovery- and problem-based learning; the teacher as facilitator; and students working cooperatively in groups.

Research approach and methodology

In carrying out the research, the researchers largely used a qualitative research approach, applying elements of ethnographic methodology whereby "researchers spend time—hours, days or weeks—observing and/or interacting with participants in areas of their everyday lives."
(Association for Qualitative Research, 2013, p.1). In the study described here, the researchers spent considerable time teaching, observing, and interacting with the students—both in the classroom, as well as in other locales before and after class.

Data collection and analysis

Data collection included the following: (a) observation data (such as students' classroom behaviours, similarities and differences between Chinese and North American colleges, etc.); (b) survey data (such as students' learning summaries); and (c) visual data (such as photos of students during classes and lab activities, photos of the classroom, school, and external environments, etc.). Data was analysed in a qualitative manner, via visual inspection, data review, and reflective discussions with other instructors.

RESULTS AND DISCUSSION

Chinese colleges—Their operation, and teaching and learning practices

Life at Chinese colleges, such as at Hebei College and Qingdao College, can have many similarities to life at North American colleges. But there can also be some distinct and important differences—some of which can positively or negatively impact students' abilities to study and learn, and teachers' abilities to teach:

College operations

- The vast majority of students at Chinese colleges and universities live on campus in shared dorm rooms—i.e., typically 6 students per room, with the beds arranged in bunks. As such, there is little of the 'commuter campus' feel (i.e., students commuting to campus only for their classes) which can be prevalent at North American colleges and universities.
- There are typically much lower tuition and living costs at Chinese colleges and universities than at colleges and universities in North America. For example, at Hebei College, tuition cost is approximately 12,000 yuan per year (about $1,700), and accommodation in a campus dorm room (6 students per room) costs approximately 8,000 yuan per year (about $1,200). The cost of food is extra but is typically very inexpensive (i.e., about $1 to $2 per meal).
- At both Hebei and Qingdao colleges, the sports field is often the social and exercise centre of campus life—coming alive with people of all ages and backgrounds, engaged in a variety of

activities (e.g., walking, jogging, basketball, soccer, badminton, table tennis, sitting and chatting, etc.)—both early in the morning, and in the early evening (i.e., from 7:00 to 10:00 p.m.).

- At Hebei College, the campus is a social and exercise hub of the surrounding local community. People of all ages and backgrounds—from young parents walking their babies and young children to elderly people out for their daily exercise—flock to campus at all times of the day, particularly early in the morning and in the early evening (e.g., from 6:00 to 11:00 p.m.).
- Classes (often one to one-and-a-half hours each) typically run from 8:00 a.m. to 12:00 p.m., and from 2:30 to 6:30 p.m.—with a dining and siesta period from 12:00 to 2:30 p.m.
- Food—both on and off campus—can be extremely inexpensive and very diverse. For example, a prepared meal can often be purchased for approximately 8 to 15 yuan (i.e., $1 to $2). At Hebei College, food was available at a 4-storey cafeteria building, with approximately five to seven food stalls of different food types available on each floor.

Teaching and learning styles and approaches

- There seems to be little use of, and experience with, collaborative, cooperative learning methods (such as learning in pairs or small groups, group discussion, group project work, etc.) in Chinese classrooms. The traditional teacher-centred lecture approach, with periodic tests and exams seems to be much more commonplace. For example, Li, Chen, and Duanmu (2010, as cited in MacGregor & Folinazzo, 2018) "found a reluctance among Chinese students to participate in group discussions" (p.304). The result can be that students accustomed "to passively following teachers' instructions may feel disoriented when they are asked to construct their own knowledge or find the answers for themselves" (Xu, 2015, p. 10). Kim (2005) found that "students seek to avoid appearing different from others, individuals learn to restrain themselves to maintain group harmony, and the fear of making a mistake or feeling embarrassed keeps many students silent" (Kim, 2005, p.341).
- Computers in campus computer labs typically do not have access to the Internet—this being reserved mainly for faculty office computers. This seems to be a government policy. This condition precludes any use of valuable online learning resources, such as YouTube videos, or, in the case of language instruction, the use of helpful language tutorial Web sites.
- In general, citizens of China are restricted from accessing a wide variety of popular Western Web sites, such as all Google-based Web sites (Google search engine, translate.google.com, Google Docs, etc.), many popular video sites (such as YouTube, etc.), and many popular news sites. All such Web sites are banned by the Chinese government.
- Similar to college classrooms in the U.S., students in the Chinese classrooms observed were often distracted from the instruction being provided by their preoccupation with their smart phones and laptops. For example, in the Database Concepts classroom, at one point, approximately 10 of the 38 students (26%) were engaged in playing video games or watching online movies.

Use of security and surveillance methods and tools

In contrast to many U.S. higher educational institutions, there is a heavy presence of various security and surveillance methods and tools—both on and off Chinese campuses nowadays. With this comes a certain *'1984 / Orwellian'* feel (Orwell, 1949) to life there. For example, WGBH Educational Foundation (2019) reported that, by 2020, it is projected that over 600 million surveillance cameras will be deployed in cities and towns across China.

One wonders about the rationale behind this policy, and to where it is leading—both on and off campuses. For example, at the colleges observed by the researchers:

- There are large manned security gates at all entrances to campus—both for vehicles and pedestrians. In some campuses, students and faculty must make use of swipe cards to enter and exit from the campus. In contrast, such security measures are largely absent from most North American college and university campuses.
- Each Chinese campus observed or visited has a large fence or wall surrounding the campus. Such fences and walls may be topped by razor wire or broken glass to prevent illegal access to the campus.
- There is a heavy presence of security cameras—both on and off campus. On campus, these cameras include observation cameras in the classroom and in the cafeteria—presumably to check attendance and/or to assess faculty, staff, and/or students' work performance. Faculty, staff, and students typically seem uninformed about the purpose and use of such cameras.
- Off campus, security cameras can be found mounted to street poles at every intersection on major streets and side streets (e.g., approximately every 50 yards or so).
- At Qingdao College, fingerprint reader access is required for entry and exit from the classroom—by students, faculty, and staff.
- All dorms have curfews (typically around 11:00 p.m.) and are typically locked after the curfew time. Any student arriving at their dorm after the curfew time must report to the Residence Life office the following day to account for their lateness.

It is worth noting that such heavy use of security and surveillance methods and tools—by imposing more control on students, faculty, and ordinary citizens—runs somewhat counter to Rogers' (1969) suggested 'freer' approach to teaching and learning, and could pose threats to student motivation and effective, deep learning—both inside and outside of the classroom.

CONCLUSION

As this paper has attempted to illustrate, there are a variety of distinct and important differences in teaching and learning norms, practices, and conditions between Chinese colleges and North American colleges. Some of these differences seem to be progressive; others seem less so. The old adage that we can all learn something from everyone seems to be appropriate here. In developing college partnerships in the future, it may be productive to pay attention to such differences, so as to create optimal teaching and learning conditions that can maximize student and faculty success.

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MAKING SPACE FOR INQUIRY IN A HIGH SCHOOL STEM LABORATORY

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ABSTRACT

This paper summarizes research conducted at a Canadian public secondary school where teachers have developed a "Project-Based STEM Laboratory" to teach science, technology, engineering, and mathematics (STEM). Based largely on interviews with teachers, the paper chronicles the history and development of the school's STEM Program and investigates educators' objectives in creating and maintaining the lab. Positioning teachers as co-researchers, the study incorporates elements of ethnographic and phenomenological research, while relying on constructivism to build a framework from which to inquire about teachers' perspectives on student learning. The study looks to models of apprenticeship, craft education, and traditions of "design & tech" to theorize STEM education and situate it historically. Moreover, the paper explores educators' perspectives on recent changes to the provincial curriculum and the extent to which the STEM Lab acknowledges new curricular competencies outlined by the Ministry of Education.

Keywords: *STEM education, curriculum theory, inquiry, constructivism, metacognitive strategies, apprenticeship, project-based learning*

GOALS AND OBJECTIVES

The objective of this paper is to present the preliminary results of research conducted at a public secondary school in Vancouver, British Columbia, where teachers have adopted a STEM Program model for teaching science, technology, engineering, and mathematics. The study explores teachers' motivations in implementing the school's STEM Lab and how teachers view a variety of contested terms and concepts—including Project-Based Learning (PBL), the STEM acronym itself, and other sometimes-related terms like *making*, *inquiry*, and *sharing*. Moreover, the study examines teachers' views on the objectives of STEM education, asks how (and why) teachers develop activities to meet these objectives, and how "STEM Lab teaching" informs teachers' practice. Related to this is an examination of how teachers view elements of the new K-12 provincial curriculum and the way it uses terms like *testing*, *making*, and *sharing* (B.C. Ministry of Education, 2016).

The study is guided by the following questions:

1. What challenges have teachers faced in the development and operation of the STEM Lab?
2. What are teachers' understandings of (and perspectives on) STEM Education?
3. How do teachers envision their role in a STEM Laboratory?

THEORETICAL FRAMEWORK

From an approach "centred" on social constructivism (Palincsar, 1996), the paper looks to theories of experiential learning (Dewey, 1933; Piaget, 1954), situated cognition (Lave & Wenger, 1991), cognitive apprenticeship (Brown, Collins, & Duguid, 1989), and distributed cognition (Martin, 2012) to consider the interdependence of social and individual processes in the co-construction of knowledge and to adapt traditions associated with social constructivism to a study of teachers' conceptions of STEM-fields education and making-in-education.

Since the establishment of the STEM acronym in Washington, DC in the early 2000s, more attention has been focused on how the fields of science, technology, engineering, and mathematics are taught and learned—often with a view to increasing participation in STEM-related professions (Bybee, 2013). Along with this trend, recent discourses on STEM-fields curriculum have sought to disrupt preconceptions about STEM disciplines (Davis, Francis, & Friesen, 2019). In order to situate concepts like "STEM Education" and "Project-Based Learning," the study relies on a series of perspectives on science, mathematics, and technology education (e.g., DeBoer, 1995; Pinar, 2015; Davis, Francis, & Friesen, 2019). Conceptions of PBL, digital fabrication and maker culture (Elliott & Richardson, 2017; Gershenfeld, 2005; Halverson & Sheridan, 2014) also inform a working definition of *making* in terms of activities that might translate to a high school STEM laboratory. Moreover, the paper looks to theories of constructionism (Papert, 1991) and work on metacognition (Dewey, 1933; Lipman, 2010), along with notions of study (Pinar, 2015; McClintock, 1971) and democratizing communities of inquiry (Cam, 2000; Lipman, 2010), as a way to frame a reconceptualization of STEM curriculum—as practiced in the school's STEM Laboratory—with elements of a Community of Inquiry approach that focuses on the roles of teachers and students in a PBL-STEM Laboratory.

METHODOLOGY

The study relies on a qualitative methodology that is largely interpretive. It employs methods to allow for the generation of rich data sets, drawing from phenomenological (van Manen, 2007) and ethnographic methods (Geertz, 1973). The study has been designed to investigate the perspectives and perceptions of a set of educators associated with a single STEM Laboratory at one public secondary school.

Study Site and Participants

From October 2018 until July 2019, one of the authors visited a Vancouver-area high school and its STEM Laboratory. Of the six teachers associated with the STEM Lab, four agreed to be part of the study. Data was generated primarily through semi-structured interviews, focus groups, classroom observations, and attendance at teacher meetings—in the form of detailed fieldnotes and audio recordings.

Data Familiarization and Thematic Analysis

Coding and theme development started early, growing out of observations and notes from initial interactions with STEM teachers. Codes and themes continue to be generated and refined as the primary researcher reviews and transcribes audio recordings, with assistance from qualitative data analysis software. Thematic analysis (Braun & Clarke, 2019) guides a reflexive process that considers (and reconsiders) patterns of shared meaning across the dataset.

RESULTS AND DISCUSSION

As of January 2020, the authors are in the process of working through recordings, transcripts, and fieldnotes. Most results are yet to come, although we can share some early observations.

Since 2013, teachers associated with the STEM Lab have been actively involved in the design, implementation, and refinement of the school's STEM Laboratory Program for students in Grades 8 to 12. According to teachers, the STEM Lab aims to address deficiencies that teachers have identified in their teaching of high school mathematics, science, and tech-related subjects. Teachers often outline these deficiencies in a series of (sometimes rhetorical) questions that underline their concerns, including:

- Can students own their learning?
- Why silo subjects into courses with titles like *Math*, *Science*, and *Tech?*
- Are exams a reliable way to measure understanding?
- Should all students cover the same curriculum content?
- Are textbook problems divorced from reality?
- What happens if I do not cover all topics in the curriculum documents?
- Should students be allowed to work in groups during exams?
- Should students be given access to the Internet during evaluations?
- What do students remember from one grade to the next?
- Do they remember *anything* after they graduate?
- How many students enjoy math and tech classes?
- Are we preparing students for university? For college? For work? For life?

With the support of administration, the teachers implemented several self-described "innovations" in the development of the school's cross-disciplinary STEM Laboratory Program. According to teachers, these innovations are designed to give students more "agency and ownership" of their learning, to encourage study "across the disciplines," to give teachers and students "more flexibility" in topics covered, and to increase opportunities for "collaboration." Preliminary analysis of data appears to show that the innovations described by teachers have indeed altered students' and teachers' roles.

Teachers refer to these innovations as "disruptive" and report a shift in focus away from domain-specific content toward what they describe as "curricular competencies" (borrowing this term from the provincial curriculum). Moreover, teachers look to the new BC curriculum to support what they see as this "shift" away from "teaching everyone the same content" toward a model that encourages students to be more independent, more confident, and to explore topics that are of importance and interest to students—even if such explorations mean that students will "miss" domain-specific content. One goal of the STEM Lab Program is to inspire students to "own their learning;" i.e., to have more control over what is studied, to be able to learn on their own and with their peers, and to adapt to unfamiliar topics and situations. This approach has consequences when it comes to which topics may (or may not) be covered in a curriculum that responds largely to student interest. In the words of one teacher, "it could be that not every student in STEM will learn Ohm's law, [but] the hope is that those who don't encounter it in our STEM program will have the confidence to learn it later, when they need it."

Shift in Focus: "Commandments" to Live By

A *shift in focus* can be seen in the Seven Commandments that STEM Lab teachers have developed to guide their practice:

1. Thy practice must be domain-authentic
2. If thou canst simply Google it, don't bothereth
3. Thy students shall work in groups
4. Students shall have topic choices
5. Students shall do, write, and say to demonstrate learning
6. Thy projects shall culminate in an artifact
7. Thou shall consider only a student's best work

In order to "live the commandments," teachers have found that they have shifted away from what they identify as "tried-and-true" elements of mathematics and science teaching (including, for example, textbooks, worksheets, and written tests) to a "heretical" (i.e., almost examination-free) style of laboratory work where students collaboratively design, build, and evaluate "real-world projects" aimed at solving "real-world problems." According to teachers, every project begins with an "ill-defined problem" (loosely described as "ungoogle-able") that:

1. is based in real-world STEM topics
2. has a clear statement of problem
3. has a clear intended goal
4. has an *unclear* pathway to the goal

By introducing students to a Project-Based Learning Cycle where students are encouraged to explore problems that are "important to them," teachers acknowledge that a teacher's role has become one of "supporting students," asking questions, probing understanding, and "trying hard to not tell students answers." As students progress through the STEM program, teachers expect them to "reflect on their learning individually and as a group" and to take on more responsibility for "owning their learning" which includes managing routines, strategies, and schedules for what teachers describe as "effective group work." This marks a definite shift from pre-STEM Lab objectives where learning standards were often defined by a set of content headings (e.g., "Students are expected to know Ohm's law"). Current STEM Lab learning standards focus on what students can *do* rather than what they *know* (e.g., "Students are expected to be able to demonstrate a sustained intellectual curiosity about a scientific topic or problem of personal, local, or global interest").

CONCLUSION AND SIGNIFICANCE

In the STEM Lab, creative projects that culminate in the production of artifacts and student-led presentations have replaced worksheets, textbooks, and final examinations. One teacher describes this focus on collaborative projects as "science fair teaching." Project-based "science fair teaching" (as practiced in the STEM Lab) has yet to be definitively categorized and theorized. In the coming months—before the STEM 2020 Conference—we plan to explore the implications of "science fair teaching" and to investigate the concerns, questions, commandments, and heresies that have led teachers to develop the STEM Laboratory Program.

At this stage of data analysis, we believe the STEM Laboratory represents a rich *place of learning* from which to engage in a series of explorations that overlap with current theories on STEM-fields curriculum, teaching practice, and professional development. We look forward to this analysis and the conversations that will result—and plan to share our conclusions and musings (inspired by the work of a few STEM teachers) on how STEM Education, making, and problembased-learning may be reconceptualized, reimagined, re-viewed, and researched in the future.

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SCIENCE FICTION CONVENTIONS AS AN INFORMAL LEARNING SPACE: EXPLORING ATTENDESS ATTITUDES ABOUT SCIENCE

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ABSTRACT

Science fiction conventions allow individuals who enjoy interacting with diverse science fiction mediums, such as literature, TV, and movies, to engage with a community that exists between the worlds of science fiction and science fact. Some science fiction conventions include science "track" themes that allow scientists to share their expertise and research on scientific findings and applications of science in connection to science fiction with enthusiasts. Despite the ability of science fiction conventions to draw crowds in the tens of thousands over the course of a week, there is almost no scholarly literature examining popular culture conventions in an educational context. Understanding who is attending non-fiction tracks at science fiction conventions and providing insight into how relevant science is to their lives can have far reaching implications for science communication, science education, and the community at large. This study documented the demographics of attendees' (n = 242) at a science fiction convention in the southern United States and explored attendees beliefs about science, appropriateness of venue for learning, and how often attendees attended non-fiction offerings at this convention. The demographic breakdown of attendees who answered the survey as follows: 55% female and 44% male, 71% identified as Caucasian, and majority held at least an Associate's degrees (75%). The majority of respondents were between the ages of 26-55. Results indicate that attendees had strong views on the relevance of science in their lives and that all believe that science fiction conventions are good places to learn about science.

Keywords: *informal education, science, science fiction*

INTRODUCTION

Scientists have often referenced *science fiction* as a motivational factor in their desire to pursue a career in science, or as an inspirational factor to design new technologies, based on tools and devices created in science fiction (Robie, 2014; Zhang and Callaghan, 2014). Additionally, there is no denying the "wow" factor of movies, literature, and comic books for "shaping how young children view [science]" (Tan, Jocz, and Zhai, 2015, p. 1). Comic book science fiction legends such as Iron Man, Spider-Man, and Batman, all portray "average" humans who have used modern technology or science to defend the world which leaves readers with the belief that they can be Batman or at the very least see themselves as scientists (Steinke, Lapinski, Crocker, Zietsman Thomas, Williams, Evergreen, et al, 2007; Tang, 2014).

Science fiction conventions allow individuals who enjoy interacting with diverse mediums (literature, TV, movies, etc.) to collaborate within a community that engages worlds of science fiction and science fact. Because the pathway and career outcomes of people who favor STEM are so often varied, a more comprehensive picture is needed of what impact these types of informal venues have on participant/attendee overall motivation to engage in science learning, and who can connect the fun in learning at informal science fiction conventions to their regular lives. In fact, the American

Academy for the Arts and Sciences (2019) found that 49% of Americans watch some sort of science fiction related entertainment and that 33% of these respondents said it helps them to understand science, technology, and medicine.

Just as professionals attend conferences to enhance their learning, science fiction enthusiasts attend conventions to interact with others in the science fiction community and share in deeper experiences of their science-related interests. At these conventions there are different *learning tracks* where participants can attend lectures delivered by “experts” in their particular genre (Bondi, 2011). These experts tend to be professionals who share a common cultural interest with the participants.

Many of the non-fiction tracks are designed and managed by science experts who are currently in a STEM career. One of the major differences between attending a lecture at a professional conference versus a science fiction convention is the science communication at a convention is much more relaxed, easy to understand, and focused on lay-person understanding of the topic. They are not rigidly structured research lectures but more community interest discussions where people from a variety of backgrounds can learn. A recent study by the American Academy of Arts and Sciences (AAAS) (2019) found while people encounter science at venues such as science fiction conventions there is still research to be done on the impacts of this type of science learning.

While the AAAS has indicated that “individuals do not necessarily engage in science-centered activities with the sole intention of learning about science” (p. vii) they also indicate science activities can increase engagement, become a safe place to discuss controversial topics, and potentially “broaden participation in STEM” (p. vii) as well as play a vital role in developing “lives empowered by STEM literacy, knowledge, and identity” (p. 29). This project sought to investigate and record data from attendees at DragonCon. Specifically, the researchers were interested in who attended, how science is relevant to them and whether this type of venue was conducive to learning. Based on the report by the AAAS there are 7 key dimensions of science capital that can influence a person's attitudes to science: science literacy, science attitudes, science media consumption, participation in informal school learning, family science skills/knowledge, knowing people in science roles, and talking about science in everyday life.

In addition, researchers chose to examine the difference in results between educators and noneducators. This was due, in part, to results from a pilot study conducted by the researchers in 2017 which showed a large number of educators participating in Science related tracks at the convention.

THEORETICAL FRAMEWORK

Understanding the learning environment at informal environments such as a science fiction convention is best explored using a sociocultural framework. The sociocultural context views attendee participation in informal science education experiences in a social context and within a community of learners (Falk & Dierking. 2000). Sociocultural learning theory has origins in Vygotsky’s Social Development Theory which recognizes that human activities, such as learning, often occur in a social/cultural context (Lemke, 2001) as social interaction are an important part of learning in a cultural context (NRC, 2010). The role of culture in sociocultural learning framework posits that, although difficult to define, culture includes language, practices, activities and affiliations in communities where individuals affiliate and participate (NRC, 2009). Because of the unique social and cultural aspects within the science fiction convention community, a sociocultural framework provides the best lens to explore this type of informal learning environment.

METHODOLOGY

Survey research methodology was implemented to obtain information from a random sampling of attendees at the 2018 science fiction convention. Survey research is an appropriate research strategy for uncovering basic information and opinions from a population (Lavrakas, 2008). Basic demographic information was collected to learn more about convention attendees and Likert items were constructed with five ordinal selections to determine perceptions of the relevance of science in their lives.

Research Questions

1. Who attends science fiction conventions?
2. What are the opinions and attitudes of attendees at science fiction conventions related to the importance and relevance of science?
3. How do educators opinions on the relevance of science differ from non-educators?
4. Do educators vs. non-educators view science fiction conventions as a potential venue for learning science?
5. How often do educators participate in learning opportunities at science fiction conventions?

Study Context

Dragon-Con "is one of several internationally known pop culture conventions. It is organized for Science Fiction fans, [it] features more than…3,500 hours of comics, films, television, costuming, art, music and gaming…" (www.mediarealtions.DragonCon.org). Over 90,000 people attended the 2018 convention in Atlanta, Ga. As of the most recent convention, participants at the convention can choose to engage in 37 different tracks, including a Science Track and a Space Track that engage participants in science learning, and the connections between science fact and fiction.

Participants (Research Question 1)

To answer the first research question, volunteer attendees answered a series of demographic questions as part of the survey. As it was impractical to survey all participants at the convention, convenience sampling was used to gather data from as many attendees as possible. Study participants (n = 242) were adults (18 years of age or older) who attended Science Fiction Convention hosted at a 2018 convention in the Southeastern United States. The study's respondents were approximately 44% male, 55% female, and 1% preferring not to answer. Of all participants 24% identified as having a career in education with the greatest number of participants in the age category between the ages of 26-35. The vast majority of respondents had at least a Bachelor's degree (approximately 70%) and identified as Caucasian (71%). Of all the participants who answered, 172 indicated that they had been to a non-fiction or Science related track at the event. Of all respondents, 83.33% indicated they believe science fiction conventions could be a good location to learn about science regardless of whether they actually reported attending a science track.

Survey Protocol

Based on several different surveys (Schreiner and Sjoberg, 2004; Tyler-Wood, Knezek, and Christensen, 2010) about the use and relevance of science, a survey was developed as a follow up to pilot data collected initially collected in 2017. Wording on several questions was modified to make it more appropriate for the audience. The survey solicited information about Science Track attendee demographics, educational background, attendance behaviors, and attitudes on the relevance of science and opinions on science fiction conventions as a venue for informal science learning. Likert Scale items are often used to measure attitudes and opinions using an ordinal rating system. The most common system is to use five categories of responses, providing a range of responses from 'strongly agree' to 'strongly disagree (Jamieson, 2004). Survey participants were asked to rate ten items related to the importance and relevance of science using a five-point scale (Strongly Agree (1), Agree (2), Neither Agree or Disagree (3), Disagree (4), Strongly Disagree (5).

ANALYSIS

Science Relevance (Research Questions 2 & 3)

In order to gauge participant's opinions on science relevance, a ten item Likert scale questionnaire was embedded into the survey. Results indicate that attendees as a whole had strong views on the relevance of science in their lives (see Table 1).

Table 1.

Item	Number	Mean	SD	Median
I find science interesting.	240	4.79	0.485	5.0
I enjoy learning about science.*	241	4.76	0.498	5.0
Science has practical value for me.	241	4.68	0.648	5.0
Science is relevant to my life.	239	4.66	0.607	5.0
Science relates to my personal goals.	240	4.42	0.804	5.0
Science challenges me.	239	4.64	0.619	5.0
Understanding science gives me a sense of accomplishment.	240	4.66	0.563	5.0
I think about how I will use the science I learn.	241	4.39	0.795	5.0
I think about how the science I learn will be helpful to me.*	241	4.53	0.652	5.0
I trust science.	240	4.6	0.670	5.0

To address our research question related to the differences in views between educators and noneducators, data was broken down based on whether participants self-identified as educators. Of the 242 participants, 59 responded that they were education professionals, and the reported mean and standard deviation for each survey item based on attendee identified career is located in Table 2.

Table 2.

Item	Ed Mean	Ed SD	Non-Ed Mean	Non-Ed SD
I find science interesting.	4.75	0.606	4.79	0.442
I enjoy learning about science.	4.76	0.285	4.76	0.463
Science has practical value for me.	4.71	0.617	4.66	0.659
Science is relevant to my life.	4.71	0.649	4.65	0.593
Science relates to my personal goals.	4.63	0.717	4.35	0.821
Science challenges me.	4.73	0.639	4.61	0.612
Understanding science gives me a sense of accomplishment.	4.69	0.595	4.65	0.553
I think about how I will use the science I learn.	4.54	0.773	4.35	0.798
I think about how the science I learn will be helpful to me.	4.63	0.639	4.50	0.663
I trust science.	4.54	0.584	4.62	0.608

To explore the differences in the survey item responses between educators and non-educators, a Mann Whitney U test was used to conduct a comparative analysis. This test is appropriate to compare ordinal scaled data (alpha = 0.05, two tailed). See Table 3 for results.

Table 3.

Item	Mann-Whitney U	Mean Rank	Z	Asymp. Sig. (2t)
I find science interesting.	5199.000	22068.000	-0.054	0.957
I enjoy learning about science.	5180.000	22016.000	-0.664	0.506
Science has practical value for me.	5207.000	22043.000	-0.544	0.587
Science is relevant to my life.	4833.500	21486.500	-1.232	0.218
Science relates to my personal goals.	4333.500	20986.500	-2.541	0.011

Science challenges me.	4625.000	21096.000	-1.931	0.054
Understanding science gives me a sense of accomplishment.	5060.500	21713.500	-0.830	0.406
I think about how I will use the science I learn.	4556.000	21392.000	-2.021	0.043
I think about how the science I learn will be helpful to me.	4830.000	21666.000	-1.414	0.157
I trust science.	5358.500	22011.500	-0.028	0.978

Based on the comparative analysis, two survey items were noted as statistically different. Educators scored significantly higher on the item "*Science relates to my personal goals*" and "*I think about how I will use the science I learn*" (p = 0.011 and p = 0.043, respectively). However, in review of the descriptive statistics of Table 2, both educators and non-educators scored items highly.

Science Relevance (Research Questions 4 & 5)

In response to Survey Question 4, "do you think DragonCon is a good location to learn about science" an overwhelming majority of respondents (81%) said "definitely yes" or "probably yes". An additional, 11% stated that it "might or might not be" a good location indicating the possibility of being a good location. Of the respondents who said "definitely yes" or "probably yes" 23% identified as being in an education field either secondary or post-secondary.

Of the educators who responded to the survey, 74% indicated that they attend non-fiction tracks at the convention. Of these, the majority indicated that they attended non-fiction events at least 26% of their time at the convention. Given that the convention is five days of almost 24 hour programming (about 120 hours) it means that, in total, educators are attending at least 31 hours of non-fiction programming over the course of 5 days.

Conclusion

People who attended the science fiction convention overwhelmingly indicated science has practical value to them, science is relevant to their lives, and they think about how to use the science they are exposed to. Findings also indicate people, from all sectors, believe science fiction conventions can be good places to learn about science, although researchers did not address the conduciveness of the venue for learning. Of particular importance is the relevance educators made to learning at science fiction conventions and classroom opportunities. In particular, teachers (both secondary and postsecondary) make up a large demographic of the participants in non-fiction tracks (24%) when compared to the number of the number of people who identify as being employed in teaching professions (secondary and post-secondary) across the United States (2%). https://www.quora.com/How-many-college-professors-are-employed-in-the-US-in-2017 and https://nces.ed.gov/fastfacts/display.asp?id=28.

While many topics at conventions may not be directly relatable in the classroom depending on the age range and topic, the Nature of Science as promoted by many states, can be enhanced through these "aha" and "wow" moments that educators share with students. The Nature of Science includes helping students learn that science: is an attempt to explain natural phenomena, people from all cultures contribute to science, science has a tentative character, science relies on observation, experimental evidence, rational arguments, and skepticism, there is no one way to do science, and requires accurate record-keeping (Science Learning Hub - https://www.sciencelearn.org.nz/resources/412-describing-the-nature-of-science). All of these areas and more are typically covered in non-fiction tracks.

While these findings are encouraging and show that educators are seeking out ways to further their knowledge through informal learning and non-traditional professional development activities, more research is needed to determine how educators are utilizing this information in their classrooms, whether this data is similar across the United States, and how to leverage informal learning into professional development. This information can be of particular interest to those who plan and implement professional development and researchers studying informal education. Science teachers could also benefit from this information as they consider ways to make connections with scientists in the field who have experience in communicating with the public.

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SCIENTIFIC CONSTRUCTION OF STEM EDUCATION CLASSROOM TEACHING AND LEARNING EVALUATION SYSTEM IN PRIMARY AND SECONDARY SCHOOLS

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ABSTRACT

At present, international research on STEM education basically focuses on the development progress and model. Research into the evaluation of STEM education is just emerging, and there is even less research on the evaluation of classroom teaching. Through a combination of quantitative and qualitative analysis, the research team has developed a STEM classroom teaching evaluation system. In this study, classroom practices were conducted a three-year period, with a sample of nearly 10,000 teachers and students. The results proved that teachers with high scores in the scale have better STEM teaching ability, and the STEM classroom teaching evaluation system is of great significance for the direction and value orientation of STEM education.

Keywords: *STEM, classroom teaching evaluation; STEM evaluation tool; system construction*

INTRODUCTION

STEM education originated in the U.S. In 1986, the National Science Foundation (NSF) released the *Undergraduate Education in Science, Mathematics, Engineering and Technology,* which marked the beginning of STEM education in the U.S. The UK, Germany, China, Finland and other highly creative countries have begun to place great emphasis on learning by doing, and STEM education practices have developed rapidly. Currently, China's STEM education is confronted with the inadequate relevant curriculum resources, STEM education evaluation standards and professional teachers. In June 2017, the National Institute of Education Sciences (NIES) released *China STEM Education White Paper*, with the purpose of strengthening STEM education and improving human resource development has become a major reform direction that responds to the demands of the new economic and social norm on talent training.[1]

I. Literature Review on the STEM Education Evaluation

1. Foreign Research on the STEM Education Evaluation

With the continuous development of STEM education, scholars at home and abroad have been conducting more and more in-depth researches on STEM education. The author searched the CNKI database with the theme of "STEM Education Evaluation" and obtained 36 valid papers.

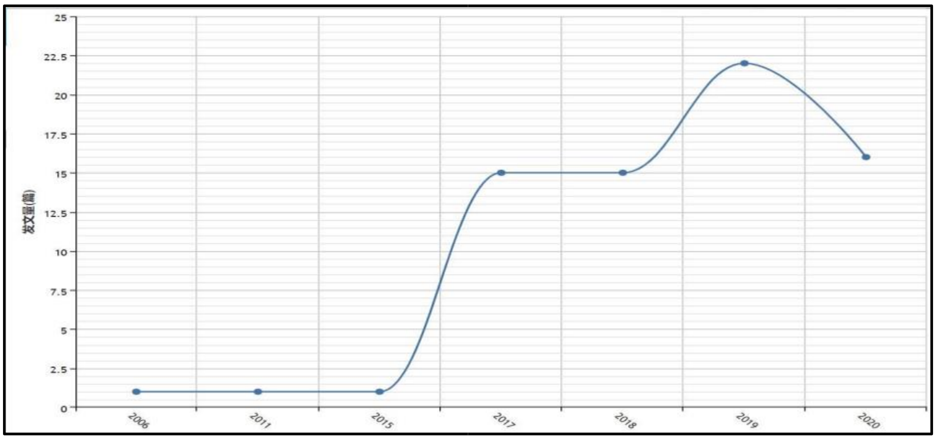

Figure 1. Trend Graph for the Number and Publication Year of STEM Education Evaluation Papers

According to Figure 1, foreign research on STEM education evaluation began in 2002, and the overall trend was initially at a low level, and started to climb rapidly from 2015. Besides, there was a gradual boom from 2017 to 2019, but only 20 papers were closely related to the study of STEM education evaluation; indicating that STEM education evaluation has gradually become a hot topic; however, the small number of papers indicates that evaluation research remains a difficulty. In contrast, the U.S. has more research results in STEM education evaluation; for example, the PORTAAL teaching evaluation system is a relatively complete evaluation system developed by Professors Sarah L. Eddy and Mary Pat Wenderoth. Nevertheless, this system is only limited to university classrooms, and STEM classroom teaching evaluation is still blank in primary and secondary schools[4].

2. Domestic Research on the STEM Education Evaluation

The research on STEM education evaluation started late in China, which basically introduced the foreign achievements and progress of STEM education evaluation. For example, Yi Bai et al. (2018) introduced the STEM evaluation developed by the Connecticut Science Center, which divided classroom teaching into seven steps and followed each step with an evaluation scale; when teachers evaluated students, they only needed to score according to the scale[3]. Through investigation and research on a large number of domestic and foreign studies on the STEM evaluation, Professor Yanyan Li et al. from Beijing Normal University focused on classroom teaching and adopted the Delphi method; nine experts, finalized four first-level indicators and 22 second-level indicators back to back through two rounds of scoring and built the STEM education evaluation system[2]. This STEM education quality evaluation indicator system has certain reference significance, but it is only a literature review with large indicators untested in practice, so it is difficult to be applied to STEM classroom teaching.

To sum up, it is imperative to develop an evaluation system and evaluation tool for the current development of international STEM education, and this is also the only way to promote the healthy orderly development of STEM education in world.

II. Research Goal and Evaluation Model of STEM Education Evaluation

The proposed STEM research team aims to explore the STEM education classroom teaching and learning evaluation system, and focus on the evaluation of students' STEM learning behavior and teachers' STEM teaching behavior, so that the evaluation system may better guide students' learning and teachers' teaching.

1. Model Construction of STEM Classroom Teaching and Learning Evaluation System for Primary and Secondary Schools

(1) Construction Program of STEM Classroom Teaching and Learning Evaluation Indicator System for Primary and Secondary Schools

Figure 2 shows the construction program of STEM classroom teaching and learning evaluation indicator system.

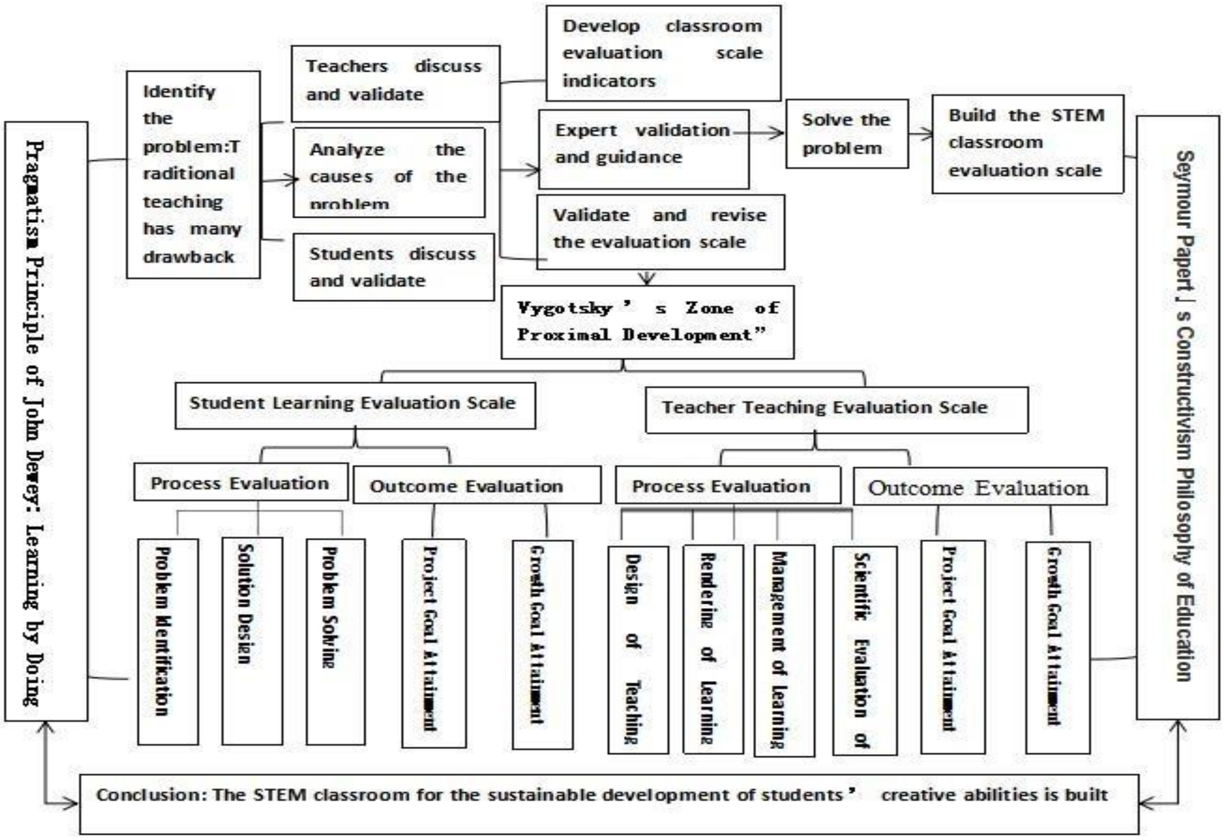

Figure 2. Construction Program of STEM Classroom Teaching and Learning Evaluation Indicator System for Primary and Secondary Schools

According to John Dewey's pragmatism principle, Seymour Papert's constructivism and Vygotsky's Zone of Proximal Development, the proposed 58 STEM experimental schools, being problem-driven, constructed the STEM classroom teaching and learning evaluation indicator system according to the research idea of problem identification - analysis of problems - expert argumentation - problem solving, and finally formed a dynamic STEM classroom teaching evaluation system for the sustainable development of students' innovation ability after three years of experimental verification.

(2) Modeling of STEM Classroom Teaching Evaluation System for Primary and Secondary Schools

In this study, the Delphi method was applied, and ten famous national experts on STEM education were invited to jointly construct the evaluation model. The STEM classroom teaching evaluation model consists of the process evaluation and the outcome evaluation, including 2 first-level indicators, 6 second-level indicators and 15 third-level indicators. Afterwards, a hierarchical analysis and the AHP method was used to comprehensively process the data results and obtain the expert comprehensive judgment matrix. The consistency test results of the judgment matrix showed CR=0.09<0.1 in the STEM classroom teaching evaluation scale, indicating that the consistency test has passed.

Table 1. STEM Classroom Teaching Evaluation (TE) Scale

First-level Module M_i	Weight W_i	Second-level Module M_{ij}	Weight W_{ij}	Third-level Module M_{ijk}	Weight W_{ijk}
Process Evaluation M_1	72.99% W_1	Design of Teaching Objectives M_{11}	34.59% W_{11}	Clarity M_{111}	17.3% W_{111}
				Relevance M_{112}	17.3% W_{112}
		Rendering of Learning Frame M_{12}	29.95% W_{12}	Scenario Design Frame M_{121}	6.98% W_{121}
				Problem Design Frame M_{122}	16.84% W_{122}
				Resource Tool Frame M_{123}	4.17% W_{123}
				Q&A Support Frame M_{124}	1.96% W_{124}
		Management of Learning Process M_{13}	3.61% W_{13}	Organizational Orderliness M_{131}	1.2% W_{131}
				Time Controllability M_{132}	2.41% W_{132}
		Scientific Evaluation of Students M_{14}	4.84% W_{14}	Completeness M_{141}	0.96% W_{141}
				Comprehensiveness M_{142}	1.51% W_{142}
				Objectivity M_{143}	2.37% W_{143}
Outcome Evaluation M_2	27.01% W_2	Project Goal Attainment M_{21}	12.98% W_{21}	Scientific Principle Attainment M_{211}	4.33% W_{211}

				Project Completion Attainment **M_{212}**	8.65% **W_{212}**
		Growth Goal Attainment **M_{22}**	14.03% **W_{22}**	Ability Goal Attainment **M_{221}**	9.35% **W_{221}**
				Educational Goal Attainment **M_{222}**	4.68% **W_{222}**

The overall situation of the STEM classroom teaching (TE) is the sum of the product of module and weight at each level, which can be expressed by the formula below:

$$\textbf{TE}= \sum_i^n \sum_j^m \sum_k^o W_{ijk} \times M_{ijk}$$

where, i,j,k∈ N; n,m,o∈ N (natural number in the range of values) (TE)

In this model, TE1=72.99% × process evaluation + 27.01% × outcome evaluation.

(3) STEM Classroom Learning Evaluation Model for Primary and Secondary Schools

The STEM learing evaluation model is similar to the teaching evaluation model. A hierarchical analysis and the AHP method was used to comprehensively process the data results and obtain the expert comprehensive judgment matrix. The consistency test results of the judgment matrix showed CR=0.0542<0.1 in the STEM classroom learning evaluation scale, indicating that the consistency test has passed.

Table 2. STEM Classroom Learning Evaluation (SE) Scale

STEM Classroom Learning Evaluation Scale					
First-level Module M_i	**Weight W_i**	**Second-level Module M_{ij}**	**Weight W_{ij}**	**Third-level Module M_{ijk}**	**Weight W_{ijk}**
Process Evaluation **M_1**	72.25% **W_1**	Problem Identification **M_{11}**	39.25% **W_{11}**	Authenticity **M_{111}**	23.55% **W_{111}**
				Value **M_{112}**	7.85% **W_{112}**
				Ethics **M_{113}**	7.85% **W_{113}**
		Solution Design **M_{12}**	9.92% **W_{12}**	Process Design Creativity **M_{121}**	1.62% **W_{121}**
				Resource Application Creativity **M_{122}**	5.34% **W_{122}**

				Tool Application Creativity $\mathbf{M_{123}}$	2.95% $\mathbf{W_{123}}$
		Problem Solving $\mathbf{M_{13}}$	23.08% $\mathbf{W_{13}}$	Implementation Feedback $\mathbf{M_{131}}$	7.69% $\mathbf{W_{131}}$
				Collaboration and Sharing $\mathbf{M_{132}}$	15.39% $\mathbf{W_{132}}$
Outcome Evaluation $\mathbf{M_{2}}$	27.75% $\mathbf{W_{2}}$	Project Goal Attainment $\mathbf{M_{21}}$	13.88% $\mathbf{W_{21}}$	Attainment $\mathbf{M_{211}}$	7.48% $\mathbf{W_{211}}$
				Timeliness $\mathbf{M_{212}}$	4.12% $\mathbf{W_{212}}$
				Energy Consumption $\mathbf{M_{213}}$	2.27% $\mathbf{W_{213}}$
		Growth Goal Attainment $\mathbf{M_{22}}$	13.88% $\mathbf{W_{22}}$	Fostering Virtue through Education $\mathbf{M_{221}}$	6.81% $\mathbf{W_{221}}$
				Mental Quality $\mathbf{M_{222}}$	2.74% $\mathbf{W_{222}}$
				Learning Satisfaction $\mathbf{M_{223}}$	4.33% $\mathbf{W_{223}}$

The overall situation of the STEM classroom learning (SE) is the sum of the product of module and weight at each level, which can be expressed by the formula below:

$$\mathrm{SE}=\sum_i^n \sum_j^m \sum_k^o \left(W_{ijk} \times M_{ijk}\right)$$

where, i,j,k∈ N; n,m,o∈ N (SE)

In this model, SE1=72.25% × process evaluation + 27.75% × outcome evaluation.

$$\mathrm{TE'}= \sum_i^n \sum_j^m \sum_k^o \mathrm{W_{ijk}} \times \mathrm{M_{ijk}} \div \sum_i^n \sum_j^m \sum_k^o \mathrm{M_{ijk}} \times 100$$

where, i,j,k∈ N； n,m,o∈ N (natural number in the range of values) (TE' is a percentage conversion score on the STEM Classroom Teaching Evaluation Scale)

$$\mathrm{SE'}= \sum_i^n \sum_j^m \sum_k^o \mathrm{W_{ijk}} \times \mathrm{M_{ijk}} \div \sum_i^n \sum_j^m \sum_k^o \mathrm{M_{ijk}} \times 100$$

where, i,j,k∈ N; n,m,o∈ N (natural number in the range of values) (SE' is a percentage conversion score on the STEM Classroom Leaning Evaluation Scale)

III. Analysis of STEM Classroom Teaching and Learning Evaluation Scale for Primary and Secondary Schools

The main battleground of education has always been the classroom, and STEM education is no exception. Therefore, the evaluation system was positioned in the classroom first.

1. Interpretation of STEM Teaching and Learning Evaluation Scale 2.0 Indicator System for Primary and Secondary Schools

(1) STEM Classroom Teaching and Learning Evaluation Scale 2.0 Indicator System

Table 3. STEM Classroom Teaching Evaluation Scale for Primary and Secondary Schools

First-level Indicator	Second-level Indicator	Third-level Indicator	Scale	Evaluation
Process Evaluation	Design of Teaching Objectives	Clarity	Clearly describe the scenarios of enlightening problems, so that teachers can accurately grasp their STEM educational connotations. (10 points)	
			Competency goals reflect the development of creativity, knowledge construction, analysis and problem solving, communication and cooperation, and exploratory learning abilities (10 points)	
			The STEM program reflects the development of a positive personality, correct values, outlook on life, and worldview. (10 points)	
		Relevance	The teaching objectives are relevant and slightly improved with the knowledge structure, physiological and psychological characteristics, and cognitive level of students in the school section, and conform with the theory of the Zone of Proximal Development (10 points)	
			The STEM curriculum is relevant with the school scenarios, school-based curriculum, and comprehensive practical activities. (10 points)	
	Rendering of Learning Frame	Scenario Design Frame	Scenario design is based on real environment, so that real problems can be solved (10 points)	
			The project implementation frame is designed to be lively, which can stimulate students' enthusiasm for exploration (10 points)	
		Problem Design Frame	The problems created are challenging and inspiring, so as to train and develop students' design thinking and creative thinking (10 points)	
			The design of the problem solution is scientific, feasible and logical (10 points)	
		Resource Tool Frame	The learning resources and technology tools provided are relevant with the courses and effectively address the course needs (10 points)	
			Teachers are familiar with technology applications such as lab equipment, programming, 3D, AR, VR, etc., and are skilled in instructing students to use such applications. (10 points)	
		Q&A Support Frame	Teachers can pay attention to and motivate each student's learning performance in a timely manner (10 points)	
			Teachers are able to guide students to think deeply, explore with them, and clear up doubts and questions	

Table 4. STEM Classroom Learning Evaluation Scale for Primary and Secondary Schools

First-level Indicator	Second-level Indicator	Third-level Indicator	Scale	Evaluation
	Problem Identification	Authenticity	Develop a problem perspective, identify real problems from scenarios and form projects. (10 points)	
			Be diligent in housework, production, public service activities and social practices, and ask questions to reform, improve, and innovate these practices (10 points)	
		Value	The formation of STEM projects is valuable for improving life, learning and work (10 points)	
			The proposed STEM project itself is meaningful and creative (10 points)	
		Ethics	The questions posed are ethical and legal (10 points)	
	Solution Design	Process Design Creativity	Be able to think about designing an architecture diagram for an effective solution to the STEM project (10 points)	
			Have a clear idea of how to design a problem-solving architecture diagram, be good at integrating problem solving through multidisciplinary knowledge, and develop a high degree of creativity (10 points)	
		Resource Application Creativity	Develop excellent information literacy, and gather effective resources from different sources to research solutions (10 points)	
			Be able to explore new values of resources from inherent resource frames and apply them creatively (10 points)	
		Tool Application Creativity	Apply tools and equipment rationally based on the solution configuration technology under a rich pedagogical frame (10 points)	
			The application of new technologies is more conducive to STEM project problem solving (10 points)	
	Problem Solving	Implementation Feedback	Be proficient in using technology during STEM experiments, and validate their designed solutions (10 points)	
			Be adept at applying interdisciplinary knowledge to solve problems or unexpected situations that arise during the implementation of STEM projects, have clear ideas for implementing solutions, and complete tasks efficiently (10 points)	
		Collaboration and Sharing	Have a clear division of labor in collaboration, and actively take on STEM project tasks (10 points)	
			Respect the ideas and achievements of others in peer support (10 points)	
			Be willing to share and present STEM ideas and work in the implementation of the program (10 points)	
			Be willing to express themselves, seek scientific	

Scoring Note: To facilitate teachers' scoring, each scale is calculated by 10 points. Finally, the evaluation system will automatically calculate the teachers' STEM literacy score and students' STEM literacy score based on the set formula.

1. Interpretation of STEM Teaching and Learning Evaluation Scale Indicator System

(1) Interpretation of First-level Indicator

The first-level indicator of both evaluations consists of the process evaluation and the outcome evaluation, which are continuous monitoring of STEM learning behaviors and STEM teaching behaviors. Through process observation, the researchers are able to grasp the development of teachers' and students' abilities, identify difficulties, and adjust pedagogy and contents in time to make teaching more consistent with students' cognitive patterns. In addition, data analysis also forms the STEM competency development curves of teachers and students, which provides a basis for decision making to improve teaching and learning. *(2) Interpretation of Second-level Indicator*

The STEM classroom is different from the ordinary classroom in the following "five shifts": the shift from teacher-centered to student-centered; the shift from effective "teaching" to facilitating "learning"; teacher's shift from classroom ruler to designer and organizer of students' learning activities; teacher's shift from the knowledge transmitter to the provider of students' learning frame as well as the guide and facilitator of learning activities; teacher's shift from the evaluator of students to the constructor of learning outcome evaluation system. Therefore, the teaching evaluation scale and learning evaluation scale in terms of second-level indicators are clearly different.

The teaching scale is evaluated from six perspectives: design of teaching objectives, rendering of learning frame, management of learning process, scientific evaluation of students, project goal attainment and growth goal attainment, reflecting whether teachers have played their roles as organizers, guides, facilitators, and evaluation constructors. In contrast, the learning scale is evaluated from five perspectives: problem identification, solution design, problem solving, project goal attainment and growth goal attainment, reflecting whether students have developed independent learning, creativity and growth abilities under the guidance of teachers.

(3) Interpretation of Third-level Indicator

According to "Bloom's Taxonomy of Six Cognitive Levels", memory, comprehension and application are weak human abilities, which belong to superficial memory; only when memory begins to learn to analyze, evaluate and even create, it belongs to higher-order thinking or deep thinking. Therefore, STEM classroom teaching is to cultivate students' higher-order thinking. There are 15 third-level indicators in the teaching scale and 14 third-level indicators in the learning scale. What's more, the organic combination of teachers' ability level and students' ability enhancement fully reflects the six characteristics of PBL project-based learning of STEM curriculum teaching, which not only guides the development direction of STEM teaching and learning, but also realizes mutual benefits.

(4) Scale Analysis

In 2014, the International Technology and Engineering Educators Association proposed the popular "6E Learning byDeSIGN" for the STEM teaching after numerous researches and practices. This pedagogy mainly includes six processes: "engage", "explore", "explain", "engineer", "enrich", and "evaluate". The third-level indicators have been integrated into the five levels of STEM teacher competency standards as well as norms and requirements for STEM classroom teaching issued by the National Institute of Education Sciences of China, so the scale is a good explanation of the 6E teaching process. Through the pedagogical exploration of "6E Learning byDeSIGN" in STEM education, it not only stimulates students' learning initiative and participation, promotes the integration of knowledge among different disciplines, and develops their problem-solving skills in real situations, which lays a solid foundation for students to adapt to future social development and personal life needs.

(5) Analysis of Evaluation Method

Evaluators include teachers, students, student groups, or parents, depending on the need for collaboration in the STEM and creative practice process. The evaluation form consists of teacher self-evaluation, teacher mutual evaluation, teacher evaluation of students, student self-evaluation, student mutual evaluation and student evaluation of teachers. Besides, expert evaluation of teachers and expert evaluation of students are adopted during competitions; parent evaluation of teachers and parent evaluation of students can also be applied during the open day. Furthermore, the combination of multiple dimensions and diversity makes evaluation a value-added process of multi-party cooperation and mutual promotion.

2. Reliability and Validity Tests of STEM Classroom Teaching and Learning Evaluation System

"STEM Classroom Teaching Evaluation System" and "STEM Classroom Learning Evaluation System" were experimented for almost a year. Based on the previous literature analysis, the reliability and validity tests were conducted. The questionnaire contents were sorted according to the order of the indicators of the STEM classroom teaching and learning evaluation scales, so as to ensure the fit between the questionnaire structure o and the research content. A total of 213 questionnaires were recovered from 38 cities in 10 provinces across the country. Also, the SPSS software was used for questionnaire analysis.

Table 5. Data Analysis of Recognition of the STEAM Classroom Teaching Evaluation System

	Design of Teaching Objectives	Rendering of Learning Frame	Management of Learning Process	Scientific Evaluation of Students	Project Goal Attainment	Growth Goal Attainment
α Reliability Coefficient	0.964	0.978	0.963	0.970	0.931	0.972

Table 6. Data Analysis of Recognition of the STEAM Classroom Learning Evaluation System

	Problem Identification	Solution Design	Problem Solving	Project Goal Attainment	Growth Goal Attainment
α Reliability Coefficient	0.969	0.983	0.985	0.919	0.937

Table 7. KMO and Bartlett Tests

KMO Value		0.953
	Approximate chi-square	23687.154
Bartlett's Test of Sphericity	Df	1225
	p value	0.000

According to the above table, the reliability test result of this questionnaire is higher than 0.9, showing a high overall reliability. This indicates that this questionnaire is reasonable and valid with a certain stability and reliability, and the data obtained is also reliable.

IV. STEM Classroom Teaching and Learning Evaluation Tools and Application Scope of Evaluation

In this study, a dynamic STEM whole process evaluation system was developed to maximize the value of evaluation. The evaluation system was used to conduct on-site evaluations during each seminar. Besides, the researchers made on-site comments based on the analyzed data, and after each seminar, teachers wrote teaching reflections and students wrote learning reflections based on the data analysis, thus truly bringing into play the evaluation, guidance and motivation functions of evaluation.

Due to the maturity of STEM classroom teaching and learning evaluation scale and advanced evaluation tools, the STEM teaching and learning evaluation begins to play an active role in STEM education activities. For instance, it is used for STEM teachers' daily classroom teaching to reflect the guiding significance; for evaluating the regional STEM education level, with the evaluation value; for selecting STEM seed teachers to give full play to the selection function; for evaluation of STEM classroom teaching competition, with the function of evaluation.

At present, the proposed STEM classroom teaching and learning evaluation system and evaluation tools have been recognized by the National Center for Educational Technology of China and promoted nationwide. However, the research on STEM teaching evaluation still has a long way to go, and it is necessary for researchers to constantly consolidate the research foundation and strive for perfection. The author looks forward to touching the core of STEM education under the leadership of international STEM experts, so that STEM will become a cradle for cultivating creative talents.

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AN ETHNOGRAPHIC STUDY OF VIDEO TECHNOLOGY USE IN SMALL BUSINESS DEVELOPMENT IN WESTERN NEW YORK

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ABSTRACT

This study reports on graduate students' learning experiences with STEM. These graduate students filmed and created short videos as their course projects for the development of a small family restaurant. Through this community engagement and business developing experience, students not only gain solid knowledge and skills in the filming and publishing process, but also learn the value of communication and cooperation. They have established connections with the community and are able to develop their skills and confidence in contributing the knowledge they learn in the course to the real society. An ethnographic approach was applied in this study to analyse the video data. Research findings indicate that students are committed to solving practical problems that make academic learning meaningful and enhance their social skills, analytical skills, and career development.

Keywords: *ethnographic study, ADDIE, video technology*

INTRODUCTION

The purpose of this case study is to explore how the digital video technology can be used to promote the development of small businesses. In recent years, the development and application of video technology has penetrated into people's daily lives. Although video technology has been applied to the development of small businesses, there are not many people who conduct research in this area. How to combine video technology with the development of small businesses is a convenient method for technology and society. Video technology can help people break through the barriers of communication and clearly communicate powerful information.

During a graduate course, the students decided to create video projects for a small Burmese family restaurant on their request for improving the custom flow. The owners of the restaurant came from Burma as refugees. They would like to have a video published on youtube.com to attract more customers. But they did not know how to make a professional video. So the students came to meet their needs and also this project idea matched the requirement of the course curriculum.

This study focuses on the research question: **"How to connect STEM learning with doing in the real world?"** The study examines how the learning experience of video technology was connected into the application of the local community.

Often many companies fail not because they do not have good management, excellent services and products; but they do not know how to represent their organization value, how to promote the image of the company, therefore, to further develop the business. At the same time, how to focus on the promotion of the business feature is also the key to business development. Customer positioning can focus on the use of the available resources to attract customers to consume and promote corporate image. Through conversations with owners and observations of multiple field trips, the researchers found that most of the customers who came to the restaurant before the video was produced were new immigrants living nearby, and many are low-income people from Southeast Asia. The restaurant owners wanted to attract more people of diversity to come to the restaurant. For example, they would like to attract more middle-income people from other neighbourhood communities, tourists visiting the Buffalo area, and some middle-class families. The owners also provided different price ranges for different customer groups, they also wanted the customers feel at home in the restaurant. The researchers interviewed and asked the owners, employees, and customers to find out how they felt about the restaurant and how they thought about highlighting the restaurant's characteristics and introducing the restaurant to others.

The owners believe that the support between their families is the key to their success and the key to allowing guests to eat and build trust. This is also confirmed by the feedback from customers, many of whom are attracted by this close relationship between the owners' family. Southeast Asia is located in the tropics, mostly in the rainforest environment, so there are many spices and fruits and vegetables used in the ingredients. Their food is bright and colorful. And these can be expressed through video. Bringing this information together and showing it through video in a limited amount of time is the purpose of the video project. The owners hope to increase the restaurant's customer flow through this video production.

LITERATURE REVIEW

Although video technology is ubiquitous in practical applications, and even many businesses use video technology to help business development, for instance, Shaikh, Hada and Shrestha (2018) found that digital video advertising was more efficient than television advertising, there is still very little research on the application of video technology in business development. One of the reasons is that because of the rapid development of science and technology in recent years, research has not kept pace with the application. People use video technology mainly in communication, and the purpose of businesses using video technology in business development is to promote their own value to attract customers and investors. In a 2011 study, researchers at Minot State University mentioned "forms of electronic communication (as Websites for social networking and blogging) through which users create online communities to share information, ideas, personal messages, and Other content (as videos)," in the role of "the exchange of information or services among individuals, groups, or institutions; specifically: the cultivation of productive relationships for employment or business" (Edosomwan et al., 2011).

Video feedback can deepen understanding and promote interpersonal communication. Through video technology, people can deepen the processing of information through sound, image and interaction (Mills & Pace, 1989). Through the application of video, people can watch videos repeatedly to repeat memories and deepen memories (Faux, 2008). The survival of the businesses lies in the embodiment and promotion of the business value, so business development is to maximize the value. The emergence of video technology helps people to combine visual information and auditory information to deepen people's processing and memory of information. The establishment of value for people is to repeat important information continuously, to generate trust and to treat this information as the primary. The primary information is the embodiment of value. Active listening and observation, often requiring detailed and clarified content, can help overcome cross-cultural challenges to build trust. It is important to listen to the key ideas and common themes among members, and the ability to frame messages is also important. Vision complements the details that can't be noticed during listening, such as the expression of a person's face or the background of the surrounding environment. The framework involves the perspective of others. In creating a supportive communication climate, responsiveness is as important as the original information being sent, which encourages security to share ideas and take risks that lead to innovation early in the development of ideas (Gibson & Cohen, 2003).

The video can actually record the process of the event, and can also reflect the details of the scene environment. Through the playback of the event process, and the details of the scene environment, people easily release their emotions to establish a memory association (Deep et al., 2010). One of the main advantages of using video technology is that it increases the depth of existing information while providing a clear, simple structure of information. Therefore, it can naturally adapt to the level of competence of various employees who learn through the system. Moreover, it combines the narrative and interactive features of the video with other relevant information, even when introducing routines (Petan, Petan, & Vasiu, 2014).

RESEARCH DESIGN

An ethnographic approach was employed for detailed interpretations of video tapes and analysis of video interviews, reflections, which reviewed students overall cognitive awareness and communications among the class members and the instructor, the owners of the restaurant and the customers at the restaurant. Ethnography is the branch in which different cultures are studied and described. Ruby (2005) suggested that the ethnographic approach, as the cultural study of video media and as an inclusive anthropology of visual communication, has become increasingly commonplace in training programs and in business. The quick general acceptance of this approach bodes well in educational research. The video ethnographic approach honors not only the objects of our attention, but mostly the real person with face and name and body that articulates her or his cultural experiences and learning process in shareable forms (Guo, 2009). A major difference between ethnographic and other research methods is the depth and intimacy of the subject under study.

Data Sources

In this study, the data collection includes student course work, filed trips, interviews, observations of class activities, video projects and student reflections. Another site is a local small business “Lin Restaurant”, established by a refugee family from Burma, where students had an chance to deepen their understanding of Myanmar culture and their perception of the business’s value, and break through language barriers to help restaurants promote their business development.

Curriculum Design

The ADDIE model was used as a framework in this case study for the curriculum design. ADDIE is an acronym for the five steps of the design process; analysis, design, development, implementation and evaluation. The first two sections of this research project have addressed the analysis portion of the ADDIE model. That includes identifying the problem, learner needs, and the time frame in which the content should be taught. The next portion of the model focused on how the material was designed, developed, implemented and evaluated.

ADDIE Model: Analysis

The nine students from the graduate course EDT610 were divided into two groups and asked for a field interview with Lin Restaurant in Buffalo Westside. Through multiple interviews, the students gathered and analyzed the information. Each group of students was required to create a video at the end of the semester based on their best information to help Lin Restaurant promote their business. Most of the students come from local Caucasians, so there are some communication barriers in terms of culture and language when helping the owner's families from Burma. Students also need to collect useful information through other means, as far as possible to record the interview process, such as through social media and other immigrants from Southeast Asian countries.

Design

Students are required to enhance their technical communication skills through this video project. With their knowledge in their respective fields, they would help local community cultural integration and economic recovery through the curriculum organization. Help students to communicate technically with people from other cultural backgrounds through the production and application of video making skills in the course. Use the skills learned in the course to strengthen students' communicative skills and overcome difficulties in communication barriers. The students were first told about the project and will have to help Lin Restaurant to expand their business. Students went to restaurants and talked to the owners of the restaurant to learn about their culture and their food. Then through the online search engine and social media the students gained further understanding of Burmese culture and living habits and sort out their interview questions. In the next few field trips, the students will ask questions and interview the owners. They will deepen the understanding of the family background and culture of the owners and to further understand the restaurant's advantages in location selection and food handling. After returning to the classroom to exchange ideas and sum up experience, the students decided to make videos to post advertisements focused on the people who do not came from Southeast Asian cultural background to help promote the business by highlighting cultural characteristics and dietary advantages.

Development

The students sorted out the information collected by their respective groups and edited the story lines of their respective videos. Through different story lines, the two groups of students evaluated each other’s work. In the classroom, the two groups of students scored each other's work and gave constructive comments. Then the respective groups further revised and modified their own works, and finally submit the works to the operators and then made final corrections to their needs for advertising. Finally, the final version was published as an advertisement on social media.

Implementation

Students teach each other according to their respective backgrounds and promote teamwork by teaching their technical knowledge to other students. In the process of teamwork, different students had taught others new tools. These tools included picture in picture, green screen and iTunes Mac screen filming. With these tools, students can better refine their work. At the same time, students also use the network's AI translator to help them communicate better with people of different languages. Finally, students then publish their own videos in social media as an advertisement.

Evaluation

Students communicated with each other throughout the project phases to evaluate the work and then continued to improve according to the needs of the owners. When the students and the professor thought that each group of students' works were in line with the technical standards, they gave the video projects to the owners for the final evaluation, the final version was determined by the needs of the owners and the course requirements.

RESULTS AND DISCUSSION

Lin Restaurant is located in the Buffalo Westside with a large number of new immigrants and refugees. Therefore, customers who go to restaurants come from all over the world. In order to produce videos, the students in the class conducted a field trip, visited the community to collect data, and then divided into two small groups to create and publish two videos for Lin Restaurant.

Some students went to the restaurant several times to collect data separately and met employees and customers. Students were gratified that they shared their data and interviews in class. In addition, we organized the entire class as a group site visit and arranged group interviews with employers, employees and customers. Students got enough information for video production. From these experiences, students realized that they needed to organize skills and technical exchanges to reach out to the community. They learned how to serve others through participation, communication and understanding.

***Figure 1*. Location of Lin Restaurant**

Near Lin Restaurant is one of Buffalo Westside's beautiful attractions, Riverside Park, which is located on the banks of the Niagara River. The owners chose the location of Lin Restaurant here was for the beautiful scenery around, and also for the reason that the restaurant is close to the Burmese community in this area. In this beautiful environment, the interior design is elegant, and the dining environment makes people feel relaxed.

***Figure 2.* Student interview with the owner**

Students took a few field trips to interview the employers, employees and customers. There are a lot of businesses in Buffalo Westside that are family owned, and the Lin restaurant is one of the family businesses. Their owners, employers and employees are mostly from the same families. The curiosity of customers towards Southeast Asian culture and the attraction of the temperament of Buddhist values are one of the main reasons why they choose to come to restaurants. While creating the video, the students put the text on the video in order to help viewers better understand the owner's recording.

***Figure 3*. The display of Burmese culture and value**

The owners embody their values through daily life and the operation of restaurants, making the restaurant with special the characteristics and Burmese culture. They attract customers by presenting the cultural characteristics of Southeast Asia, while demonstrating the qualities of Buddhism and peace of mind to make customers feel at ease.

Figure 4. **The restaurant's working environment and food**

Many customers are allured by the dining environment and ingredients of the Burmese food. The environment here is quiet and elegant, allowing people to relax and enjoy the food. These ingredients are imported directly from Southeast Asia and carefully selected by the owners for cooking.

Figure 5. **Green screen to edit information**

In the production process, the students added the introduction section using the green screen feature to make the video professional and informative. The students used the green screen technique to use the background to add images that were not in the original recorded shot. The scenes that were added were shot in front of a green background, and then was merged into the background image or video.

CONCLUSION

Prior to this study, most of the students had not any experience in using video technology. Yet, once they became committed to the project, the students were motivated to learn from the instructor, and from the collaboration that developed among their peers. At the very beginning of the semester, none of the students understood how the project was going to be completed. Through the video project, they built solid skills of video technology design and creation. Learning from doing is proved to be an effective learning strategy. After the video was published on youtube.com, the owners repeatedly indicated that customers have been growing even the prices of the dishes have been increased 20% compared to the price before the video was created.

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SITUATED LEARNING TOWARD C++ PROGRAMMING LANGUAGE ACQUISITION

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ABSTRACT

Programming language is notoriously difficult to learn and teach. Learning C++ programming language can be a boring and painful experience for many beginners. This study focused on how to guide students to effectively learn a C++ computer programming language. The study examined the pedagogical approach of situated learning theory, which requires social interaction and collaboration within the learning community. Over the course of four semesters—with 21 to 24 students in each course—the authors looked at various approaches, including teacherled instruction, Cengage's MindTap online learning tool, and software such as DEV-C++ and CODE:BLOCKS. The authors analysed and compared students' assignments, outcomes of exams, and course drop-out rates. Findings reveal that a situated learning environment provides an effective way for students to learn C++ programming.

Keywords: *STEM education*, *C++ programming, situated learning theory*

INTRODUCTION

Research problem

Learning programming C++ can be a boring and painful experience for many students, particularly for beginners. Although, typically, there are tutors available for programming students at both the institution and department levels, students face considerable challenges during the learning process, and some of them end up dropping the course. When this happens, questions such as "how to encourage students to continue to learn C++ programming?" and "how could the learning objectives of the course be better achieved?" emerge.

Purpose of research

The purpose of this study was to examine teaching and learning strategies and tools for students who are taking an undergraduate entry-level C++ programming course. Learning how to program a computer seems to be a key competency in STEM education nowadays.

The course under study is *'CIS 151: Information Processing I'*—an introductory course in C++ programming and a required course for first-year computer information systems (CIS) students. Topics in the course include: basic introduction to computers; concepts of languages and programming; basic properties of computer languages, such as branching, looping, array handling, subprograms and functions; and their application to the solution of a variety of problems. The emphasis is on structured programming techniques.

Research question

This study focused on the following research question: *'How can an effective learning environment be created for students so as to enhance learning outcomes in a C++ programming course?'*

LITERATURE REVIEW

Herrington & Oliver (2000) noticed that the instructional technology community has been in the midst of a pedagogical shift from a behaviorist to a constructivist framework, a move that might begin to address the importance of authentic learning. *Situated learning theory* promotes authentic learning: It is an instructional theory based on the work of John Dewey (1938) and Lev Vygotsky (1934, 1978), who claimed that students learn in an environment where they are able to put learned theory into practice by solving problems in a real-world setting.

Situated learning theory maintains that knowledge should be delivered in an authentic context, and that beginning learners should be involved in authentic settings of daily practice, applying knowledge, and making use of the learning process in productive but low-risk ways.
This usually requires social interaction and collaboration within a 'community of practice'. Later, learners gradually move away from this community to become engaged in more dynamic and complex activities, and transition into the role of the expert (Lave & Wenger, 1991).

While some theorists regard knowledge acquisition as a solitary and individual pursuit, others have observed that learning only occurs in social situations and practices (Besar 2018; Dewey, 1938). Also, while some theorists see learning as the passive acquisition of facts and knowledge, others see it as active participation in a constructivist learning environment.

METHODOLOGY

Action research was applied in this study. The intent is to obtain insight, develop reflective practice, make effective changes in the educational environment, and improve student learning outcomes (Mills, 2011). The action research process is illustrated in Figure 1.

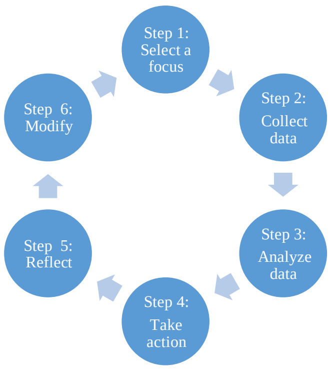

Figure 1: Action research methodology.

Research site and sample

The research site was a 4-year comprehensive university located in Western New York State, U.S.A. A convenience sample of 93 students enrolled in four sections (spring 2018 to fall 2019) of the course CIS 151 was used. This included: 23 students in spring 2018 semester; 24 students in fall 2018; 22 students in spring 2019; and 24 students in fall 2019 semester.

Action research process

In the current study, an iterative instructional design approach was used to design and implement different methods and tools over the four semesters, and also to examine how situated learning might best be implemented. Table 1 shows how the course evolved over the four semesters.

Course Semester	Teaching/Learning Strategy Used	Learning Tool(s) Used	Other Characteristics	Learning Outcomes
Spring 2018	Traditional instructorled instruction	Dev-C++ software, Textbook, PPTs, paperbased coding assignments	Pair programming (students working in pairs)	Most students were struggling
Fall 2018	Traditional instructorlet instruction	Dev-C++ software, Textbook, PPTs, paperbased coding assignments	Pair programming (students working in pairs)	Most students were struggling
Spring 2019	Situated learning	Dev-C++ software, Textbook, PPTs, paperbased coding assignments, along with MindTap, more learning resources	Pair programming (students working in pairs), group work, active participation	Improved, Students were less stressful
Fall 2019	Situated learning	Dev-C++ software, Textbook, PPTs, paperbased coding assignments, along with MindTap, more learning resources	Pair programming (students working in pairs), group work, active participation	Improved, students are more engaged and more confident.

Table 1: Instructional design of course over four semesters.

Data collection and analysis

Data collected included: classroom observation of students, verbal feedback from students, student assignment and exam results, and course final grades. Data was analysed via data review and reflective discussions with students and other instructors.

RESULTS AND DISCUSSION

In the first two semesters, the instructions focused on traditional teaching using DEV-C++ or Code::Blocks and the textbook "C++ Programming: From Problem Analysis to Program Design (8th edition)" by D. S. Malik (2018). This course covers much of the content contained in the Chapters 1-8 of the textbook.

In the last two semesters, situated learning approach was adopted due to the adoption of the online learning tool Cengage's MindTap. With MondTap, students can access to the digital book by D.S. Malik in addition to many other online resources: such as a video to show a programming example, interactive flashcards on main concepts and even the ReadSpeaker function for the textbook. The students can get instant feedback before they submit their programming codes or after they submit their test. However, the grading system of MindTap only accepts only one way of coding for the assignment while in reality there are many ways of coding for any programs. So the situated learning approach allows students to be engaged in an authentic learning environment by using the software DEV-C++ or Code::Blocks and by working together as a team. In the situated learning environment, the students can easily meet the objectives of the course syllabus and gained a wide range of learning experiences.

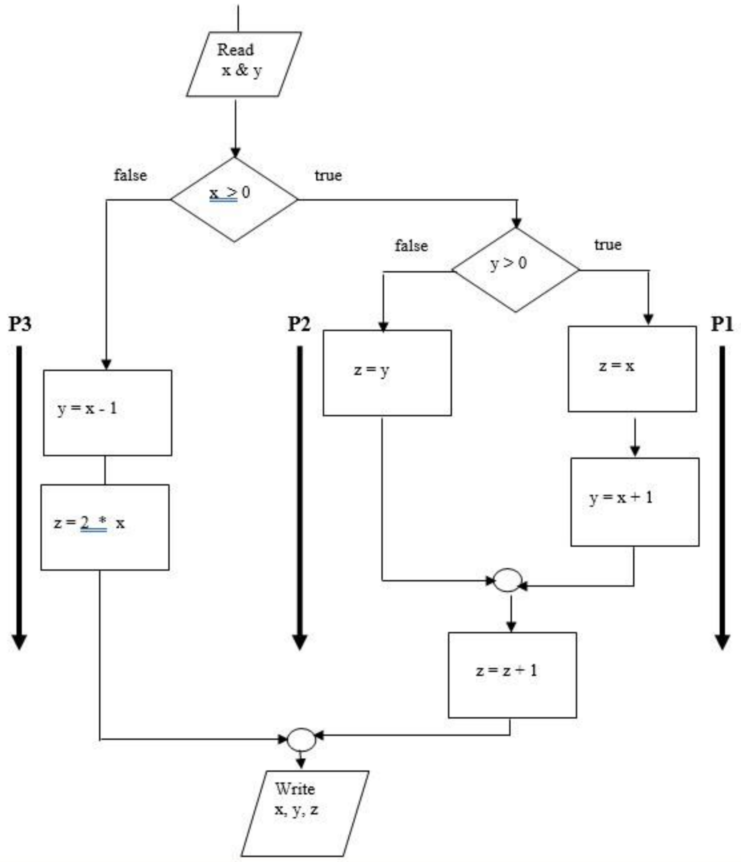

Figure 2: Assignment in CIS151 curriculum completed using situated learning.

In many programming work environments, the programmers must cooperate and work as a team. Figure 2 is a sample assignment from the course curriculum. In this 'IF Statement' assignment, students are asked to write a program based on the flowchart. At first, most students felt intimidated to complete this assignment alone. So the class members were divided into five big groups and each group worked on a part of the project. Each group brainstormed together and presented their proposed coding to the class together. The following group then had to check if the preceding group's code was correct, before they could continue. Then, at the end, a complete solution was written together by the whole class.

After class, the students formed into pairs to write the program from the beginning to the end in order to digest the whole process of what they learned. Afterwards, the students reflected that they were fortunate to be able to learn this difficult subject in such an enjoyable manner. They felt that it was fun to work together and be able to reinforce the learning process. The students increased their interest in learning and their learning outcomes were improved as well.

CONCLUSION

In a situated learning environment, students can obtain the knowledge and skills relevant to a real working environment. They are able to learn and complete more challenging work with their peers. In the current study, situated learning supported beginning learners to acquire the knowledge of the C++ programming language more effective. Findings revealed that the students enjoyed the process of situated learning and improved their learning outcomes. Such opportunities can help students to make meaning of their classroom learning experiences and help to bridge the gap between their classroom learning and their future careers in STEM fields.

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MOTIVATIONAL AND CHALLENGING FACTORS THAT CONTRIBUTE TO GENDER IMBALANCE IN POST-SECONDARY COMPUTER SCIENCE EDUCATION

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ABSTRACT

STEM education and careers and especially computer science (CS), engineering and technology are male dominated. Programs in post-secondary institutions and the workforce struggle with gender imbalance. Efforts are being made to reduce the gender gap; however, this problem has deep roots in sociocultural circumstances. In this paper we examined motivational and challenging factors that influence students of different genders to pursue post-secondary CS education. In order to gain a comprehensive understanding of how students' experiences vary across gender, we interviewed not only female but also male and transgender students. This study employed a qualitative methodology based on indepth semi-structured interviews with 21 participants recruited from a postsecondary computing program: 13 women (two of which identify as transgender) and eight men. Data was analysed in an iterative process by a team of coders using the MAXQDA software package. The data suggest that there are no differences between genders in interest and passion for CS, and in perceptions of short or long-term rewards for a career in this field. However, important differences were found with respect to self-image and identity as female participants were subjected to stereotypes and harassment. Additionally, female identifying participants reported higher personal costs and sacrifices than the male participants.

Keywords: *STEM post-secondary education, gender imbalance in STEM education, computer science postsecondary education, motivation, LGBTQ*

GOALS AND OBJECTIVES

At our post-secondary institution, the number of female students enrolled in computing undergraduate programs is very low: the September enrolment between 2015 and 2018 was 10.9 -14.6%. These numbers are lower than the 21.6 - 22.75% percentage of women enrolled in computer science and software engineering majors programs in a university from the same geographical region in the same time period. Even if in the last decade studies and initiatives were focused towards solving the gender inequality in STEM and computer science education, women continue to be under represented (Cheryan, Plaut, Handron, & Hudson, 2013; Hill, Corbett, & St. Rose, 2010; Lazarides & Ittel, 2015; Robnett, 2015). A recent comprehensive examination of women's persistence in STEM over the course of undergraduate or graduate studies conducted by Statistics Canada found that "women's representation is lowest in the engineering and computer science fields, where the large majority of science and technology jobs are concentrated" (Wall, 2019, p. 2). The same study also found that

“women in each STEM field of study were equally or more likely than men to persist in their initial field of study, and completed their STEM undergraduate degrees more rapidly than men” and therefore the “lower enrolments in STEM programs at the start of their postsecondary education” are responsible for the gender gap (Wall, 2019, p. 10).
This paper is derived from a larger study aiming to identify strategies, instructional models, and technological tools that can be used to motivate girls and women to pursue STEM/CS education and careers. We will focus in this paper on identifying how gender affects students’ career choice and experience in a computing and technology undergraduate program. The research question to be answered was:

What motivational and challenging factors influence students of different genders to pursue CS post-secondary education?

THEORETICAL FRAMEWORK

There are several sociocultural factors that affect women’s STEM/CS career choices. Related literature revealed that women are exposed to stereotypes threats, for example the perception of girls’ low math abilities which is enforced by parents and teachers (Gunderson, Ramirez, Levine, & Beilock, 2012). Even if girls or women have positive attitudes towards math or report that they do not believe in stereotypical views, the stereotype threats can influence negatively their attitudes towards STEM subjects (Hill et al., 2010; Shapiro & Williams, 2012). However, research suggests that making women aware of negative stereotypes can help them improve their performance, and that successful interventions should focus on teaching active coping mechanisms in response to gender bias (Robnett, 2015). Women lack confidence: in a study of gender differences in CS, Beyer et al. found surprisingly that “women’s computer confidence was much lower than men’s, even when we statistically controlled quantitative ability. In fact, female CS majors had less confidence in their computer skills than did male non-majors!” (Beyer, Rynes, Perrault, Hay, & Haller, 2003, p. 52). Women are discouraged from pursuing male-dominated careers because of an image of incompetence, lack of support, harsh mistreatment and life priorities (Gaines, 2017). LGBTQ students experience additional challenges in school e.g., extra cognitive load in active learning environments (Cooper & Brownell, 2016). Although there is more acceptance in society, many LGBTQ employees encounter differential treatment (Yoder & Mattheis, 2016).

The theoretical framework used in this study to identify motivational factors is Eccles’ expectancy-value theory of motivation (Wigfield & Eccles, 2000). According to this theory choice, persistence, and performance with respect to learning can be explained by students’ beliefs of ability, the expectancy of a successful outcome, and the task’s value (Wigfield & Eccles, 2000). Evaluated in empirical studies, Eccles’ theory demonstrated that expectancy and value constructs are “the most immediate or direct predictors of achievement performance and choice”(Wigfield & Cambria, 2010, p. 37), and follow “gender stereotypic patterns”(p. 55).

METHODOLOGY

This study employed a qualitative methodology using in-depth, semi-structured interviews with 21 participants. As we intended to compare experiences of students of different genders, we recruited male, female and LGBTQ participants. The participants were current undergraduate students, recent graduates (within one year of graduation), or students who recently abandoned their program: 13 women (two of which identify as transgender) and eight men. Of the 21 participants, three had dropped out: all women, one of which was transgender. The interviews ranged in length from 1:06 – 2:39 hours. Ages ranged from 18 to 30; however, five participants did not disclose their age. Our participants came from different ethnicities, races, and cultural backgrounds, representative of the context of our institution.

The data collection instrument designed for this study was a semi-structured interview guide developed by the principal investigator and refined over three months and several brainstorming sessions by the principal investigator and three student research assistants. For consistency, the interviews were conducted by the same two research assistants: one male and one female. The interviews were conducted on campus (except for two via Skype due to scheduling constraints). The research assistants were trained in conducting interviews in two pilot studies. Interviews were recorded and transcribed in full.

DATA ANALYSIS

Data was analyzed in an iterative process using the MAXQDA software package. We assured the inter-coder reliability using team coding. The first coding phase was deductive, based on initial codes resulting from the theoretical perspectives which inform our research. Therefore we started our analysis by coding Eccles' expectancy-value theory of motivation task values: intrinsic, attainment, utility and cost (Wigfield & Eccles, 2000), and perspectives identified in literature: stereotypes, gender differences, challenges and obstacles, role models, influences, and self-concept (Beyer et al., 2003; Cheryan et al., 2013; Hill et al., 2010; Ikonen, Leinonen, Asikainen, & Hirvonen, 2018; Lazarides & Ittel, 2015; Robnett, 2015; Shapiro & Williams, 2012). Emergent codes which resulted were analyzed during a second phase.

RESULTS AND DISCUSSION

We found that each participant's story was unique and special. Our data revealed similar issues across genders, as well as important differences. We did not observe differences with respect to intrinsic values related to STEM attitudes like childhood play, interest in science and technology in elementary and high-school, creativity, curiosity and passion for computing and coding. When talking about their choice to study CS all participants indicated the practical importance of finding jobs, financial stability and the excellent reputation of this post-secondary institution. Passion and excitement was described by all genders: all participants reported enjoyment. Michelle described coding: "it's kind of fun, like, just, having that challenge and it's kind of like an adventure, like there are ups and downs, and crazy stuff that happens and, it's just, it's a lot of fun to be, just so enthralled in what you are doing". Ann (unfortunately she dropped out) was also very passionate: "I mean like the things that you can do with, um, computers and technology, is like really, really cool". April is not afraid to enter a male-dominated field because "I see that, um, everyone is trying to change that. And it is um, it's starting to be less male dominated, and, I feel privileged that I get to be, um, that I get to enter, and be part of that change in time". Only five participants preferred playing alone during childhood (three females, one male and one transgender), contradicting the universal stereotypes of lonely computer scientists.

Generally, most valuable experiences during their CS post-secondary education occurred through collaboration and teamwork, which challenges a theme reported in related literature that women prefer working in a team environment (Kuhn & Villeval, 2011). However, in terms of group composition, as the number of the female students is very low, some male participants reported that they never collaborated with female students. In terms of role models who influenced and shaped their interest in CS, our participants reported parents, high-school and post-secondary teachers and peers. Our study revealed that fathers were very supportive for three of our female participants in their decision to study CS. Several aspects presented gender differences and based on our analysis, we associate these aspects with issues of consistency with self-image and identity, as well as with the personal effort and sacrifices experienced by our participants when decided to enroll in the program and during their studies. Of the 21 participants, two women had dropped out (one of them is transgender) because of the pressure they felt in the program. When asked, all participants were aware of stereotypical views; however female participants were subjected to stereotypes in family, high school and during their post-secondary education for example when suggested traditionally female careers or given secretarial roles in team projects. Even some female participants expressed believes in gendered career choices. One male participant articulated very strong stereotypical views. He justified his believes: "trades, that's mostly a male field because men aren't scared to get hurt, well usually, anyway" and female students prefer "always some sort of… something like art history". He talked highly of his project collaboration with a women; however he escribed her as having "a somewhat male personality".

All participants reported costs related to stress, wellness, burden on relationships (lack of time for family and social life), emotional, mental and physical health problems, and lack of sleep, exercise and healthy food choices. However, costs reported by some women demonstrate an almost unsustainable situation. Serious challenges were reported by six female-identifying participants including harassment, hostility and isolation. The most serious situation was reported by a female student who witnessed an incident of harassment during a lab activity which resulted in the victim's withdrawal from the program: "she accidentally deleted a folder or whatever, and instead of telling her what happened, or trying to help her out, the guys in her group, were just posting things […] like "RIP Folder" […] she just felt really awful about it […] I was so furious, because I couldn't understand why they would just make fun of her, instead of just telling her, or helping her, and none of them talked to her in person […] I didn't know what to do to fix the situation, and I feel like that instance kind of like solidified something in her that was just, like, "I'm not good at this and I'm not going to get help when I need it" […] I tried to help her as much as I could, and in the end she was just so anxious, and she couldn't, she just quit, at mid-terms, she just quit." It is important to note that none of the students wanted to report the incident.

Transgender students faced their own challenges. Danielle, a transgender woman, reported harassment in a computing job prior to her studies in her program: "I actually, changed my gender during then […] So, I felt for a long time that they were trying to get me out. Trying to fire me. So, they were always like, trying to sabotage me". Our other transgender participant Julia reported that the school did not provide support during her period of transition: "So the more problems I was going through, the less I could talk to about it [transitioning] with other people". Even if she was very passionate about computing, she felt isolated and as a result, she decided to withdraw from the program during her last semester of studies.

Statistics Canada reported that women's lower enrolments in STEM programs at the start of their postsecondary education are responsible for the gender gap (Wall, 2019); however they did not give an explanation why? Our study revealed that sociocultural circumstances and attitudes preceding post-secondary enrolment are not the only factors. The negative experiences suffered by our female identifying participants had an impact not only on themselves but also affected all students' well-being. These experiences can undermine women's and girls' interest in STEM and CS and eventually affect enrolment.

SCHOLARY SIGNIFICANCE

This study is relevant to college and university administrators and educators in STEM and CS programs as it offers a detailed view of issues that can impact students' experiences and ultimately can hinder women's STEM and CS career choices. The negative aspects reported in this paper should be addressed and discussed openly with administrators, professors and students, and should influence policy makers in colleges and universities to revise policies and promote a more inclusive learning environment. Outcomes of this study include recommendations at the institute level to discuss gender diversity issues early in the program, find better ways to identify "at-risk" students, provide curriculum changes aimed to foster collaboration, provide more support for gender diversity and transgender students and overall improve students' wellness.

As this study revealed the importance of experiences and role models in elementary and high school education, we intend to continue this endeavor with a study aiming to motivate and inspire middle and high school girls to study CS. Intervening before post-secondary education is crucial as gender-related attitudes and stereotypes in early education have a negative influence on girls' interest and performance in STEM impacting their later career choices (Shapiro & Williams, 2012; Wang & Degol, 2017). Additionally, in order to generalize our study we will conduct a future quantitative study.

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EXAMINATION OF EFFECTS OF TRANSDISCIPLINARY STEAM EDUCATION ON STUDENTS' CAREER CHOICES

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ABSTRACT

Raising students who can adapt to the industrial developments of our era and future has become a priority in educational systems. Although STEM is a careerfocused education system, its main objective is to raise more students from STEM fields and industries. However, STEAM, a trending branch of STEM, which includes art as a subject as well, focuses on students' talents and career awareness and tries to lead them into what they can do best. In this study, the effects of a transdisciplinary STEAM education program on students' career choices were analyzed. This program was applied to ninth and tenth-grade students in a public high school in a metropolitan city for one semester. For quantitative analysis, Career Tendency Questioner was used. For qualitative analysis, a descriptive analysis method was used, and students' words, which were written in reports, rubrics, and evaluation forms, were analyzed by categorizing contextual themes of the words. Both qualitative and quantitative findings indicated that students had increased awareness of different career options. According to the findings, it was concluded that a transdisciplinary STEAM program had illuminating effects on students' career choices. Students can explore their talents with STEAM education and choose a career path accordingly.

Keywords: *transdisciplinary, STEAM Education, career choice, attitude*

INTRODUCTION

STEM is the acronym of Science, Technology, Engineering, and Mathematics. Although STEM education was born in the US as a result of the concepts of Industry 4.0 and 21st-century knowledge and skills, education programs have become STEM-centered in many countries since it is predicted to provide an economic advantage. Since art, as a subject, supports creative inquiry, this accelerated movement turned into STEAM with the addition of the letter A (Henry & Costantino, 2015; Costantino, 2017). STEAM education plays a role in providing students with competencies such as creativity and critical thinking, which are among 21st-century requirements (Liao, 2016; Trilling & Fadel, 2009; Sousa & Pilecki, 2013) while exposing students to future career options.

With Industry 4.0, current life problems and occupational needs have changed considerably. Besides today's occupations and fixed program education, individuals can solve complex and dynamic problems, have 21st-century knowledge and skills. The study of Çorlu and Çallı (2017) shows that professionals who are continually collaborating with their colleagues in different countries are thriving. STEAM is not only about code writing and robot movement, but also raising awareness and integrating the real world into education so that future generations can find themselves in the right professions. In this study, we investigated if a STEAM program had effects on students' career choices.

LITERATURE REVIEW

The technology race and industrial revolutions have accelerated the reform movement in education, and STEM training has been created by combining critical areas for future professions and needs. According to Bryan, Moore, Johnson, and Roehrig (2016), the goal of Integrated STEM is to incorporate Science, Technology, Engineering, and Mathematics into the teaching and learning process.

The first aim of STEAM is to raise productive individuals who can solve problems and renewing themselves by adapting to newborn professions or situations by making lifelong learning a habit in children. At the same time, they will be involved in many different technological applications from today, and they will take their place professionally within the STEAM professions that we cannot predict what they will be born (Bastani and Kim, 2017; Constantino, 2017; Guyotte et al., 2014). Therefore we can assume, in the planned training, it is meant that all branches of art should be designed in such a way that each component constituting the STEAM acronym can be used with equal and full functions within each other. Transdisciplinary STEAM training melts the subjects, and workplaces are increasingly developing into an intercultural and collaborative environment.

Social Cognitive Career Theory - SCCT (2016) was developed by Lent and Brown and emphasized lifelong learning. This theory is adapted to students' STEM career needs and the current learning environment (Dickinson, Abrams &Tokar, 2016; Flores, Navarro & Ali, 2016; Sheu & Bordon, 2016). SCCT (2016) also emphasizes the relationship between student, environment, and attitude variables in predicting students' interest and career choice. SCCT (2016) outlines the main factors that play a crucial role in career development, attitude, performance, and skills, as well as the impact of demand in the career sector (Chachashvili-Bolotin, Milner-Bolotin & Lissitsa, 2016; Lent et al., 1994). In parallel with the research, SCCT can explain the relationship between the designed science program and students' STEAM career choice in more detail.

RESEARCH DESIGN

A mixed-method design was used in this research. In the mixed-method research approach, qualitative and quantitative data are collected using a pragmatist world view, and the data obtained from them is integrated (Cameron, 2011; Creswell, 2014; Johnson & Onwuegbuzie, 2004). Also, the findings must be combined or mixed at some point. Combining two types of data in the research process can take place at different stages, such as data collection, data analysis, or data interpretation.

The research was carried out in a selective course related to STEAM. This course lasted for one semester, in which students participated in STEAM course modules for a total of 52 hours. Thirtytwo ninth and tenth grade students were registered for the course. However, at the end of the first module, some students could not do the requirements and dropped off the course. As a result, the research was done with 18 students, consisting of eight females and ten males. Two of the participants were tenth grade students.

In order to measure the impact of STEAM activities on participants' career choice, the 'Career Tendency Questionnaire' prepared by the Ministry of National Education (MoNE) in 2015 was applied to the students in the beginning and at the end of the STEAM course. There were 160 items in the questionnaire distributed under 16 main career groups, in which students indicated whether they agree or disagree with some career-related statements. Each agreed answer counted as 10 points and disagreed answers counted as 0 points. According to the scale for each career group, the scores between 0-40 meant that a student had no interest in those occupational groups, the scores between 50-70 meant that a student did not have enough background to choose a profession, the scores between 80-100 meant that a student had to think before choosing a profession, the scores between 110-130 meant that a student showed interest and could select a profession, and the scores between 140-160 meant that a student was highly appropriate for the chosen profession.

In this study, scores of over 80 points counted as a student's eligibility to a career path, while 160 points indicated the most appropriate match. The occupational groups represented by the letters are as follows. In the original MoNE scale, score ranges were shown as 80-100, 100-130, and 130-160; but in this research, for clarification and making an equal-rate, the score ranges were listed as 80100, 110-130 and 140-160.

Careers were grouped by MoNE scale, and some examples were as:
A: Agricultural Engineer, Forest Engineer, Fisheries Engineer, Sports, etc.
B: Textile Engineer, Mechanical Engineer, Architect, Radio-TV Technician, Technical Teachers, Dental Technician, Interior Designer, etc.
C: Lawyer, Judge, Business, Executive, etc.
D: Photography, Sculptor, Architect, Landscape Architect, Archaeologist, etc.
E: Teacher, Journalist, Advertising, Marketer, History, Guidance, etc.
F: Psychology, Philosophy, Sociology, Anthropology, Law, Marketing, Public Relations, etc.
G: Translation, Philology, Hospitality, Tourism, etc.
H: Biologist, Pharmacist, Doctor, Dentist, Veterinary, Nurse, etc.
I: Economist, Public- Private Sector Manager, etc.
J: Computer, Physics, Construction, Aircraft engineering, Industrial Engineering, etc.

After normality tests were performed, the analyses were continued with nonparametric tests. Applied One Simple Test automatically selected binominal testing as the appropriate test. On average, students scored fewer points before (Mdn=0) than before completing the STEAM course (Mdn=1). A Wilcoxon Signed Rank test indicated that these differences were statistically significant T= 3556.50, z=-2.40, p=0,16.

For the qualitative analysis, the literature on attitude was searched, and words, phrases, or expressions expressing the attitude towards anything were identified and coded. Mcload's (2018), Osgood's (1957), and Mahoney's (2010) publications were taken into account to assess the words used in students' self and peer assessment forms and end-of-module reports. The frequency of word usage was examined and the number of students using the codes was expressed. Themes were subsequently created and analyzed by taking into consideration the student's words and general STEAM field literature and building blocks.

RESULTS AND DISCUSSION

It has been investigated whether the STEAM program has a significant effect on career choices in comparison with pre-test and post-test. In the analysis conducted for the Career Tendency Questionnaire (MoNE, 2015), the sub-categories of the job selection category, which means the change of opinion on career choices, more choice assessments, or interest in new careers, were determined at a rate of 55.55% according to students' expressions. This ratio showed that more than half of the participants questioned their career choices after the STEAM course and re-evaluated their decisions, abilities, and interests in line with their interests. These are also consistent with the results of the career selection questionnaire in which the students in the final tests think more career options.

Table 1: Choosing a Career Path

	80-100				110-130				140-160			
	fSB (n=18)	pSB (n=18)	fSA (n=18)	pSA (n=18)	fSB (n=18)	pSB (n=18)	fSA (n=18)	pSA (n=18)	fSB (n=18)	pSB (n=18)	fSA (n=18)	pSA (n=18)
A	7	18.9	4	10.8	-	-	3	8.1	2	5.4	-	-
B	7	18.9	3	8.1	-	-	1	2.7	-	-	2	5.4
C	8	21.6	4	10.8	3	8.1	4	10.8	1	2.7	-	-
D	3	8.1	5	13.5	5	13.5	1	2.7	1	2.7	1	2.7
E	2	5.4	4	10.8	7	18.9	2	5.4	1	2.7	1	2.7
F	8	21.6	4	10.8	1	2.7	2	5.4	1	2.7	-	-
G	5	13.5	4	10.8	8	21.6	2	5.4	2	5.4	-	-
H	3	8.1	6	16.2	5	13.5	2	5.4	1	2.7	2	5.4
I	3	8.1	2	5.4	2	5.4	1	2.7	-	-	1	2.7
J	5	13.5	9	24.3	4	10.8	7	5.81	1	1.23	1	2.7

For this reason, students. SB: pre-test, SA: post-test, numbers 1-18 indicate the student choice of that score and the profession, and the scores between 80-160 indicate their score. Frequency and percentage values of chosen occupational groups were given in the table. fSB is student frequency before implementing STEAM Modules, pSB is student percentage before implementing STEAM Modules, fSA is student frequency after implementing STEAM Modules, and pSA is student percentage after implementing STEAM Modules. A total of 18 pre-test students selected 88 professions and M = 4.88. The result of the final test reveals the value of M = 4.61 by selecting 83 professions of 18 students. In general, students showed an increased tendency for multiple career paths areas rather than cluttering into one area.

Student opinions were picked from the words used by all participant students in their self and peer assessment forms, end-of-module reports and face-to-face interviews for some students. For faceto-face interviews, nine students volunteered (Students 1, 2, 3, 4, 5, 11, 12, 13 and 14). Four female and five male students were interviewed at the end of the course to learn more about their opinions. For example, one of the students, S11 (student 11) said: "Uhm, I wanted to be a doctor, but after STEAM lessons, I started thinking about engineering, and we are talking about it with my family.". S3 (student 3) said: "I wanted software engineering. I am still thinking about software engineering, but after class, I started thinking about industrial engineering. I like to design the product I coded at the same time.". There has been a change in the way of changing ideas or expanding professional options. The sub-categories of students, which means that they have changed their minds about their career choices, started looking for more options, or are interested in new careers, were determined at a rate of 55.55%. In other words, 55.55% of the students questioned the careers they wanted after this STEAM course. These are in line with the career thinking results of the students in the final tests in the career selection survey.

Looking at the literature, it was found that the participants received career assistance and information mostly from their teachers or faculty members, half of them had working experience, half had internship experience, preferred the most artistic and social activities, and half preferred to turn their leisure activities into a career (Korkut-Owen & Eraslan-Çapan, 2018). Findings were obtained that students had little knowledge about job opportunities, that their future expectations were not related to their talents and knowledge, and that they did not have a consistent career plan (Crişan, Pavelea & Ghimbulut, 2014). Resources used for the remaining categories include a total of 18 students attending the STEAM course.

CONCLUSION

In this study, it was observed that transdisciplinary STEAM education had a positive effect on students' career choice, and the number of professions selected by students increased. In the qualitative analysis, it was seen that the majority of the students thought about new professions other than the professions they stated in the course registration form. This shows that the STEAM course broadens the students' career vision.

Moreover, 21st-century skills that may be to be gained through STEAM education have a direct or indirect effect on students' career choices. However, it is also a gateway for STEAM professions that are not yet expected to be born in the coming years. According to Herdem and Ünal (2018), only technology-based applications are not enough for students to gain ethical, social, understanding, and communication skills are required. In this study, it was found that a program appropriate to the STEAM model contributed positively to the acquisition of 21st-century skills.

According to Wiebe, Unfried, and Faber (2018), students' career choices at secondary and high school levels are not fixated, but they show stability towards high school second-grade level. In the same study, it is seen that the STEM program influences the orientation of students on STEM careers. In this respect, the results of this study overlap.

Implications

The fact that the professions and related professions in the center of the course are very wide and may cause problems for the progress of students' courses. Also, if students research their tasks before each lesson, it has positive effects on their participation. It was observed that there was more active participation in the activities prepared according to their abilities and wishes. It is essential and necessary to use the online classroom application effectively to avoid the surprises that may arise in face-to-face lessons and to carry out activities that will cause time loss during the application.

Suggestions

It is possible to select only the problems that are directed towards individual countries over the world problems followed in the course and to catch other countries by placing STEAM culture in our schools with them.

TogetherWeCan, World Ocean's Day and similar organizations can create a new training period from current reports on hunger, gender equality, and up-to-date information. By identifying current needs, such current issues can help the student to adopt that it is a way of life to develop their competences, as their professional competence is the source of topics such as new professions.

It is recommended that STEAM is included as an additional course in the National Education Curriculum, as it enables students to explore their talents by discovering their talents through a transdisciplinary STEAM program that focuses on the professions. Students who complete certain STEAM modules at the end of each semester can be provided with internship opportunities in the real occupational field to enable them to visualize themselves in their future professions better, and students can be trained in appropriate occupations in line with our national goals. However, prior to this, it is suggested that the occupations in the center of the transdisciplinary STEAM program should be reviewed, and course programs prepared for this purpose will be analyzed by which occupational groups our country needs in the future and in which field it is foreseen to lead the world.

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A RESEARCH ON CAREER-ORIENTED STEM CURRICULUM DESIGN STRATEGY

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ABSTRACT

Students have problems with unclear career goals and lack of career thinking and current career education has problems such as design deficiencies, lack of sustainable teaching strategies and relationships with the students' career development. The study highlights the need for integration of STEM education with career education and explores a method for career-oriented STEM curriculum in high-school, which promoting students' understanding, interests, self - efficacy and outcome expectations. As designing a career-oriented STEM curriculum, authors provide various teaching strategies in three processes including the theme selection process, the scientific inquiry process, and the collaboration process by integrating career education elements into STEM education key processes. Besides, this paper shows a case analysis and improvement named "Water Resource Protector" which combines the high school knowledge of chemistry, geography, ecology and environmental science. This case not only uses diverse educational technology but also lets students experience different STEM occupations through role-playing and collaborative learning during the process of solving practical problems. It is hoped that this study tested later in practice will contribute to the students' career development and STEM learning, and provide curriculum design suggestions to cultivate future-oriented workers.

Keywords: *STEM education, career education; career-oriented STEM curriculum design*

INTRODUCTION

Under the background of the new college entrance examination in China, the subjects that students need to study are no longer uniformly packaged. Students need to choose subjects on their own under the guidance of the teachers and parents, which has put forward better requirements for students' ability to plan for the future. In this way, the importance of career education has become more prominent. Some schools tried to increase their understanding of the future through career courses, discipline penetration, career exploration, and practical activities to help students know more about subjects and ignite their interest in careers. But it is rarely efficient due to problems such as design deficiencies, lack of sustainable teaching strategies and relationships with the students' career development.

STEM courses provide a new kind of way to solve the problem above. STEM education is a comprehensive interdisciplinary course that allows students to actively think about or explore the qualities that a career type or role needs, the prospects for future development, and the efforts that need to be made. This will transform students from passive experiencers and recipients of career education to career designers and motivators, and it is internalized and meaningful learning. It can help students to understand themselves, explore the future, and finally realize the realization of a selfplanning career. It is a powerful complement to current career education. The research questions guiding this study are:

1. How to design a STEM curriculum with career orientation to achieve the dual goals of interdisciplinary and career education?

2. What kind of strategies can be used in a career-oriented STEM curriculum to let high school students experience different STEM careers?

INTEGRATING STEM AND CAREER EDUCATION

The crucial role of integrating science, technology, engineering, and mathematics (STEM) to foster students who need to be equipped with 21st-century skills has drawn wide attention (National Research Council 2011). STEM education originated in the United States and many countries and regions have recognized the benefits of STEM education in quality learning and literacy development (Gamse et al., 2017). STEM's flexible, comprehensive, and practical characteristics can help students get known about various professional knowledge and skills. STEM career is a science-related profession consisting of science, technology, engineering, and mathematics. Foreign studies show that early-career expectations of students have an important impact on future academic achievement and career acquisition (Archer et al., 2015). At the same time, the socialization process of adolescents is an important period for the formation of professional intentions.

Career education refers to the integration of social life and professional world information into students' learning life to develop personal interest and ability, and build a personal source of meaning and career identity. The career education in this article points to finding the future of professional interests, areas that are suitable or good at, and building career aspirations, not just the stage of career choice or preparing for career choices. Accordingly, combining career education to STEM curriculum can help to expand their career options (Lindsay et al., 2019) and promote career expectations. With the deepening of clarity and the accumulation of professional information by STEM curriculum and other activities, future work self salience (Strauss et al., 2012) would gradually transform into a more lasting value orientation. We hope to build a bridge between students' present and future through STEM courses for career education.

THEORETICAL BACKGROUND

STEM curriculum design for career education needs to be based on the characteristics of students' psychological development. According to E. H. Erikson's eight-stage theory of personality development, adolescents 12-18 years old are in disorder for self-identity. We can help them determine their career goals and form a professional identity by making use of the contradictions of students' self-awareness. Besides, Super's Self-concept developmental theory pointed out that career choice is a dynamic 5 phases and the exploratory phase is a critical period for the development of career aspirations. At the age of 14-24, children gradually narrow their career choices through their own and professional information and ultimately form career decisions.

Social cognitive career theory (SCCT) pointed out that enduring interest, self-efficacy, and positive outcome expectations are contributing to goals conversion to activities that foster level of performance (Lent & Brown, 1996). It concludes four aspects to create multiple learning experiences--Achievement performance, alternative learning, verbal persuasion and emotional arousal—which can contribute to enduring interest, self-efficacy, and positive outcome expectations. STEM curriculum-aligned making foster self-efficacy, science identity, and possible selves among students from unrepresented groups (Schlegel et al., 2019).

CAREER-ORIENTED STEM CURRICULUM

The STEM curriculum for career education is designed to develop students' 21st century skills and achieve the dual goals of interdisciplinary and career education. In order to helping teenagers obtain practical skills and know about knowledges related to future careers, we need to integrate subject knowledge with career education in the local education systems as well as make career education more prevalence and innovative. As career leaders in the development of adolescents, career teachers not only should improve their skills in interpersonal communication and new technology, but also need to learn from teaching and practical experience continuously, striving for evaluating and improving professional works of themselves (Patton & McMahon, 2014), which is in line with the STEM education process.

Curriculum design is a preparatory work for STEM education and will benefits the effectiveness of STEM education and career education directly. The course design includes not only the content design but also the activity plan. Teachers can integrate the elements of career education into the key steps of STEM education, and promote the organic integration of the two kinds of education (Table 1).

Table 1. Curriculum design strategy

Items1	Items2	Explanations	Examples
Theme selection	Interdisciplinary theme	Different disciplines from the perspective of subject groups	Scientific career expectations
	Professions theme	Explore different careers	Architects, Astronauts, and navigators, etc.
	Professional character theme	Professional characters lead the way to explore a profession	Mrs. Curie's day
Scientific inquiry process	Key concepts	Incorporate key concepts into the scientific inquiry process	Time view and target view
	Advantages	Play different student specialties	Design and writing, etc.
	Make their work	Making	System thinking
Collaboration process	Role	Play different roles	Team leader and coordinator, etc.
	Cooperation	Teamwork	Cooperation
	Communication	Class communication	Communication

The STEM curriculum model emphasizes students' collaborative exploration of specific topics in a meaningful context, making plans and hands-on operations, and expecting great results. In this process, students are full of interest and gradually gain knowledge, skills, and literacy, enhancing self-efficacy and outcome beliefs.

Theme selection

STEM curriculum involves science, technology, engineering, and mathematics education, and its interdisciplinary nature helps students understand the thinking models and the role and relationship of different disciplines from an epistemological perspective. The different disciplines and fields in STEM courses also enable students to gain more intuitive perceptions and to establish reasonable career expectations by comparing different disciplines from the perspective of subject groups.

STEM curriculum design allows you to choose career-related topics and lead students to explore different professions such as architects, astronauts, and navigators. Teachers can set up different roles for students to complete the work by working together. For example, in the aviation theme, astronauts, nutritionists, physicists, mathematicians, etc. are required to participate together, and solutions are proposed from different angles. Teachers can also choose a professional figure as the mainline, setting the course with several clues that need to be dealt with, and explore different professional characters in detail.

Scientific inquiry process

STEM courses for career education can incorporate key concepts into the scientific inquiry processes such as time view and target view. In the STEM course, students need to plan the limited time to achieve the desired goals. We also need time view and target view with limited time of life, and we want ultimately to realize the transfer of key concepts from the STEM project to career planning through the application of key concepts in the STEM curriculum

In scientific inquiry activities, students can discover and understand their strengths and weaknesses through self-analysis, and establish a sense of opportunity and a positive attitude towards life. The STEM curriculum design for career education also reflects the attention to the differences and individualized development between students, and students with different personality characteristics, different interests, and different skills can be developed in the STEM classroom. Besides, students often need to make their work from survey to design and production, even modification in STEM projects. It is a good exercise for students' system thinking development and project management ability attainment, which helps students' future career decisions.

Collaboration process

STEM course helps to show and develop the personality characteristics of different students. Different students in the team play different roles according to their characteristics, such as team leader and coordinator. Students explore and gradually recognize themselves in teams or classes, and explore career direction in their understanding. In future career decision-making, they can find a career that suits their characteristics, and each student can generate positive expectations, selfefficacy, and confidence in the future. All students can be personalized.

Due to cooperation and exchange, exploration and practice, we attain the necessary qualities and skills for future careers in STEM education. Teachers should promptly discover and affirm the students' efforts, establish a specific model for students, pay attention to the students' performance in the evaluation, and create a multi-learning experience for students. It's necessary to pay attention to the students' characteristics and teach students according to their aptitude. Every student can find his or her position and play a role in the collective.

CASE IMPROVEMENT—WATER RESOURCES PROTECTOR

As global warming gradually deteriorates, education for sustainable development has quickly entered people's horizons and is increasingly being promoted. The lack of water resources and pollution are the top priorities in environmental issues and have seriously threatened the development of the world economy and human survival. The STEM course content comes from the chapter on water conservation in the elective course of China High School Chemistry (People's Education Press). This section contains rich knowledge of chemistry and other disciplines, so it is appropriate to adopt it form the teaching model to STEM case.

Through the study of the previous content, the second-year senior high school students have learned that water is one of the precious material foundations on which all life on earth depends and the role of water in the human body. We can study the section of Water Resources by requiring students to complete the project "Designing a City Water Treatment Plant and Water Treatment Process" because it will be based on the actual situation and may include different careers.

This course is designed to develop interdisciplinary knowledge and STEM literacy and to deepen understanding of professional roles through the understanding of the roles involved in the project. The curriculum design starts from five aspects: setting situation, scientific inquiry, making production, communication, display, and evaluation (Table 2).

Table 2. "An urban water treatment plant" case design

Stage	Teacher activities	Student activities	Aim	Notes
Setting situation	introduce course learning by playing water conservation videos and asking questions.	Access to basic knowledge of water resources and water treatment processes.	Set situations to stimulate students' interest in learning.	Search specific problems such as the main components of sewage, aluminum saltwaterpurification methods, etc. online.
Scientific inquiry	Guide students to think about how to clean water with poor water quality.	Access to water treatment method and detailed process.	Giving students the role of a water quality engineer, placing students in the field of future career choices.	The teacher carefully guides the students.
Making production	Guide students to consider several key issues in water plant construction such as site selection, sewage treatment process, investment and cost, and environmental protection.	Comprehensive consideration of social, process, environmental, and cost factors to complete project.	Involved in many fields such as chemistry, economics, geography, etc.; student roles include engineers, finance divisions, quality inspectors, etc.	Visual rendering schemes can be drawn by drawing.
Communication and display	Organize a water plant exchange seminar.	Role-playing: project leader, environmental protection director, water plant design engineer, geological engineer, technician, resident, etc.	Role-playing can stimulate students' enthusiasm for learning, develop students' language skills, enhance students' selfconfidence; clearly define the roles and responsibilities of different roles.	Teachers need to help students identify different roles and responsibilities.
Evaluation	Teacher evaluation	Self-evaluation, peer review.	Learn and deepen your understanding of yourself and your classmates; learn from each other and optimize your work.	Make clear evaluation criteria from the perspective of process and results.

The STEM project-based learning with the theme of “protecting water resources” combines the knowledge of chemistry, geography, ecology, and environmental science, and uses multimedia techniques and calculations in mathematical ideas. This STEM project guides students to stand in the perspective of global views to identify problems and constraints in the engineering field, and comprehensively apply scientific, technical, mathematical and other subject knowledge to experience the process of solving practical problems with engineering ideas.

Students' STEM literacy and career knowledge are cultivated in a five-stage progressive practice of project implementation. STEM project-based learning focuses on the combination of classroom knowledge and practical production. Teachers should reasonably choose teaching content and my cross-disciplinary parts, and shape real situations. We should develop and integrate more STEM project activities to create opportunities for students to solve real-world problems and develop the skills and literacy needed for future careers and lifelong learning.

CONCLUSION

Education should make students put the scores aside, pay attention to establishing long-term goals, thinking about their own lifes and future plans. What our children really need to know is that life always needs to go through the development process of exploration, discovery, understanding, practice, and sublimation, with the growth of students themselves. The integration of career education into STEM teaching using project-based learning as a specific way of curriculum realization plays an important role in the cultivation of students' interest, the improvement of selfefficacy outcome beliefs, which contributes to the realization of career development goals.

The STEM curriculum design can be linked to career education in three aspects: theme selection, Scientific inquiry process and collaborative process to promote the realization of two-way goals. Factors from society, family, school and class play an important role in the development and implementation of STEM curriculum for career education. Improving the ability of career education ability is important to teachers’ professional development, and teachers should respond proactively to connect the future goals of students with current actions.

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STUDENTS' COMPUTATIONAL THINKING IN TWO MATHEMATICS BLOCK-BASED PROGRAMMING ENVIRONMENTS: RESEARCH DURING COVID-19

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ABSTRACT

This paper analyzes the computational practices that four 7th and 8th grade students engaged in when learning geometric transformations in two different online block-based programming environments**.** The data sources include video footage of students' interviews in Zoom where they shared their screens and cameras. The findings determined that students utilized in particular, decomposition and pattern recognition as important computational thinking practices required for learning in STEM disciplines. The paper also describes the changes made in how research method, data collection, and analysis configured opportunities to study computational thinking in remote locations due to the restrictions brought on by COVID-19**.** We identified three main challenges in the transition to online research: (a) recruiting research participants which included instituting necessary revisions to ethics protocols; (b) rethinking data gathering and analysis techniques along with interactions with participants in virtual settings; (c) dealing with glitches associated with technologies and virtual communication media in just-in-time ways. We conclude that even given the challenges with researching during COVID-19, there are still opportunities for rich, robust research in online settings.

Keywords: *computational thinking, geometric transformations, block-based programming*

INTRODUCTION

Several scholars have suggested that integrating computational thinking can productively transform STEM education (Sengupta et al., 2018; Wilensky, Brady, & Horn, 2014). Mathematics is a subject that shows many disciplinary overlaps with computer sciences (Hoyles and Noss, 2020; Weintrop, et al., 2015; Wing, 2008). In particular, programming as a practice has a geometric engagement tradition since Logo's environment appeared in the 1980's. Such programming environments allow for the study of geometric shapes and its transformations in order to create geometrical meaning as students program the path of a turtle (Edwards, 2009; Papert, 1980).

Although there is a long history of research that has explored the development of students' understandings about geometric transformations through programming, there has been less work to date studying the development of students' computational practices as they learn about geometric transformations. The primary aim of this presentation is to share the computational practices demonstrated by 7th and 8th grade students in two computational environments, a video game and Scratch, in the context of learning about geometric transformations. A secondary aim will be to describe how COVID-19 restrictions led to a pivot in regards to the research method, data collection and analysis, and preparation of manuscripts while still configuring opportunities to study computational thinking in remote locations.

The global pandemic has shuttered public life in many ways, but STEM educators have not halted their duties as "homeschooling" has become the "new normal." These settings bring in new challenges for educators and researchers as they face uncertain environments that demand adaptative capacity to cover the students' learning necessities (Manning, 2020). In this respect, STEM education research can provide suggested strategies and activities that allow students to develop skills in physically distanced scenarios with in some cases, a lack of accessible communication and access (Bakker & Wagner, 2020). This paper focuses on addressing these issues by describing some computational practices grade seven and eight students performed when interacting within a conceptually integrated videogame and a Scratch activity adapted for learning in a virtual setting.

COMPUTATIONAL THINKING

Extending on Wing's (2008) elucidation, computational thinking has been broadly defined by The National Research Council [NRC](2011), as a skill that "everyone, not just computer scientists, can use to help solve problems, design systems, and understand human behavior. [As such,] computational thinking is comparable. . . to the mathematical, linguistic, and logical reasoning. . . taught to all children" (p. 3). According to Sengupta et al. (2018), the core of computational thinking is found in "abstractions," that "are generalized computational representations that can be used (i.e., applied) in multiple situations or contexts" (p. 355). The notion of computational abstraction in "use" (Sengupta et al., 2018) is understood as a practice that considers the concepts (e.g., loops and conditionals) and other practices (e.g., solving-problem, debugging, pattern recognition) of the computer's science. For instance, programming underlies the notion of an abstraction of a process that executes a series of steps and provides an output (solution) to the desired problem (Hoyles & Noss, 2020; Wing, 2008).

Several investigations have characterized concepts (abstractions) and practices (abstractions in use) fundamental to computational thinking development (Brennan & Resnick, 2012; Gadanidis, et al., 2017; Weintrop et al., 2015). For this study we drew on computational practices as suggested by Hoyles and Noss (2020) as follows:

- **Decomposition** involves solving a problem by solving a set of smaller problems (Weintrop et al., 2015; Sinclair & Patterson, 2018).
- **Algorithmic thinking** is the propensity to see tasks in terms of smaller connected steps (Hoyles & Noss, 2020).
- **Abstraction** involves seeing a problem at different levels of details as well as the ways in which expressions within a situation can point beyond the boundaries of that situation. In other words, is a process from the experience to the concept (Hoyles & Noss, 1996).
- **Pattern Recognition** is "seeing a new problem as related to problems previously encountered" (Hoyles & Noss, 2020).
- **Generalization** involves the transition from seeing specific cases only as such to seeing specific cases as generic examples (Hoyles & Noss, 1996).

From our analysis, we noted that the students, though engaging to a greater or lesser extent in all computational practices, resorted most often to (a) decomposition of the sequences or series of individual steps or instructions that can be executed by the computer, and (b) pattern recognition in the form of the loop, a technique utilizing the iterated repetition of a set of instructions over and over again (Brennan & Resnick, 2012; Sinclair & Patterson, 2018), promoting computational efficiency (where the code runs the shortest possible script to achieve the most robust action).

Our study also recognizes the social aspects involved in computational thinking. Sengupta et al. (2018) warn about the fallacy of *technocentrism*, i.e., questions about technology which reference the technology itself, leaving aside the individuals who interact with it. Sengupta et al. state that commonly the learning objectives and the evaluation of computational thinking focus on the production and improvement of understandings about computational abstractions, instead of focusing on the role of discourse, corporeal reasoning or aesthetic experiences of people, as phenomenological aspects of computational thinking. Adding a social vision of computing and mathematics in research highlights people's productions and their collective experiences. In this way, the uses of the abstractions will differ from individual to individual, depending on their context and their reason for use. Therefore, we acknowledge that the development of computational and STEM thinking together not only relies on conceptual intersections but also on practices and phenomenological aspects.

METHODOLOGY

This study focused on four student cases learning about transformations in two different computational environments, a video game and Scratch. Qualitative comparative case study was selected as methodology because it allowed for inquiry that was exploratory, explanatory, pragmatic, and phenomenological (Harrison et al, 2017). Given COVID-19, we had to re-envision this research in an online as opposed to classroom setting. Revisions to the research plan were submitted to the university ethics board (CHREB) and approved prior to engaging in the online work with students. Due to limited response to participation requests, authors 1, 2, and 4 worked with four students individually, each in four separate sessions, two in the game and two in Scratch. Each student brought a unique background to the research study as indicated in Table 1.

Table 1. Students' block-based programming and mathematical experience

Student	Grade	Block-based programming experience	Mathematics profile
Zach	7	Extensive experience creating games in Scratch	Previous year's teacher indicates average performance in mathematics
Simon	8	No block-based programming experience	None provided.
Paul	8	No block-based programming experience	Parent indicates strong mathematical capability but often underachieves
Eric	8	No block-based programming experience, but observed friends	Parent indicates struggle and lack of confidence in mathematics

The design of Transformation Quest, led by Author 3, draws on conceptual integration and disciplinary integration as indicated by Clark, Sengupta, et al. (2015) where mathematics and computational thinking concepts are integrated directly into the mechanics as a central focus for reward and achievement, rather than being embedded as an activity that appears after completion of other goals in the game.

In playing the game the students use programming blocks with transformations directives to position a red right triangle in a Cartesian plane 20x20 sized; The objectives are related to the collection of magical yellow or blue gems strategically disposed into the cartesian plane, avoiding static enemies that block gems' positions and minimizing the number of transformations blocks (e.g. using the loop block).

The Scratch activity, Code the Quilts, developed by Author 1, was inspired by the work of Lehrer et al., (1998) and features the exploration of code sequences used to develop multiple quilt patterns. In the first session, the students played with the existing code to determine how it led to emergent quilt patterns. In the second session, the students were encouraged to create their own code, or use existing code to design a new quilt pattern.

Due to the constraints related to Covid-19, the video footage of student participation was recorded in a virtual setting (Zoom), where the participants shared their screen with the researchers during the game play and Scratch activity. Researchers one and two engaged in ongoing dialogue while the students at this time. Guiding questions helped understand students' predictions (e.g., What is your plan? Based on your code, can you tell us where the triangle will map?) and explanations (e.g., Can you explain what happened?) It should be noted that when working with student Zach, our first participant, we were joined by his former teacher (Author 4), who interacted with him as well.

Data analysis of the video footage took place using Nvivo 12 in virtual zoom sessions. Assigned codes, developed prior to analysis, were utilized to determine student understanding of computational and mathematical concepts, as well as student implementation of computational and mathematical practices as evidenced by their discourse, embodied expressions, and coding sequences in both environments. In addition, researchers observed and noted student comments related to the game and Scratch experience.

FINDINGS

All four students show evidence of how their prior experiences influenced their understandings of geometric transformations and computational thinking abstractions, depending on their individual context and their reason for use. We provide three examples of student computational and mathematical thinking while engaging in game play and the Scratch activity in an online environment.

Example 1: Pattern recognition in the service of efficiency

In Scratch (International Scratch Wiki Community, 2020), efficiency is linked to more content in larger projects within a smaller file size. Following this idea, one problem that makes programming sequences inefficient is the use of multiple similar scripts (patterns) that can be reduced into one instruction allowing the program to run faster. In this respect, Zach uses his previous experiences with Scratch programming:

> ***A4:*** *Can you just explain more about that loop? Why do you want to repeat it four times? [Figure 1 right dashed rectangle]*
>
> ***Zach:*** *This, this makes it look more efficient. Because if you did this, you'd have to do something like this [Figure 1 right]. This is just incredibly inefficient. So that's probably why you have it there.*

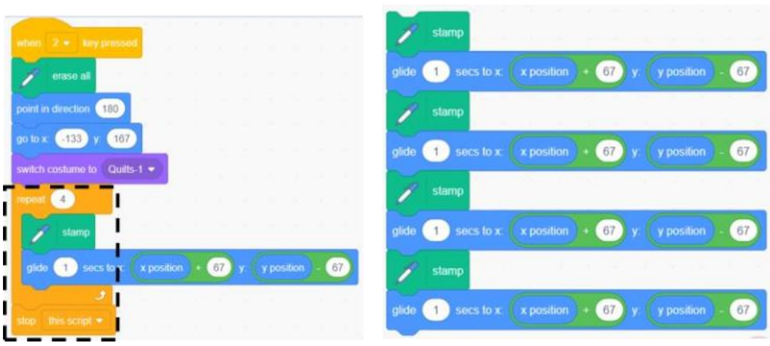

Figure 1. Zach's examples of efficient and inefficient code.

Zach's left code sequence uses a loop. To explain his understanding of efficiency, Zach shows us a counterexample to make his point (Figure 1, right). This counterexample shows a repetition pattern of two instructions that can be synthetized with a repetition block. Zach uses the loop abstraction as an instantiation for efficiency in relation to pattern recognition in computational thinking practice.

Example 2: Decomposition in Transformation Quest

Paul explores Transformation Quest by screen testing block by block until he solves the problem. His decomposition practice, using only individual translations, rather than employing reflections in a pattern is useful for him with no prior programming experience. He explains:

> ***Paul:*** *I will go across to these three [right blue gems], and then down to both these ones*

Later he realizes that to finish the level, he needs to apply at least one reflection across the y-axis, in order to invert the triangle for a successful exit.

> ***Paul:*** *that are reflected on the y-axis to collect this one [blue gem at the left button]. Then we have this one and then down to the bottom, and then across to here.*

Based on his limited experience, Paul does not discern the potential repeating pattern inherent in using the reflection block, therefore his strategy is to decompose single translation moves in the game, using inversion as a reflection property only when necessary. That said, Paul constructs an efficient (in terms of number of blocks used) and pragmatic (in terms of goals achieved) inscription.

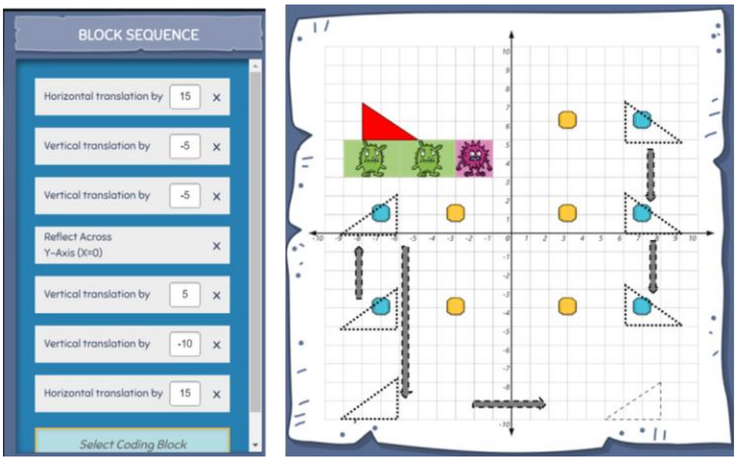

Figure 2. Paul's level 4 solution.

Example 3: Decomposition in Code the Quilts

When asked to create his own quilt, Eric engaged in an aesthetic experience (Sengupta & Farris, 2016) by modifying the original colors of the quilt and creating a tank shape. In order to achieve his goal, Eric indicates that simplicity not efficiency, was crucial. Eric built a sequence reusing the simplest code available (number one) utilizing only the "glide t secs to x y" Scratch block (Figure 3, left).

> ***Eric:*** *Okay, yeah. Well, since I'm gonna be trying to keep this fairly simple. I think I might base it off number one.*

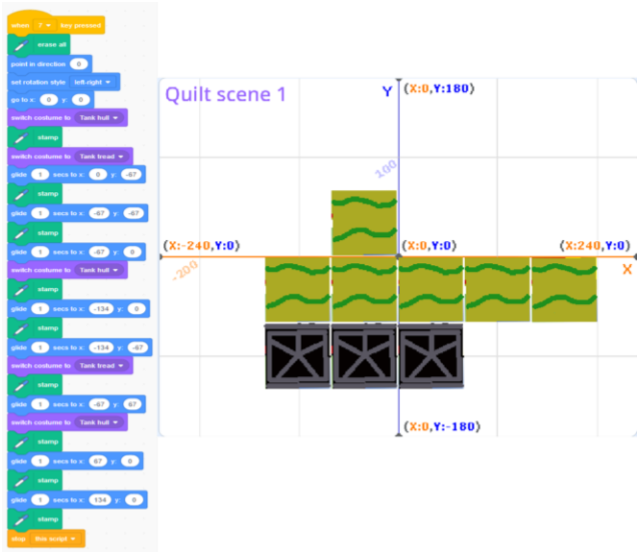

Figure 3. Student Eric sequence and final tank design

Eric modified this code by using decomposition, testing block by block. Although he articulates an emphasis on simplicity, his explanation shows he understands the basic functions of the blocks.

> ***Eric:*** *So, point in direction 90 that basically tells the block which way to point. Orient itself. Go to x and y tells the block where to go. And then switch costumes to quote one gives it the appearance and stamp closet to stay there.*

In this example, Eric was engaged in a personalized programming activity, where his primary focus was on the construction of the tank shape. By necessity, he oriented the computational practices he performed to his overall goal. Due to his limited experience in coding, the decomposition practice was the most affordable way to achieving his goal.

DISCUSSION, COVID-19, AND CONCLUSIONS

In this study, decomposition appears as an intersectional practice of computational and mathematical thinking. As stated by scholars (Edwards & Zazkis, 1993; Francis & Davis, 2018), not only is it a powerful problem-solving technique that can be adopted by novice programmers, it is an experiential-based learning practice that can be used in addition to pattern recognition practice. For Zach, his experience with pattern recognition and the loop block in the service of efficiency allowed him to show his transformation geometry understandings using loop abstractions. For Paul and Eric, their goals in achieving levels in the game and completion of an aesthetic quilt design led them to utilize decomposition to achieve those ends. The pattern recognition and decomposition practices exemplified in this study were crucial in the students' multidisciplinary approach to the development of thinking required for STEM disciplines. In this respect, the activities in the game and in Scratch, even though they took place in remote locations, allowed all students to express phenomenological aspects of computational thinking.

The challenges created by the COVID-19 pandemic, though real, also helped create new opportunities for us as researchers who turned to online settings as sources of interaction. In particular, we identified and faced three main challenges: (a) recruiting research participants which included instituting necessary revisions to ethics protocols; (b) rethinking data gathering and analysis techniques along with interactions with participants in virtual settings; (c) dealing with glitches associated with technologies and virtual communication media in just-in-time ways.

This meant we had to be flexible and open to contending with complications as they arose. By initiating revised ethics permissions from the university ethics review board, we were able to contact participants through known teacher associates and parents. Given the limited number of volunteers, however, we had to shift our online sessions to only one student participant at a time. In addition, we had to ensure students were comfortable in participating with their webcam on, sharing their screen, and sharing their thinking aloud which allowed researchers to observe and record embodied (e.g., body motion and the mouse position on the screen) and verbal data. There were technical complications that arose during the virtual interviews (e.g., missing data from zoom recordings or difficulties linking to the online game) which presented implications for thorough data analysis.

Even given the challenges faced in conducting online research however, we were able to engage in rich learning experiences for both the students and ourselves, as evidenced by Simon and Eric, who indicated they would like to continue working with us. In this sense, social aspects inherent in these computational thinking activities may enhance the interactions between participants, researchers, and teachers in online settings.

We contend that even given the challenges with conducting research during the time of COVID19, there are still opportunities for rich, robust study in online settings. Though we would have preferred to conduct research in student pairs with a broader range of participants, we did find that students drew on their own experiential background to enact computational practices that assisted them in achieving the goals they set within a game and Scratch environment.

ACKNOWLEDGMENTS

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MATERIALITY OF TABLETOP GAMES: EMERGENCE OF LEARNERS' DESIGNS AND MATHEMATICAL PROBLEMS

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ABSTRACT

Recent research shows that game design approach supports students' interestdriven learning while engaging them in systems thinking. On the other hand, there is very little research on how the materiality of tabletop games engage learners differently. In this study, grade 3 and 4 learners went through the process of playing and redesigning an existing tabletop game called, *Triominos*. It was conducted in a STEM learning classroom in a western Canadian school. Each group considered what they could change in the original game, and created a unique game that explored various shapes mathematically. We collected ethnographic data, including video recordings of the classroom, photos of students' in-progress and final games. We discuss three groups' materializing their ideas into playable game pieces, using different shapes (i.e., triangles, squares, and rhombuses). The findings demonstrate how learners encounter mathematics and pursue their own mathematical problems, forming assemblages of mathematical and game-making practices.

Keywords: *STEM learning, mathematics, game design, tabletop game, materiality*

INTRODUCTION

Recent research shows that game design approach supports students' interest-driven learning while engaging them in systems thinking (Baradaran Rahimi & Kim, 2019). Games indeed require a system of various meanings, such as game pieces that represent the system elements, the rules that govern the relationships among them, numbers or points that represent the values of their actions (Kim & Bastani, 2017). Players make progress by managing resources, determining moves, and responding to the consequences of their decisions (Salen & Zimmerman, 2006). Learners make numerous decisions while designing games to create these meanings while responding to the unexpected consequences and engaging in emergent goals and problems. Through this process, learners may develop unique relationships with the designed artifacts (i.e., their own games) and the knowledge they explored (Kafai, 2006; Kim, 2018; Kim & Reeves, 2007; Kim, Tan, & Bielaczyc, 2015). Many game designers would argue that any game play or design would require and resemble mathematical thinking exhibited in everyday practices. Mathematical goals, seen in assembling, coordinating and communicating household resources (Stevens et al., 2006), indeed emerge in learners' boardgame play (e.g., Treasure Hunt; Saxe, 1992).

In this paper, we consider the materiality of mathematical meanings, which influence learners' engagement in mathematics as well as their decisions of using and understanding what they see and observe. We advocate learners' designing of games, especially tabletop games, for the potential offered to learners to think and learn with their evolving artifacts. In the recent mathematical education literature, the agency or the distributed nature of designing artifacts are recognized as significant not only for a deeper conceptual understanding but also for growingtogether (e.g., Roth, 2016). At the same time, learners' gestures and movements coupled with other symbols and materials express mathematical ideas (Alibali & Nathan, 2012; Ferrara, 2014). The agentic view toward materials are relevant to the views that see the materials as part of an assemblage or a collective for the meaningful mathematical activities (e.g., de Freitas & Sinclair, 2013; Nemirovsky & Ferrara, 2009). We suggest that understanding learners' developing relationship with knowledge and materials are fundamental to our improving the designs of learning environments. We take the agentic view of the materials and artifacts that learners' designs emerge from the choices they make as well as the forms that take shapes and evolve (Kim, Rasporich, & Gupta, 2019). Taking this perspective, the purpose of this paper is to explore how the materiality of tabletop games engages learners in different problems and how different mathematical practices emerge through the design process.

RESEARCH DESIGN

This study was conducted in an urban Canadian elementary school during the second year of a design-based research (DBR). The research was focused on engaging students in game design for mathematics learning by co-designing the lessons with teachers and engaging in reflective inquiry into this practice (Collins, Joseph, & Bielaczyc, 2004). In our co-design sessions, teachers played games, engaged in redesigning those games, and brainstormed how they could engage their students in similar activities with the researchers and a professional game designer.

Ms. Lennox was teaching STEM classes for varying grades, and we have decided to focus on a combined grade 3/4 class for this project. Early in the year, students played a variety of games for their mathematics learning. The teacher and grade 3/4 students selected *Triominos* as a game to redesign during their STEM learning class. As a two to four player game, each player starts with 79 tiles out of 56 triangular tiles. Each tile has three numbers (between 0 and 5) in three corners. They earn points by matching two numbers on one side of the triangle, and first player to reach 400 points wins the game. Learners' task was to redesign *Triominos* as a paper-crafted game to explore different shapes and numbers or symbols and change the game rules. Figure 1 shows the chart paper used to discuss the rules of *Triominos* at the beginning of the project.

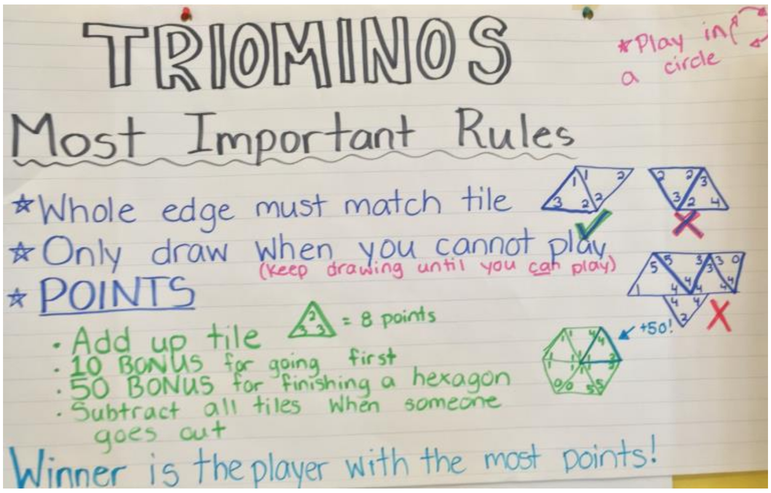


Figure 1. Discussion on the rules of *Triominos*

Throughout the six weeks of redesigning games (two or three 45-minute sessions a week), we collected ethnographic data of observation notes, video recordings of the classroom, and photos of the students' evolving game designs. Ms. Lennox sometimes held a small action camera during her conversations with the groups. For this paper, we analysed how learners' design decisions led to different mathematical problems while going through the iterations of materializing their game ideas.

We first identified the episodes where the groups made design decisions, or their previous choices were influencing their mathematical or design problems. We then analysed how learners used their evolving materials and artifacts as part of the assemblages of their mathematical cum game-making practices.

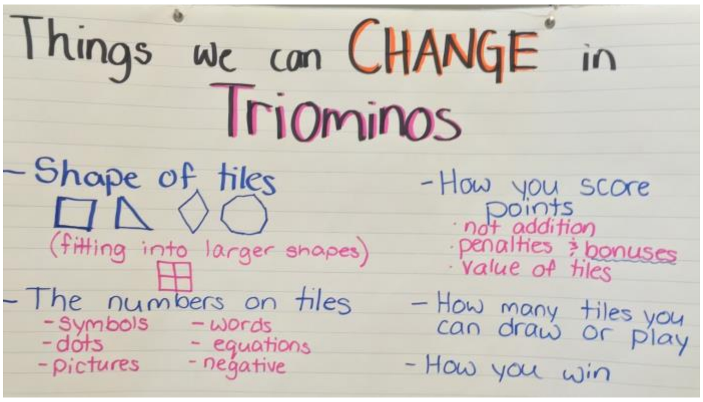
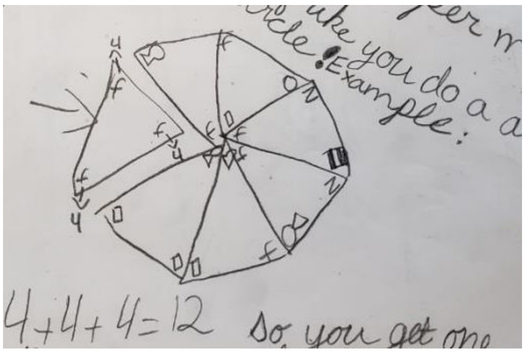


Figure 2. Discussion on the things to change in *Triominos*

FINDINGS AND DISCUSSION

Students initially came up with some individual ideas to redesign *Triominos* after discussing what they could change from the game (see Figure 2). Students explored different shapes (e.g., squares, rhombuses, circles, stars, right triangles) and different numbers or symbols (e.g., shapes, letters, symbols from *Pokémon*). Ms. Lennox then assigned three to four students in a group based on the similarity of individual game ideas, especially the shape of tiles they chose to change. The choice of the tile shape indeed influenced group’s mathematical encounters. In the following, we briefly exemplify our findings through three groups that chose different shapes. Their games were called, *Squareominos*, *Riominos*, *Rhombinoes (Wild Edition)*. We briefly discuss the overall patterns of materializing their redesign ideas.

(a) 

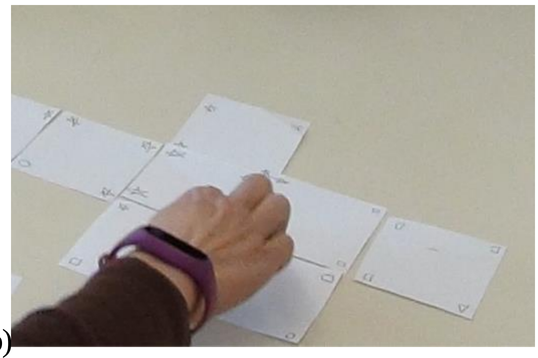
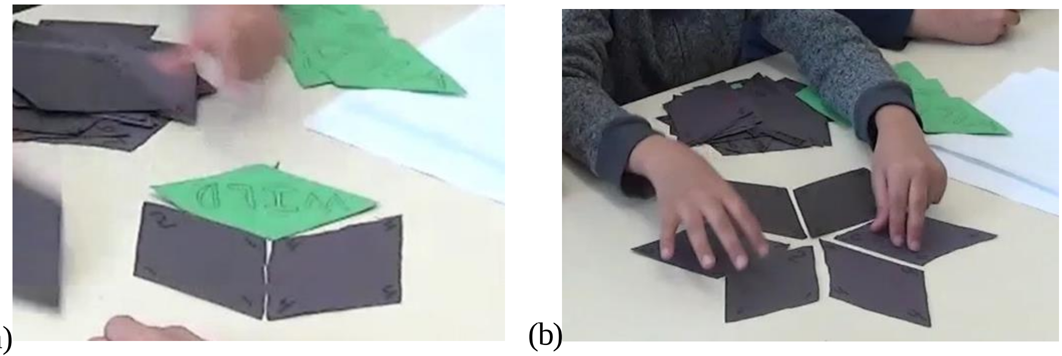
(b) 

Figure 3. Creating a bigger shape in the game: (a) *Riominos*’ rulebook on creating a hexagon; (b) Creating a bigger square while playing *Squareominos*

Encountering the Rules of Shapes

We observed that students come to use shapes and their patterns deeply in their designs overtime. In creating rules, they considered what shapes they could make out of arranging their game pieces (e.g., squares to bigger squares, right rectangles to square or rhombuses), and how to create rules when making those shapes (e.g., earning bonus points). *Riominos* (by Mina, Amal, Lail) stayed with triangles, *Squareominos* (by Mimas, Uranus, Apollo) used squares, and *Rhombinoes - Wild Edition* (by Kia, Dennis, Aron) used rhombuses. *Riominos* was one of the groups that were able to test their games multiple times and adjust their rules. In terms of exploring the rule of shapes, *Riominos* stayed with triangles with the rules of *Triominos* (see Figure 1), where being able to match all three sides was rewarded by adding values of all three corners of the placed tile when creating a hexagon, although the drawing was incorrectly done with seven triangles (Figure 3a). They did not explore creating other shapes (e.g., a bigger triangle, rhombus, parallelogram) that do not require matching three corners.



(a) (b)

Figure 4. Aron demonstrating making bigger shapes with *Rhombinoes* during interview: (a) hexagon; (b) hexagram or 6-pointed star

Creating a bigger square (e.g., 2´2) while playing *Squareominos* (Figure 3b) could happen more frequently, also matching three corners. They created the rule that the player would be rewarded by adding up all the values of the four tiles. During the interview, they realized that they have not ruled out other shapes (e.g., rectangles or 3´3 squares), which made a player to win by far greater points. In creating rules with their rhombus pieces, *Rhombinoes* group also proposed rewarding players making two different shapes that require matching three corners, that are hexagons and hexagrams (or 6-pointed stars) (Figure 4). These three groups' game-making processes were intermingled with their exploration of shapes and accompanying rules. The shapes they initially chose influenced their decisions, as well as their mathematical exploration of various geometric shapes.

(a) (b) (c)

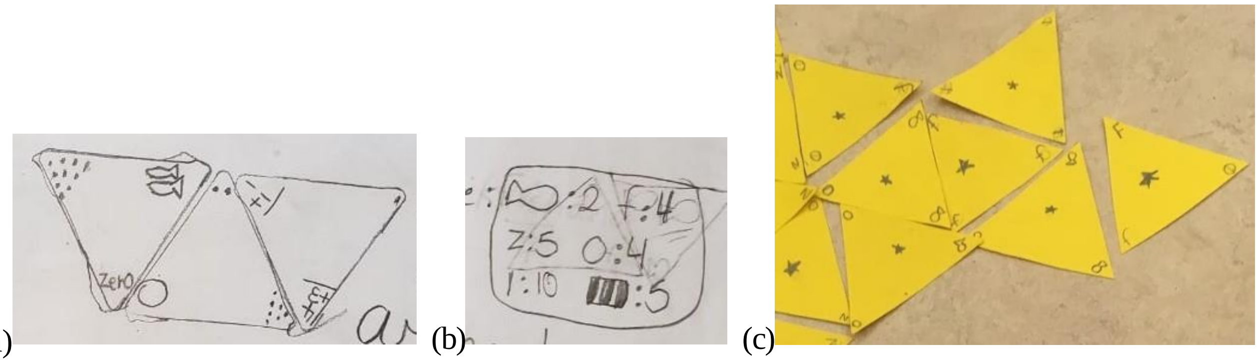


Figure 5. *Riominos*' symbols: (a) Earlier version; (b) Final choice and values of symbols; (c) Play

Encountering the Rules of Symbols

Groups realized the consequences of having four corners (i.e., rhombuses and squares) rather than three corners (i.e., triangles). At the same time, they explored numbers versus letters or other symbols as well as how many of variations they need to have for their pieces. Following the existing triangle shape of *Triominos*, the members of *Riominos* tried out variations from early on (Figure 5a).

They initially wanted to create a game that had a mixture of words, operations, symbols repeated, and so forth. They finally decided to have a combination of letters, symbols, and numbers that essentially resulted in a game required less game pieces using a very similar game logic as *Triominos*. They used two groups of symbols, and three symbols in each group can be matched (Figure 5b; from top left, fish shape, f, z, 0-zero, **I**- French fries, **III**- zebra). One group includes f, fish, French fries, and the other has z, zero, and zebra. The players gain points by matching the symbols as indicated in Figure 5b. The right most piece in Figure 5c shows that the player was matching "f" with fish, and the player gains 8 points by matching two fs (4 points each). The number of points they determined might be relevant to how hard they could match them (e.g., having smaller number of pieces with French fries symbols), but they could not clearly explain it during the interview.

(a)  (b) 

Figure 6. The symbols of games pieces: (a) *Squareominos*; (b) *Rhombinoes - Wild Edition*

Squareominos decided to use four different shapes as their symbols (Figure 6; stars, squares, triangles, circles) after trying using numbers (0-10) and having difficulties. They put the values based on how many sides each shape has (i.e., star = 10 points, square = 4 points, triangle = 3 points, circle = 1 point). With the limited number of symbols, they were able to create a game playable after making the change. *Rhombinoes* group, on the other hand, had trouble making all the pieces after deciding to use 1-6 on their rhombus pieces. The students had to systematize their crafts considering the number of cases they needed to have, but it was a challenging task for this group considering the variations they needed to come up with four corners and six numbers, as well as the amount of craft work (i.e., cutting the right size pieces and writing numbers). After seeing what other groups were doing, they came up with the idea of adding wild cards that could be placed anywhere during the play, instead of creating all combinations. They also added "Wild Edition" as part of the game title. The use of symbols were learners' choices, but at the same time, their choices might not have been carefully considered. The learners' continued making activity and playtesting with the partially crafted game, on the other hand, helped them grow with their designs.

CONCLUSIONS

This research provides insights on how the acts of redesigning and making tabletop games embody mathematics and how the choice of the original game brings about different challenges and mathematical encounters. Our findings demonstrate how the materiality of tabletop games challenged learners both mathematically and practically beyond the mathematics topics they were exploring. It also shows that learners' designs emerged from the choices they make as well as the forms that take shapes and evolve. We argue that redesigning and making tabletop games not only help learners make meaningful connections between mathematics and their designs, but also engage learners in mathematical problems and practices unique to their own games.

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RECOGNITION OF STEM HUMAN RESOURCES COMMUNITY BY HIGHER EDUCATION STUDENTS IN JAPAN AND MALAWI

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ABSTRACT

The Japanese government is currently promoting a wide-ranging transformation of the higher education system and its policies. They are calling for competencies that they consider key to primary and secondary education, fostering a competency model that the Japanese government calls "Zest for life" and calling for academic abilities to be continued into higher education. To examine the role of such competencies in the international framework, it is necessary to conduct comparative studies that take into account the cultural background of the respondents. This study focuses on the consciousness and recognition of the key skills required for STEM (Science, Technology, Engineering and Mathematics) careers among students during their early years of higher education, comparing responses by gender. The following research questions were used to direct this study: (1) What competencies do students perceive to be necessary for a STEM career, and do these perceptions differ by gender? (2) To what extent do students desire to develop core competencies in STEM? Significant differences were confirmed in 5 of the 21 ability elements in the *t*-test results for male and female values. Students reported a low recognition of the importance of 12 out of the 21 ability elements. These results indicate a gender gap in the perceptions of competencies required for STEM human resources, and potential difficulty may arise in recognizing the need to develop competencies due to the low level of clarity on the nature of the STEM careers. For further study on this topic, additional interviews or surveys could be conducted.

Keywords: *STEM education, higher education, competency of STEM, nature of STEM, gender of STEM*

INTRODUCTION

The Japanese government is currently promoting a large-scale transformation of the higher education system and its policies. This is being done under the "Zest for life" rubric, guiding the revised concept and competency model of the Japanese government for the Course of Study in Japan since 2002. The Central Education Council of Japan (2014) asserted that the cultivation of competencies currently included in primary and secondary education, including fostering a zest for life and the three elements of academic abilities, should be continued in higher education. For this purpose, they have altered the basic policy of Japanese higher education. Fostering the competencies of zest for life and academic ability, on this understanding, involves the following aspects: (1) richness in humanity, (2) health and physical fitness, and (3) academic ability (Central Education Council of Japan, 2008). Academic ability is assessed in terms of the three categories of (1) knowledge and skills; (2) thinking ability, judgment, and expression; and (3) initiative and collaboration (Ministry of Education, Culture, Sports, Science and Technology, 2007).

Simultaneously, the Cabinet Office of Japan (2016) is promoting the idea of Society 5.0. One definition of this concept is that of a human-centered society that balances economic advancement with the resolution of social problems through a system that deeply integrates cyberspace with physical space (Cabinet Office, 2016). Society 5.0 for education includes a process for which the Minister's Meeting on Human Resource Development for Society (2018) defined STEM (Science, Technology, Engineering and Mathematics) and citizen common competence as (1) the ability to accurately interpret and respond to writing and information; (2) the ability to engage in and apply scientific thinking and inquiry; and (3) the sensitivity and ability to discover and create value, curiosity, and inquisitiveness.

On the industry side, the Japanese Ministry of Economy, Trade and Industry (METI, 2006) is promoting what it calls communities of Fundamental Competencies for Working Persons. On this telling, society (especially in Japan) has a high demand for human resources that have the basic skills required to work in organizations and communities. These consist of 3 competency categories and 12 competency factors developed by a committee including intellectuals from business and academia. The 12 competency factors, divided into the 3 competency categories, are (1) the ability to step forward (action), taking initiative, ability to influence, and execution skill; (2) the ability to think through (thinking), detecting issues, exhibiting planning skills, and being creative; and (3) the ability to work in a team (teamwork), delivering messages, listening closely and carefully, being flexible, grasping the situation, applying rules and regulations, and controlling stress.

There are many skill sets, competency models, and frameworks available: among these are, for example, 21st-century skills (The Partnership for 21st Century Learning, 2015) and key competencies (Rychen and Salganik, 2003). These competency models share many keywords and have similar contents. Many countries are currently taking action in pursuit of higher education transformation. In the United States, the government is promoting STEM competencies as an important means of developing the economy. The US wishes to take action to decrease the dropout rate among students in STEM majors (PCAST, 2012). When this policy was advocated in 2012, its aim was to increase the number of people who gained a degree in a STEM field over the following 10 years by one million. The policy recommended an expansion of the First-Year Experience (a program for first-grade students), recognizing that fundamental skills are important for developing human resources in STEM.

The Organisation for Economic Co-operation and Development (OECD, 2015) has found that comparative study is possible in certain cultural areas because competencies remain the same. Where we can grasp these competencies within an international framework, comparative study is necessary because of the varying cultural backgrounds of the target respondents, although comparison is also possible within a single cultural or linguistic sphere. It can thus be assumed that the STEM community has a unique culture and background and that in focusing on the STEM community, it will become possible to compare the perceptions of competencies required by STEM human resources on a global scale.

In this study, I focus on the consciousness and recognition of abilities required for STEM careers, taking into account differences by gender among students in the early years of higher education. The following questions guided this study: (1) What competencies do students perceive to be necessary for a STEM career**,** and do these perceptions differ by gender? (2) To what extent do students desire to develop core competencies in STEM?

OVERVIEW OF THE CASE

In this study, I surveyed Japanese and Malawian students to conduct a comparative study of students in different cultures. The Japanese students were composed of 228 first-year university students (male, 172; female, 56) studying at the Faculty of Science at a National University, and the survey was conducted at the end of their second academic quarter. For graduates of this university, whose students major in mathematics, physics, chemistry, biology, or geography, approximately 30% can expect to find a job after graduation, approximately 30% can expect to become schoolteachers, and the remaining 30% will attend graduate school.

There were 82 Malawian students, in their first or second year of study (male, 36; female, 29; not answered, 17) at an Information and Communication Technology vocational school, and the survey was conducted at the end of the year. Malawi is one of the poorest countries in the world, with a per capita gross national income of 320 US dollars (World Bank, 2018). It emphasizes science and technology as a strategy for economic growth in its national policy (The Republic of Malawi, 2017). For many years, the Japanese government has provided educational support in science and mathematics to Malawi as a form of Official Development Assistance. The main areas of support are elementary and secondary science education.

METHOD

This study, which focuses on the consciousness and recognition of STEM competencies, surveyed on the abilities required for STEM careers. The questionnaire items covered the following general areas: (1) the importance of STEM skills and abilities for people seeking STEM careers and (2) the degree to which the respondents hoped to improve their skills/abilities. The ability elements included 21 items based on the Fundamental Competencies for Working Persons (Ministry of Economy, Trade and Industry, 2006) instrument. All items in the Question (1) of the questionnaire took replies on a 5-point Likert scale, with values of 5, very important; 4, important; 3, somewhat important; 2, not very important; and 1, not at all important. In the Question (2), the 5-point Likert scale had the following values, 5, very much; 4, much; 3, some; 2, a little; and 1, not at all. Averages were calculated for both sections.

RESULTS AND DISCUSSION

Table 1 presents the combined results. It should be noted that there is a majority of positive responses, along with a difference in the male and female responses.

In the first portion of the questionnaire, 12 out of the 21 items had higher values among the male respondents, and 8 had higher values among the female respondents. In addition, the results of the *t*-test revealed that 5 items showed a significant difference (independence, ability to transmit, listening, stress control, and ethics; $p < .01$). This appears to imply that the male respondents exhibited a strong awareness of the importance of stress control, whereas the female respondents placed importance on communicating and listening, emphasizing ethics. For this reason, no significant difference has been confirmed, although the responses of the female respondents indicate a higher value with respect to the communication figures. Although the numbers are high for almost all items, there is a serious possibility that the perceptions of the elements required for STEM personnel differ between the male and female respondents.

The results also confirmed a correlation between students' perception of the elements required for STEM personnel and the abilities that they wanted to improve (Table 2). The correlation coefficient for corresponding competencies is shown in Table 2. Of the 21 items, 12 showed a low correlation, with a significant difference at the 10% level. Therefore, there is a high possibility of a difference between the importance assigned to an ability for STEM personnel and the desire to improve that same ability. This may be because the respondents were not able to specifically recognize what they want to improve. The students surveyed were also in the early stages of higher education, which implies the possibility of a discrepancy between their specific professional perceptions and their own later career. Furthermore, given that the values in Table 1 indicate a weak awareness of career, it may have been difficult for the students to think specifically about their future.

Table 1. STEM human resources community ability *t*-test

		MALE Mean (SD)		FEMALE Mean (SD)	t	df
1	Expertise (general)	4.30 (0.816)		4.25 (0.948)	0.457	285
2	Leadership	4.18 (0.843)		4.14 (0.828)	0.337	285
3	Management	4.02 (0.816)		3.92 (0.844)	0.968	286
4	Information, Media, and Technology Literacy	4.20 (0.774)		4.16 (0.848)	0.372	286
5	Initiative **	4.26 (0.699)	>	3.99 (0.890)	2.790	286
6	Ability to Influence Others	4.22 (0.678)		4.13 (0.777)	0.998	286
7	Executing Plans	4.55 (0.622)		4.47 (0.754)	0.887	286
8	Ability to Detect Issues	4.54 (0.645)		4.48 (0.802)	0.605	286
9	Creativity	4.48 (0.661)		4.42 (0.701)	0.700	286
10	Critical Thinking	4.36 (0.676)		4.36 (0.774)	-0.005	286
11	Collaboration	3.82 (0.917)		3.86 (0.828)	-0.267	286
12	Communication	4.28 (0.772)		4.42 (0.783)	-1.410	285
13	Innovation	4.06 (0.786)		4.05 (0.731)	0.152	286
14	Ability to Deliver Messages *	4.18 (0.841)	<	4.36 (0.774)	-1.691	286
15	Ability to Listen Closely and Carefully **	4.18 (0.829)	<	4.41 (0.766)	-2.170	286
16	Flexibility	4.42 (0.741)		4.39 (0.839)	0.339	286
17	Ability to Grasp Situations	4.35 (0.737)		4.37 (0.907)	-0.199	128
18	Ability to Apply Rules and Regulations	4.06 (0.935)		4.20 (0.947)	-1.159	286
19	Ability to Control Stress *	4.11 (0.879)	>	3.89 (0.856)	1.901	286
20	Ethics ***	3.89 (1.03)	<	4.28 (0.928)	-2.987	286
21	Career Development and Planning	3.86 (0.942)		4.00 (0.733)	-1.362	194

※ * : p <.1 ** : p <.05 ***: p<.005

Table 2. STEM human resources community ability and student recognition correlation

	N	r			N	r	
1 Expertise (general)	300	-.345	***	12 Communication	299	.025	
2 Leadership	301	.008		13 Innovation	301	-.233	***
3 Management	302	-.091		14 Ability to Deliver Messages	301	-.112	
4 Information, Media, and Technology Literacy	302	.030		15 Ability to Listen Closely and Carefully	300	-.143	
5 Initiative	302	-.307	***	16 Flexibility	300	-.249	***
6 Ability to Influence Others	301	-.264	***	17 Ability to Grasp Situations	300	-.205	***
7 Executing Plans	302	-.326	***	18 Ability to Apply Rules and Regulations	300	-.016	
8 Ability to Detect Issues	301	-.311	***	19 Ability to Control Stress	300	-.131	**
9 Creativity	301	-.345	***	20 Ethics	300	-.092	
10 Critical Thinking	301	-.071		21 Career Development and Planning	300	-.122	**
11 Collaboration	300	-.148	*				

※ * : r <.1 ** : r <.05 ***: r<.005

CONCLUSIONS

This study focused on STEM students' perceptions regarding abilities. A significant difference of 10% was found between the male and female respondents for 5 out of the 21 competencies, showing gender differences within the STEM student community. Additionally, 12 out of the 21 ability elements showed a low correlation between the recognition of the importance of STEM abilities and students' desire to obtain these abilities. We note a gender gap here with respect to the perception of requirements of STEM human resources, as well as a potential difficulty in projecting into the future, as there can be little present knowledge of these students' future careers.

However, this research had certain limitations. First, it took data from only two countries. It is, therefore, necessary to gather more country data. The study also has not been able to adequately investigate the consciousness of the respondents and the framework of recognition. For future research, it will be necessary to gather additional data via interviews and questionnaires.

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INCLUSION IN A STEM INNOVATION HUB: PERSPECTIVES OF TEACHERS AND ADMINISTRATORS

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ABSTRACT

The purpose of this study was to explore teacher and administrator perspectives on STEM education in two STEM Innovation Hubs. This was done as part of a larger study to evaluate the effectiveness of our STEM Innovation Hub sites. Including a STEM approach to education can prepare students for the future by teaching them skills such as critical thinking to address issues in society. A qualitative approach was used to collect data. Data were collected through interviews with school-based leaders and teachers, artifacts such as STEM family night materials and posters, and observations from STEM family nights and various professional meetings. Data are being analyzed using thematic coding. As data collection and analysis is still ongoing at this time, many findings will be forthcoming. However, preliminary results indicate that one of the schools has a more positive STEM culture, for various reasons, and the other school may need more district support to develop this culture among students, teachers, and administrators. As data analysis continues, we hope to further reveal what teachers and administrators need and want as a STEM Innovation Hub site in order to continue to provide support or change our approach in order to better support schools. This study will add to existing research by exploring both teacher and administrator perspectives on STEM education.

Keywords: *STEM education, teacher perspectives, administrator perspectives*

INTRODUCTION

We are both part of the STEM team in the school district where this research took place. Our definition of STEM education involves students engaging in problem-based learning, participating in engineering and design challenges, being exposed to coursework and experiences that can support future employment in STEM fields, and having opportunities to engage with the community through mentoring and research opportunities.

Purpose of Study

Our purpose for this research was to explore teachers' and administrators' (principals and assistant principals) perspectives on STEM education in their schools in order to determine factors that are facilitating or hindering the inclusion of STEM. This was done as part of a larger study to evaluate the effectiveness of our STEM Innovation Hub sites and for us to ultimately use this information to better support schools. In this study, we focused on two of these Hub sites which will be identified as pseudonyms: school A and school B.

The following research questions guided this study:

- What are teachers' and administrators' perspectives on participating in STEM Innovation Hub sites?
- What factors facilitate or hinder the integration of STEM in our schools?

- In what ways can district personnel help support teachers and administrators in our STEM Innovation Hub sites?

Overview of STEM Innovation Hub Sites

Although the district has been working to increase STEM efforts in our schools for several years, the STEM Innovation Hub concept began in 2017 with the first cohort of eleven STEMfocused schools. In 2018, 16 more schools were added and then in 2019, two more schools were added to existing Hubs.

Through a collaborative effort between these schools, the central district office where we are based, and community teams, the STEM Innovation Hub concept provides schools with district and community resources to positively influence STEM culture within schools, collaborate across schools, increase the STEM identity of teachers and students, and improve student achievement in all subject areas. Among other things, STEM Innovation Hubs are provided with teacher professional development to assist with the integration of STEM in their classrooms, a funded STEM family night for teachers and administrators to share STEM initiatives with parents, and special invitations to participate in various STEM events in the district.

The district is subdivided into five smaller areas and each area is assigned an area superintendent. About half of our STEM Innovation Hubs are part of Area 2. The Area 2 superintendent has a strong belief in STEM education and is very supportive of integrating STEM into schools. The two schools selected for this study are both located in Area 2.

Issue and Rationale

We view the integration of STEM in our schools as essential to quality education. Alienation from STEM disciplines in schools is an issue because students lack a foundation to prepare them for jobs that address social problems. Participating in STEM activities in school can help build a STEM identity and improve attitudes towards science (Chapman & Feldman, 2017; Dou, Hazari, Dabney, Sonnert, & Sadler, 2019; Sorge, Newsome, & Hagerty, 2000), which is linked to the likelihood of pursuing STEM careers in the future (Dou et al., 2019).

Previous research has demonstrated that school personnel view STEM education as important (El-Deghaidy, Mansour, Alzaghibi, & Alhammad, 2017) and recognize the significance of engaging in STEM activities, such as engineering design challenges (Lesseig, Slavit, & Holmund-Nelson, 2017). However, teachers may not feel like they possess the skills needed to effectively teach using STEM approaches (El-Deghaidy et al., 2017). Teachers and administrators need to understand the importance of STEM and how to effectively implement STEM pedagogy in their classrooms and schools before they can be an effective STEM Innovation Hub site. For this to happen, teachers and administrators may need to engage in additional professional development to enhance their understanding of STEM education to increase student learning and engagement (Hall & Miro, 2016).

As part of the STEM team in the school district, we wanted to better understand how to support our STEM Innovation Hub sites. As school-based leaders and teachers are a main driving force in the integration of STEM, their perspectives were specifically taken into consideration. Using the data collected as part of this study, we attempted to identify factors that both facilitate and hinder STEM efforts in our schools and develop ways to move forward with these schools to maintain and improve the quality of STEM education in our school district.

CONCEPTUAL FRAMEWORK AND BACKGROUND INFORMATION

For STEM efforts to be successful, the support of school personnel and other stakeholders is essential (El-Deghaidy et al., 2017). Teachers' and administrators' perspectives on STEM education should be considered when evaluating the effectiveness of STEM initiatives (Tofel-Grehl & Callahan, 2013). This study is based on literature on perspectives of school personnel and characteristics of effective STEM schools.

Teacher and Administrator Perspectives on STEM Education

Previous research has demonstrated that school personnel view STEM education as important (Asunda & Walker, 2018; El-Deghaidy et al., 2017; Madden, Beyers, & O'Brien, 2016; Tofel-Grehl & Callahan, 2013) and recognize the necessity of engaging in STEM activities (Lesseig, et al., 2017). Teachers and administrators have also acknowledged the importance of creating a STEM community within the school (Tofel-Grehl & Callahan, 2013).

However, teachers have also demonstrated concern with implementing STEM approaches (Asunda & Walker, 2018). This may be because they lack the support needed to include STEM pedagogy in an effective manner (Asunda & Walker, 2018; El-Deghaidy et al., 2017). Some research has even shown that school personnel may need to learn to collaborate with each other and identified this as the most difficult part of STEM initiatives (Asunda & Walker, 2018). Other potential obstacles to STEM education include the need for out of school programs, access to current STEM content, appropriate school facilities and tools for students to engage in STEM, and hands-on training for students (Eijwale, 2013). Because of these potential barriers, schools want and need support when including STEM pedagogy and content as a focus.

Effective STEM Schools

Teacher self-efficacy and pedagogical knowledge, collaboration within schools and other stakeholders, and a positive STEM culture and community involving all stakeholders have been identified as factors that contribute to an effective STEM-focused school (El-Deghaidy et al., 2017; LaForce et al., 2016).

STEM education requires a different culture than non-STEM focused schools (El-Deghaidy et al., 2017; LaForce et al., 2016). This involves collaboration between stakeholders and building a supportive community within and between schools. Through discussions between teachers and administrators, a more positive STEM culture can be fostered. This can help students create a stronger STEM identity (Dou et al., 2019; LaForce et al., 2016) and develop STEM knowledge and higher-order thinking skills (Fan & Yu, 2017).

Teachers need to feel confident in teaching using STEM approaches in order to effectively portray the STEM focus of their schools (El-Deghaidy et al., 2017). Providing professional development to advance knowledge in STEM pedagogy may be necessary to prepare teachers and administrators for participation in a successful STEM school (Asunda & Walker, 2018; Eijwale, 2013). Done in an effective manner, these trainings can facilitate student learning opportunities (Hall & Miro, 2016; Lesseig et al., 2017). In this study, we explored teacher and administrator perspectives to determine the types of professional development needed in order to best serve our STEM Innovation Hub sites.

RESEARCH DESIGN

Site Description and Participants

This study took place in a large school district located in the southeastern United States. This school district employs over 15,000 teachers with over 200,000 students enrolled and is the eighth largest district in the country (County School District, n.d.).

Participants were recruited from two of our STEM Innovation Hub sites located in the western part of the district (school A and school B). These schools are similar in demographics and are also geographically close. The area superintendent is the same for both schools and he has a strong belief in STEM education. These schools were chosen for this study because as district employees, we have noticed a difference in how these schools approach STEM education and participate in the STEM hub.

Teachers and administrators at both school sites were interviewed for this study. Participants were recruited via email and interviewed to provide feedback on STEM initiatives in the district and their participation as part of a STEM hub.

Data Collection

We used a multiple case study approach in this research to explore real-life, bounded cases over time using multiple sources of information (Creswell, 2013). Data was collected from a variety of sources including interviews, observational notes from meetings and STEM family nights, and artifacts such as STEM posters created by the schools and STEM family night documents. We interviewed principals, assistant principals, and science and math teachers. Interviews were recorded and transcribed. Observational notes were recorded at STEM hub meetings, STEM family night meetings, and various other professional learning meetings.

Data Analysis

Thematic coding was used to analyze the data (Stake, 1995). Data were coded using a hybrid approach of inductive and deductive coding (Fereday & Muir-Cochrane, 2006) to look for patterns and relationships within and between cases (Creswell, 2013; Stake, 1995). Prior to data collection, an initial a priori codebook was created from the research questions and the research literature on STEM education. As the research progressed, data were coded using the initial codebook as a guide and additional inductive codes were added (Fereday & Muir-Cochrane, 2006; Miles et al., 2014).

Each case was analyzed separately for its own situational issues, and then cross case findings were analyzed to look for similarities and differences across the cases (Stake, 2006). The cross-case analysis was conducted in order to deepen understanding about teacher perspectives on STEM education (Miles et al., 2014). Findings between the two cases were compared to look for patterns and make assertions about the two cases.

RESULTS AND DISCUSSION

Data collection and analysis are still ongoing. However, preliminary findings indicate that both schools share a similar supportive network of leaders in the district and other schools in the STEM hub. However, while both schools have similar support systems and student populations, school A is not as invested in STEM activities at the school and is less collaborative with other schools in the hub. This school has not exhibited as much interest in participating in events, such as STEM family nights, and have yet to reach out for support.

School B has had more time to build a positive STEM culture as they were part of the first cohort of STEM Innovation Hubs. They also had existing STEM programs prior to their inclusion in the STEM hub, such as a successful robotics club. As school A was part of the second cohort, it is possible they need more time to develop a STEM culture. As district employees, we will create a plan of action to help school A build a more positive STEM culture among school leaders and students. While we do provide a "STEM mindset training" to our STEM Innovation Hub sites, we may need to offer additional support to help create this culture and be mindful that support requires more than providing a school the opportunity to be part of a STEM hub.

CONCLUSION

Results show there is a difference in STEM culture between school A and school B. This may be because of the time each school has had to develop a positive perspective on STEM education. Moving forward, we will provide additional support to school A to ensure their success as a STEM Innovation Hub site.

Significance

Participating in STEM activities in schools can help build a STEM identity and improve attitudes towards science (Chapman & Feldman, 2017; Dou et al., 2019; Sorge et al., 2000), which is linked to the likelihood of pursuing STEM careers in the future (Dou et al., 2019). Alienation from STEM disciplines in schools is an issue because students lack a foundation to prepare them for jobs that serve society by taking on social problems. Therefore, this study was focused on improving STEM education in our school district to better prepare students for the future. This research allowed us to reflect on STEM integration in our schools as district leaders and to also develop a plan moving forward to better support our STEM Innovation Hub sites in providing quality STEM education to our students.

Contribution to Existing Research

While some research exists on effective STEM schools, there is little research on STEM Innovation Hubs and how they can contribute to the effective implementation of STEM approaches. This study will add to the existing research by exploring both teacher and administrator perspectives on STEM education. It will also provide an example of district employees reflecting on our role in STEM education and developing a plan of action to move forward.

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DEVELOPMENT AND IMPLEMENTATION OF CITIZEN SCIENCE BASED STEAM PROGRAMS FOR ELEMENTARY STUDENTS IN KOREA

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ABSTRACT

In this study, we developed and evaluated the effectiveness of citizen science based STEAM programs for elementary students in Korea. As students participate in identifying and solving real-life problems and exercising scientific process of identifying problems, gathering, analysing and interpreting data, they are able to develop self-directed learning, inquiry skills as well as scientific knowledge. In particular, we employed Positive Behavioural Interventions and Supports (PBIS) teaching and learning model as a framework for students to find solutions to authentic problems through collaboration among students. We developed citizen science based STEAM programs for students and accompanying teachers' guide. The specific topics of the programs include 'Noise! Who are you?' (3rd grade), 'Creative idea competition for reducing light pollution' (4th grade), and 'Where are X-rays in our everyday life?' (6th grade). The developed programs were implemented in 10 elementary schools with 588 students for pilot-testing. The participating teachers reported that the topics were closely related to students' everyday life and in turn, students' interests in the programs were high. However, the teachers felt the contents were somewhat difficult for the target learners and a lack of time was always an issue. About 80% of the participating students reported that the programs were interesting. The students were particularly satisfied that they were able to study real-life problems through interdisciplinary approaches and had an opportunity to solve problems through collaboration with peers. Besides students' scientific understanding, students also were able to develop core competencies such as self-efficacy, communication skills, and problem-solving skills.

Keywords: *citizen science, elementary school, STEAM program, authentic inquiry, collaboration*

INTRODUCTION

Citizen science is scientific research conducted, in whole or in part, by amateur (or nonprofessional) scientists (https://en.wikipedia.org/wiki/Citizen_science). Alternatively, citizen science also refers to the participation of nonscientists in the process of gathering data according to specific scientific protocols and in the process of using and interpreting that data (Lewenstein, 2004).

Situated learning (Lave & Wenger, 1991) defines learning is a process in which individuals gradually participated in a community of practice from legitimate peripheral participation to acquiring a core membership. According to this situated learning theory, learning science can mean a participation in a community of scientists understanding and exercising same ways that scientists think, communicate and practice in their everyday culture. Nonetheless, many of school science practices have been criticized for a lack of relevance to authentic problems in students' real-life. School science has been more focusing on acquiring scientific knowledge rather than participating in scientific community. Compared to the traditional school science, citizen science can provide students opportunities to experience authentic science processes more like scientists.

STEAM (Science, Technology, Engineering, Art and Mathematics) is designed to provide students with interdisciplinary understanding of real-world problems. Real-world problems cannot be solved with knowledge of single subject. To solve real-world problems, students need to identify the problems as complex issues and integrate various knowledge, skills and competences from various disciplines. Thus, citizen science and STEAM shares a common aspect of learning and understanding science as authentic inquiry process.

In this study, we designed and developed citizen science based STEAM programs for elementary students from grade 3 to grade 6 in Korea. Through the citizen science based STEAM approach, we believe students would be able to experience more authentic scientific inquiry process compared to the traditional school science. Through this authentic inquiry process, students are expected to develop interests in science and technology and foster creativity, critical thinking, communication and collaboration competences as well as scientific knowledge. We developed the STEAM programs and evaluated educational effectiveness of these programs by implementing the program in 10 different elementary schools with 588 students. Our research questions were:

Q1; What are the characteristics of experiences the participating students and teachers in the citizen science based STEAM programs have?

Q2: To what extent are the participating students and teachers satisfied with the STEAM programs? What are the obstacles the teachers have when they implement the programs?

LITERATURE REVIEW

Citizen Science

Citizen science refers to public participation in scientific research including data collection and analysis by non-professional scientists often in collaboration with or under the direction of professional scientists and scientific institutions. Other researchers extended the definition to include public engagement in science related policy decision making process and engagement of scientists in the democratic and policy process (Dickinson & Bonney, 2012; Irwin, 2003; Lewenstein, 2004; Sismondo, 2010).

Students also can participate in citizen science through awareness of various real-world problems around themselves such as light pollution, fine dust, and global warming issues. By collecting scientific data around each of the participants, the community can efficiently develop a big database and effectively come up with a solution through collective intelligence. Students can foster scientific inquiry skills, awareness and responsibility of citizenship, and collaboration, creativity and problem-solving skills necessary for the future (Wilson, 1998).

STEAM Literacy

There is no single real-world problem that can be solved by knowledge from one subject only. The future society would require more interdisciplinary experts who are equipped with creative and adaptable problem solving skills than before as the society gets more and more complexed and uncertain. Korea has been emphasized the importance of STEAM literacy in schools, and systematically and national widely implemented various STEAM content development programs, support programs for teachers and schools, research projects related to STEAM effectiveness since 2012. The recently revised and implemented Korean National Curriculum 2015 addresses the importance of core competences in addition to subject-based knowledge that has been traditionally focused on. The core competences include creativity, communication, self-management, information-technology management, aesthetic emotion, and community competence. STEAM education is expected to be one of effective teaching and learning approaches that can foster students' core competences.

Positive Behavioral Interventions and Supports (PBIS) in Science

Positive Behavior Interventions and Supports (PBIS) is a set of ideas and tools that schools use to improve the behavior of students. PBIS uses evidence and data-based programs, practices and strategies to frame behavioral improvement in terms of student growth in academic performance, safety, behavior, and establishing and maintaining positive school culture (https://en.wikipedia.org/wiki/Positive_Behavior_Interventions_and_Supports). Unlike many previous studies of PBIS use this framework to deal with disciplinary behaviors, we adapted this concept to science learning culture. Through this PBIS in Science, we emphasized students' autonomy and control over their own practices in science learning. The specific steps of PBIS in Science are as follows.

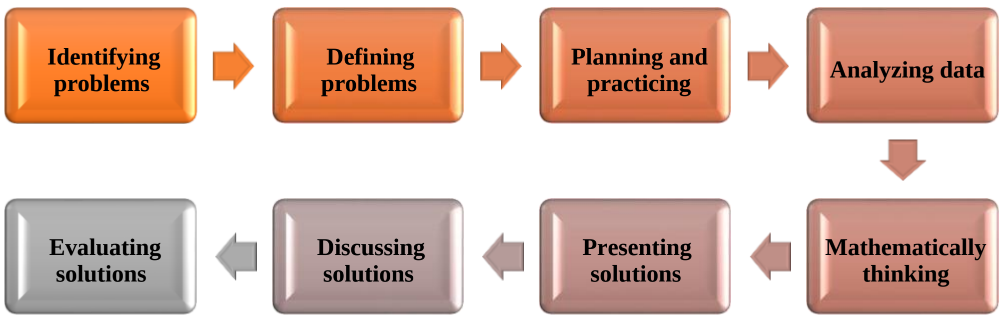

Figure 1. Process of PBIS in Science

RESEARCH DESIGN

Citizen Science Based STEAM Programs

We employed Positive Behavioral Interventions and Supports (PBIS) teaching and learning model as a framework for students to find solutions to authentic problems through collaboration among students. Based on this theoretical framework, we designed and developed citizen science based STEAM programs for students and accompanying teachers' guide. The specific topics of the programs include 'Noise! Who are you? (3rd grade), 'Creative idea competition for reducing light pollution' (4th grade), 'How to protect yourself from fine-dust' (5th grade) and 'Where is X-ray in our everyday life?' (6th grade). The programs were implemented through 6~10 lessons over 2~3 weeks.

Subjects

A total of 588 students and 19 teachers from 10 different elementary schools in Korea participated in the pilot implementation of the developed programs.

Research methods

The participating teachers and students were administered a survey asking their experiences of the programs, level of satisfaction with the programs, and changes in their perceptions after the participation. In addition, the artifacts created by the students were collected and analyzed to examine students' performance.

In addition, a survey of students' interests, communication, self-efficacy, motivation and careeraspiration was administered to both the participating students and non-participating students to find the effectiveness of the program by comparting two groups.

RESULTS

Program implementation

The research team provided the participants with students' workbook, program guide for teachers, and various instruments necessary for scientific investigation. The participating teachers had to attend off-line professional development before the programs began, and had opportunities to continue interaction and collaboration through online community with researchers and colleagues while implementing the programs.

3rd graders enjoyed measuring noise levels around themselves using a simple App on their smartphones. After they collected noise data from various locations, they realized the level of noise were quite problematic. Then, they created a sign for their peer students to illustrate the problem of noise around us. It was challenging but at the same time very engaging experience for the students.

4th graders investigated light pollution issues. They also used an App on the smartphone to measure levels of brightness in various locations at different time of the day. The students with their parents' help created a light pollution map of their town. Then, they came up with creative ideas to reduce light pollution.

Fine dust is one of the most concerned issues in Korea. Every morning, students have to check today's fine dust condition along with weather. 5th graders collected fine dust data from various locations and times. They analyzed the data to find any relationship between fine dust level and other environmental data such as temperature, humidity, winds, cars, factories. Then, the students created video clips to tell other students about the results of their investigation and how to prevent fine dust problems at the individual, community, and national level.

6th graders studied less familiar concept, i.e., radiations. The students investigated different types of radiations (such as x- rays, UV-rays, infrared rays) and benefits and harms those radiations may cause. They measured level of radiation around themselves and found out we were exposed to more radiations than what we thought. They were amazed when they found out the benefits the radiations can provide to our daily life.

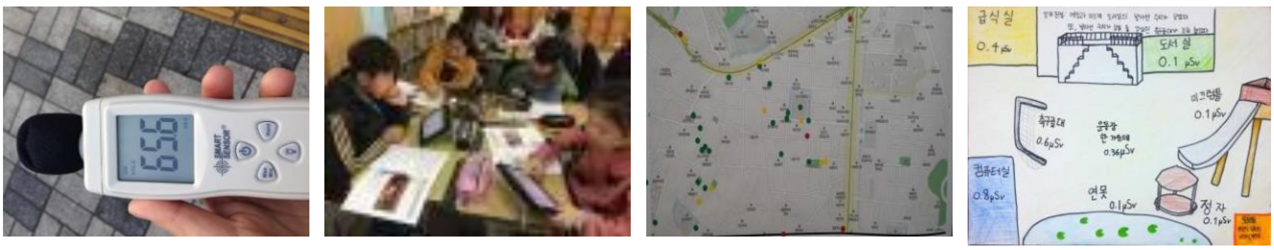

Figure 2. The program implementation and students' artifacts

Student Satisfaction

The participating students also satisfied with the programs as well. After participating the program, students perceived that they became interested in science & technology, enjoyed science learning and understood science better (see Fig. 3).

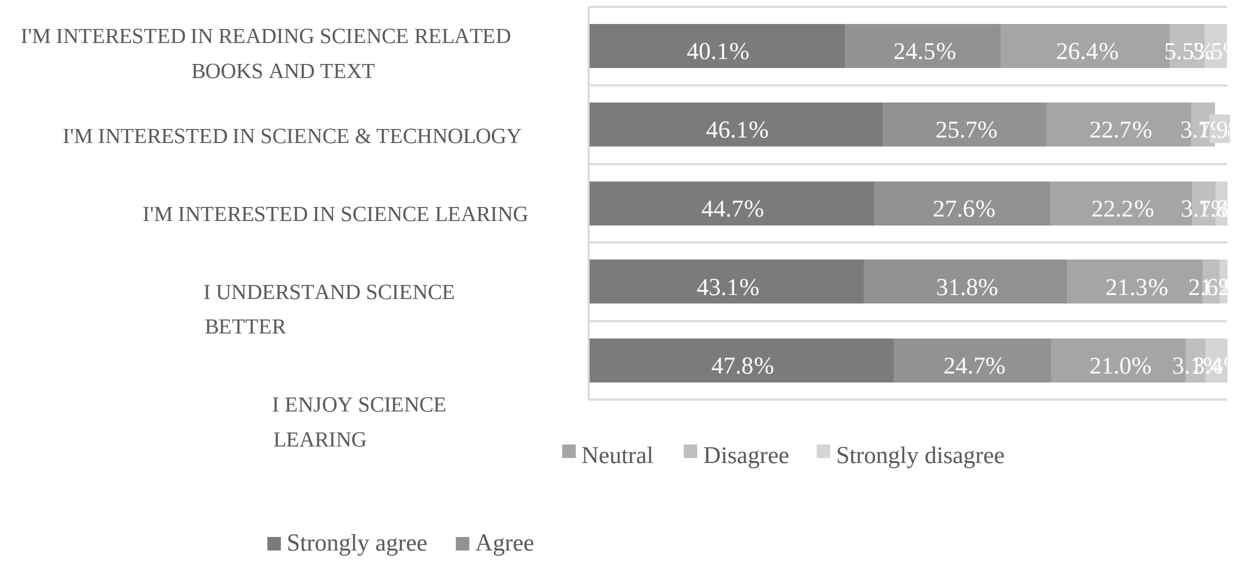

Figure 3. Student satisfaction with the programs

In addition, the participating students' levels of interests in math & science, considering others & communication skills, self-directed learning, and S & T Job aspiration were all higher than those of their non-participating counterparts (Table 1).

Table 1. Comparisons of non-cognitive achievement levels between participants and nonparticipants

		STEAM program participation				Total		Mean Difference	p
		No		Yes					
		M	SD	M	SD	M	SD		
Interests	Math	2.45	0.51	2.77	0.66	2.61	0.61	0.31	**
	Science	2.75	0.45	2.98	0.58	2.87	0.53	0.23	**
Considering others & Communication	Considering others	2.94	0.56	3.27	0.57	3.1	0.59	0.33	**
	Communication	2.97	0.53	3.31	0.56	3.14	0.57	0.34	**
Self-directed Learning	Motivation for learning	3.07	0.52	3.18	0.62	3.12	0.57	0.12	0.14
	Self-efficacy	2.7	0.8	3.13	0.68	2.92	0.77	0.43	**
	Self-concepts	2.38	0.7	2.86	0.8	2.62	0.79	0.47	**
S & T Job aspiration		2.96	0.81	3.29	0.7	3.13	0.77	0.33	**

**p <0.1

The participating students showed high interests in the topics and tasks because the topics are very familiar to their everyday life and the experiments, observations and data collection and analysis processes were all engaging. Also, enjoyed the fact that the results of their scientific inquiry led to a solution to their real-world programs. It was a rewarding experience for the students.

Teacher Satisfaction

In general, the participating teachers satisfied with the program. The teachers reported that the programs were very relevant with real-world situations, the topics and themes were very novel that can evoke students' interests in student-centered activities.

The teachers were provided with teacher's guide to the programs and they were given both offline and on-line professional development on the programs before implementation. Since the citizen science based STEAM programs required more scientific knowledge and inquiry skills of the teachers, some teachers felt the programs were somewhat challenging for their students as well as teachers themselves. Nevertheless, they commented that they believe the written curriculum and workbooks for the students were very helpful.

DISCUSSION AND CONCLUSION

The citizen science based STEAM programs provided the students with opportunities that they could experience themselves that science could be fun, interesting and relevant to my daily life. Most common comments from the teachers were their students actually enjoyed the program. The students took initiatives to conduct investigation and collected scientific data. They had a chance to work with rather messy, unorganized, real-world data. It could be challenging and frustrating to analyze real data and find any meaningful patterns out of the data. Once they analyzed their data, they felt ownership to the data and the problems and issues became so relevant to them. In traditional science classrooms, students write investigation reports to show the investigation process and results to teachers. However, in our program, the results of their investigation led to an action. Based on their investigation, they developed solutions and preventions that they can practice in their daily life. Through these experiences, the students moved forward to the center of scientific community. Learning became action. Based on the results of this study, we are planning to expand the programs to include more diverse topics and themes. In addition, the program will incorporate more diverse subject areas such as language art and social sciences into STEM.

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REALIZING STEM HEURISTIC IN A MATHEMATICS PROBLEM SOLVING ACTIVITY

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ABTRACT

This paper follows up the author's paper presented in a STEM in Education Conference in which problem-solving cycle was interpreted as an overarching STEM inquiry process across the different STEM discipline domains. This paper reports the findings from a small-scale teaching experiment carried out by the author to gather evidences that could ground the formation a STEM pedagogical model based on problem-solving. A mathematical task was given to a group of student-teachers and they were asked to solve the problem systematically following a problem-solving sequence consisting STEM heuristic. Four types of solution strategies were found: mathematics, engineering, concrete manipulative and digital. The experiment shows that STEM heuristics can be a useful guide to produce fruitful solution strategies that are not bounded by one disciplinary knowledge domain, and in some cases, this guiding process foster creativity.

Keywords: *problem-solving heuristics, boundary object, STEM pedagogy*

INTRODUCTION

In general, school curriculum compartmentalizes knowledge. Different subject domains are taught and learnt separately usually with rigid pedagogical boundaries, and teachers from different subject domains often have difficulties relating their expertise with each other. This is understandable since institutionalized subject areas arise from different socio-cultural contexts with diverse epistemological assumptions. However, as the advancement of digital technology enables learners to access different subject domains easily and simultaneously, knowledge boundaries could be softened and may even become permeable. This motivates a need to rethink and advance pedagogy correspondingly.

A basis for knowledge acquisition and advancement is problem-solving. While solving an authentic real-life problem, problem-solvers need to evoke past learnt experiences and facts from different knowledge domains when they explore possible solutions. These multi-dimensional experiences require problem-solvers to imagine and construct cognitive connections which could blend their prior knowledge together. Sometime this blending brings about new knowledge. STEM education falls into is this kind of pedagogical orientation.

This paper follows up the author's paper presented in a STEM in Education Conference (Leung, 2018). In that paper, problem-solving cycle was interpreted as an overarching STEM inquiry process across the different STEM disciplines. This paper further discusses and explores the idea that a generic problem-solving cycle can be regarded as an overarching object that embeds 21st century STEM-skills which students should learn. A mathematics problem-solving class activity is presented as a source for the discussion.

THEORETICAL FRAMEWORK

Each STEM discipline has its own epistemic inquiry process. These processes differ mainly due to the nature of the disciplines; however, they may concur in knowledge evolution trajectory. In science education, the dominant pedagogical approach is the Inquiry-based BSCS 5E Instructional Model (Bybee, 2006) which consists of five learning phases. Furthermore, when doing science, there is the scientific method sequence reminiscing John Dewey's Complete Act of Thought (Dewey, 1910). When working and thinking with technology, the four elements in computational thinking are used to compound solution algorithms (Cuny et al, 2010). In the engineering realm, design thinking drives cycles of modification and refinement of protype creation (English et al, 2011). Behind all these processes lie mathematics, a systematic rigorous analytical tool to represent the real world through mathematical modelling process.

These four inquiry processes share a common epistemic iterative frame. They all involve cycles of inquiring, generating, evaluating and improving of ideas. This echoes with what Andreas Schleicher, the Director for the Directorate of Education and Skills at OECD, said about creative thinking. Creative thinking is defined by OECD as

> the competence to engage productively in an iterative process involving the generation, evaluation, and improvement of ideas that can result in novel and effective solutions, advances in knowledge and impactful expressions of imagination. (Lego Foundation, 2019; p.12)

Therefore, STEM inquiry process is in-line with creative thinking, a much sought after 21st century generic skill. To foster student creative thinking, OECD summarized the creative process into the following categorization: inquiring, imagining, doing, and reflecting (Vincent-Lancrin, et al, 2019; pp. 43-44). This categorization essentially coincides with George Pólya's four in-step problemsolving principles (Pólya, 1945): understand the problem, make a plan, carry out the plan, and look back on your work to ask how could it be better? The author subsumed the four STEM inquiry processes under Pólya's problem-solving cycle and interpreted it as a pedagogical boundary object which serves as an over-arching frame connecting the STEM disciplines' epistemic processes. A pedagogical boundary object is a mediating artefact whose role is to translate and transfer pedagogy between different knowledge domains (c.f. Star and Griesemer, 1989; Leung, 2019). A STEM problem-solving checklist, acting as a boundary object, was proposed to categorize the STEM disciplines' problem-solving heuristics under a generic boundary crossing problem-solving frame (Leung, 2108).

METHODOLOGY

A small-scale teaching experiment was carried out by the author to test the pedagogical usage of the proposed checklist. The subjects of the teaching experiment were 21 students from a Master of Mathematics Education course taught by the author in a local university. The course was about teaching and learning of shape and space, and the students were in-service kindergarten, primary and secondary mathematics teachers; therefore, the mathematics ability of the students were very diverse. In the course, students were divided into groups for a problem-solving assessment. Figure 1 is the problem-solving task.

Student groups were given 4 weeks to work on the problem in class and outside class. During the 4 weeks, students were introduced in class to the Dynamic Geometry software *GeoGebra* and they became familiar with using the rudimentary functions of the software environment to do simple geometric construction and calculation. Each group were required to solve the problem following a problem-solving strategic sequence which was designed based on a STEM heuristic checklist. Student groups were asked to record their problem-solving process according to the sequence: Understand, Design, Implementation Cycle (Solve and Analyse, Reflection, Evaluation and Refine). There was no intervention from the instructor. At the end of the 4 weeks, each group presented its findings in class.

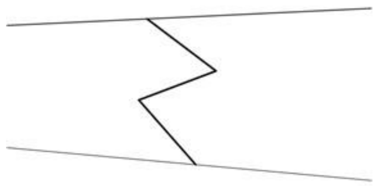

Figure 1. The Problem-solving Task: Property A and Property B are separated by a zigzag fence. The picture is an example of a zigzag fence with two abrupt alternate turns. Due to some practical reasons, the owners of the two properties decide to use a straight fence instead. How to do this without the owners losing any land?

RESULTS AND DISCUSSION

It was observed that students found the digital tool *GeoGebra* very useful as a thinking tool, helping them to develop different solution strategies for this mathematical problem, in particular; *GeoGebra* enhanced their thinking and reasoning skills. Hence digital technology could play a pivotal role in mathematical learning. When students were asked to follow the suggested problemsolving sequence with the suggested heuristics for assessment purpose, most of them did it diligently and carefully. This assessment approach motivated students to learn how to solve problem in a systematic way and to deepen their strategic insights that might go beyond the boundary of, in this case, the mathematics domain. Students were very keen in making different assumptions since the problem appears to be ill-posted. By making different assumptions, students were able to develop different solution strategies, in some cases getting rigorous solutions, and in some cases getting good approximation. In the student work, there were four types of solution: mathematics, engineering, concrete manipulative and *GeoGebra*. Each type is generated by a student group. Highlights of these solutions are described below according to the problem-solving sequence: Understand, Design and Implementation Cycle.

Understand

Mathematics

The problem is assumed to be a 2D problem. Solving the problem involves knowledge about area of triangle and parallel lines. A simple situation would be to assume that the upper and lower land boundaries are parallel and there is only one zigzag turn. Upon solving one zigzag turn, the two zigzag turn situation can be reduced to one zigzag turn, and henceforth, the method can be reiterated for more zigzag turns. After taking care of the parallel boundaries case, investigate how to extend the solution method to the general case.

Engineering

Consider to transferring the problem from a 2D area problem to a 3D volume problem. Make use of Archimedes Principle (water displacement) to locate a straight-line water level which gives a solution to the problem. Knowledge of 3D printing, scientific measuring techniques, concepts of volume, mathematics of proportion and water displacement are needed.

Concrete Manipulative

Understand area in terms of area retention (rotating, cutting, position change), area measurement (covering, patching, counting in grid, unit conversion), and area inclusion relationship (combination of different shapes). There is not enough information given in the problem, therefore; many assumptions must be considered. Comparing areas involve physical movements as suggested above, hence consider solving the problem by using paper cutting or pre-cut shapes to make rearrangement while preserving the areas.

GeoGebra

Search for mathematical formula and geometrical construction to calculate area for irregular shapes. It turns out that they are difficult to apply for the problem situation. The dynamic interactive nature of *GeoGebra* can avoid calculation and supports a “drag to think” problem-solving environment.

Design

Mathematics

Assume the problem to be a 2D Euclidean geometry problem. Design an iterative mathematical model to construct straight line solution successively. Construct solutions in *GeoGebra* for verification, to look for variation and invariant, and to seek alternative solutions.

Engineering

Assume the land is flat. Outline on paper two identical pieces of land containing properties A and B with arbitrary left and right boundaries. For one of the pieces, cut to separate property A and property B into two pieces along the zigzag boundary. Scale up or down the resulting three pieces with the same ratio and 3D print them with the same thickness using the same material. Choose a measuring cup with marking and fill it with water to level mark M. Submerge one of the property pieces, say A, completely into the measuring cup and record the new level mark N. Use the same measuring cup with water level at M, put the large piece with both A and B into the water vertically heading with A. Stop when the water level mark reads N. Mark the horizontal water level on the large piece and it will be a straight-line solution for the problem. In the water displacement process, assume there is no water spillage.

Concrete Manipulative

Assume that the land is flat and the land piece that contains properties A and B is rectangular in shape to begin with. Construct the land piece using pre-cut shapes (rectangles and triangles) with a triangle near the middle in an orientation such that two sides of the triangle represent a one zigzag turn boundary. Rearrange the shapes to relocate the triangle resulting with a straight edge of a rectangle near the middle. This straight edge would be a solution of the problem.

GeoGebra

Construct different versions of the problem in *GeoGebra*. Explore different possible solutions using the dynamic functions of the software.

Implementation Cycle

Mathematics

GeoGebra is used to construct approximate solution by dragging a straight line to balance land lost and land gained. This method works well with two zigzag turns but gets very complicated afterward. Hence, the intended iterative mathematical model in the Design stage is carried out. A geometrical two zigzag turn solution is shown in Figure 2. In the process of working out the model for a parallel boundaries and fixed zigzag formation case, area calculation shows a generalizable pattern and mathematical induction is used to verify it. For more general situation, the calculation depends on many variables and might not be generalizable. To transfer this model to the real-life situation, it is inevitable that many errors will be encountered: there exists no ideal straight and 2D objects, measurement error is always there, the land is not flat, etc.

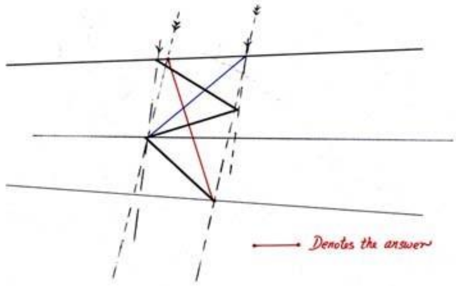

Figure 2. A geometrical two zigzag turn solution

Engineering

Figure 3 shows pictorially a conceptual implementation of the design. The design is creative but during implementation many errors may occur. What is the right scale and material to use to 3D print the pieces? There may be error due to approximation when transferring the drawn outlines to the 3D printing software. How to ensure that the pieces do not float in the water? The water level is usually curved, not completely straight, due to surface tension. There is always error in reading measurement. This is an experimental solution and continuous refinement, even re-design, must be done during the experimenting process. This hypothetical solution idea can be extended to more general setting with a curved boundary instead of a zigzag boundary.

Figure 3. A water displacement solution using Archimedes Principle

Concrete Manipulative

Figure 4 are a products of the intended solutions. Perform the solution design using an A4 paper as the piece of land. Draw a zigzag boundary and outline a rectangle that contained the boundary (Figure 4 (a) left). Cut up the rectangle into pieces of different shapes and arrange them at both ends of the land pieces making sure that A and B do not loss any land areas. This results in an empty rectangular gap in the middle. Push the two re-shaped A and B together meeting along a straight edge. This would give a solution (Figure 4 (a) right).

(a) **(b)**

Figure 4. (a) Solution buy paper cutting and rearranging (b) A Tangram Solution

To present the idea in a more refined and robust fashion, use Tangram pieces instead of paper shapes. Figure 4 (b) is a Tangram solution. The solution idea is a primitive one for primary school setting and is not applicable in real-life situation. However, behind it are two important defining properties of the concept of area: (1) Shapes that are congruent must have the same area (2) If a shape is split into a finite number of non-overlapping parts, then the area of the shape is the sum of the areas of these parts.

GeoGebra

Figure 5 shows snapshots of a progressive dynamic thinking pictures of the *GeoGebra* exploration. The end-product is a good approximation of a possible solution. The accuracy of the answer can be adjusted to desired decimal place. Hence, for practical purpose, this would solve the problem. However, the width of the fence should also be considered in the real situation.

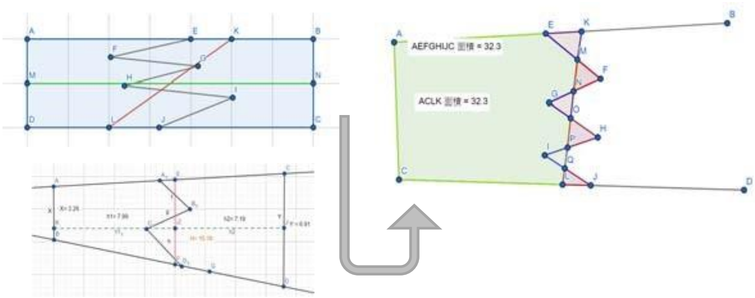

Figure 5. A progressive refinement of solution in a GeoGebra exploration

CONCLUSION AND SIGNIFICANCE

The student work produced in this teaching experiment shows that asking learners to following a sequence of problem-solving heuristics based on the STEM disciplines inquiry processes could produce fruitful solution strategies that are not bounded by one disciplinary knowledge domain, and in some cases, this guiding process foster creativity. In this connection, STEM heuristics can be used to create STEM problem-solving rubrics for the purpose of formative assessment and the rubrics could become boundary objects based on which to conceptualize a boundary crossing pedagogy for STEM education.

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STEM EDUCATION THROUGH SOCIOSCIENTIFIC ISSUES: OPPORTUNITIES AND BARRIERS TO ACHIEVING SOCIAL JUSTICE

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2. *The University of Waikato*

ABSTRACT

This paper argues for the importance of embedding social justice consideration when we do STEM education. In our earlier study, we reported that using 'obesity' as a socioscientific issue has supported university students to consider social, political and moral aspects associated with the issue in a general education course. As a follow-up study, which we report in this paper, we identified students who insisted that obesity is a self-inflicted problem and resisted to consider obesity in terms of broader societal aspects. Interviews were conducted to elicit their reasoning. It was found that *reasoning biases* and *underestimation of the power of marketing* explained their resistance. This points to the need (1) to teach probabilistic reasoning that facilitates students to discern epidemiological knowledge claims and personal experiential knowledge and (2) to raise students' awareness toward the broader context that shapes direct-to-child marketing to facilitate a shift to considering social justice dimension of obesity.

Keywords: *socioscientific issues, obesity, social justice, conceptual change*

INTRODUCTION

Technological advances that are often employed within STEM fields have led to global problems (Harding, 2006), such as processed foods that account for obesity epidemic (e.g., Williams & Nestle, 2015), and burning of petroleum that accelerates global climate change (Klein, 2014). The adverse side effects are often inequitably shifted to the underrepresented populations. For instance, obesity tends to affect people of lower socioeconomic status (SES) in developed countries than those of higher SES (Wang & Beydoun, 2007); the poorest populations, who have contributed least to greenhouse gas emissions, are most vulnerable to threats of public health as a result of climate change and extreme weathers (Campbell-Lendrum & Corvalán, 2007).

"Techno-fixes" without attending to the social, moral and political aspects are far from adequate to overcome these global challenges. For instance, given the multifaceted and complex nature of obesity, it requires complex solutions at societal level. Techno-fixes such as weight loss treatments at individual level without considering the social and political aspects of obesity (e.g., the aggressive marketing of nutritionally poor food, the power and underlying interest of food giants in food lobbying, and weight discrimination) will hardly be an effective cure to obesity (Conroy, Smith, & Frethey-Bentham, 2018). Similarly, it would be hard to mitigate climate change through the use of solar energy without the support of funding and technology-specific policy (Creutzig et al., 2017).

There has been increasing attention to developing students' understanding of social issues in STEM education for equity and the human good (e.g., Amadei & Sandekian, 2010; Calabrese Barton & Tan, 2011; Vaz, 2005). As stated by Garibay (2015, p. 17), "Making social justice goals more explicit in STEM education and providing students the opportunities to learn about structural and institutional dysfunctions that create inequality may help promote the development of STEM students' social and civic outcomes." Nevertheless, this goal is often overlooked (Zeidler, *et al*, 2016)

In science education, there has been the science-technology-society-environment (STSE) movement in the 1980s and 1990s that aims at connecting science and technology to society. This movement has evolved to *socioscientific issues* (SSI) that extend to foster a broader sociocultural view of scientific literacy (Zeidler, Sadler, Simmons, & Howes, 2005). SSI refer to issues emerging from the interrelationship of science and society that are often factually and ethically complex, subject to ongoing inquiry, and based on uncertain, fragile, and conflicting evidence and have no clear solution (Sadler, 2004). Examples include climate change, energy crisis, designer babies, microplastics and alike. Bencze et al. (2018) proposed integrating STEM and STSE for STEMSE education to equip citizenry in solving issues faced by humanity for a better world with a more critical and holistic use of STEM knowledge, skills and disposition. This is in line with the alternative Zeidler (2016) offered that applies a sociocultural perspective framed through socioscientific considerations in making STEM a deficit framework to a surplus one. We share this rationale and envisage that empirical findings on students' learning of SSI may offer insight on the integration of a sociocultural perspective to STEM education.

LITERATURE REVIEW

Obesity as a socioscientific issue

Obesity has become one of the most pressing health challenges worldwide and has been labeled a global epidemic by the World Health Organization. However, secondary school students (Ozbas & Kilinc, 2015), parents (Vittrup & McClure, 2018), and even physicians (Gies et al., 2017) often have a limited understanding of obesity. Health professionals and health students were reported to be the sources of weight bias (Puhl & Heuer, 2009). Past studies reported that health professionals hold the same degree of weight bias as the general public (e.g., Brown, 2006; Robinson, Ball, & Leveritt, 2014). Weight bias may result in the perception among health professionals that obese patients are lazy and should be responsible for their obesity (Schwartz, Chambliss, Brownell, Blair, & Billington, 2003) and that they tend to invest less time and effort in treating obese patients (Puhl & Heuer, 2009). In turn, obese patients may avoid or delay health care because of negative comments from health professionals or feeling embarrassed about their weight (Persky & Eccleston, 2011). Therefore, weight bias among health professionals may lead to avoidance or delay in health care among the obese.

Technocratic dimension and emancipatory dimension of obesity

With respect to the above discussion, limiting one's thinking to a technocratic view about obesity does not help eliminate weight bias. Although the technocratic dimension of thinking may also acknowledge biological factors that are beyond one's control (e.g., genetics, maternal nutrition and gut microflora), it largely views the fight against obesity as one in which the obese should assume responsibility for their condition and eat less, exercise more, and live a healthier lifestyle. At its extreme, this dimension of thinking may assume the issue of obesity to have moral implications for

obese people, in which they are blamed and society develops an attitude of ‘fat shaming’ towards them.
To eliminate weight bias against the obese, it is essential to also embrace an emancipatory dimension of obesity. This dimension has less to do with the technical examination of a phenomenon and more to do with challenging the status quo through an ethical and political scrutiny of the issue. The emancipatory dimension focuses on the broader social institutions and examines power relationships, inequality and social justice. Such a problematisation of the status quo challenges us to reconsider the possibilities of creating a society that values justice, equality and moral virtues.

Prior findings suggest that majoring in a STEM field is negatively associated with social agency outcomes, which in turn, may go against the notion of medical organizations in developing altruism and empathy among health professionals (Garibay, 2015). We believe that a technocratic dimension, which is often emphasized in STEM education, should be coupled with an emancipatory dimension of obesity to eliminate weight bias among health professionals and the general public.

The findings referred to here are part of a larger study on students’ learning of obesity as an SSI. Earlier paper reported the significant impact of a 12-week teaching intervention on students’ conceptual change about the causes of obesity (Leung & Cheng, under review). This paper differs from the earlier one in that it focuses on two cases of students majoring in STEM who failed to exhibit the expected change. Through a nuanced analysis of these two cases, barriers that may hinder students’ shift from a technocratic dimension to one that embraces an emancipatory dimension of obesity would be revealed. These findings would be valuable in offering insight to inform teaching designs that aim at promoting social justice in STEM education.

RESEARCH DESIGN

110 undergraduate students enrolled in a general education course titled *Obesity: Beyond a Health Issue* offered by a comprehensive university in Hong Kong were invited to participate in this study. They were pursuing degrees in Arts, Business Administration, Education, Law, Social Sciences, Science, Medicine, Nursing, Pharmacy or Engineering. The course aimed to enhance students’ understanding of obesity from a personal, straightforward problem to a multifaceted worldwide phenomenon. The course included the following modules: 1) multiple determinants of obesity, 2) the consequences of obesity in which weight bias was introduced, and 3) the non-mainstream attitudes and actions taken by critics in the war against fatness and the underlying rationales. The course design was informed by the Socioscientific Issues Teaching and Learning (SSI-TL) model (Sadler, Foulk, & Friedrichsen, 2017).

Data sources

We conducted individual semi-structured interviews with all of the students who indicated that they were available six months upon course completion. These interviews elicited the students’ changes in conceptions about obesity and a deeper understanding of these changes. A total of 18 students volunteered to be interviewed. Each interview lasted for 30 to 40 minutes and was audio-taped and transcribed verbatim. Throughout the course, students kept a weekly reflective journal to record their conceptions about obesity. This reflection, along with a guided essay writing task that probed students’ conceptions about obesity at pre-course and post-course, served as multiple data sources for triangulation. In this paper, we report two barriers that may hinder students' embrace of the emancipatory dimension of obesity through a narrative analysis of data.

RESULTS AND DISCUSSION

Barriers hindering embracing an emancipatory dimension of obesity

Of the 18 interviewees, one of them did not exhibit a shift in conception at the post-test (Travis [pseudonym], majoring in Engineering), while one shifted her conception against our expectation (Yvonne [pseudonym], majoring in Nursing). The interview data of Travis and Yvonne revealed barriers to embracing an emancipatory dimension of obesity. Two themes emerged from the interview data: *Reasoning biases*

As revealed in the follow-up interview, Travis held a strong view that obesity was the result of a lack of willpower:

> Other than problems like gene or body defects that only affect minority of people, there may be different surgeries, like gastric bypass, *that can be used to lose weight*... I believe that to a large extent, obesity can be regulated. I used to *force myself* to exercise, and now I keep exercising as well. As long as I eat and sleep well, metabolism increases; perhaps in just a week, I can already lose weight. I am not saying that I am fasting; *I don't understand why people are saying that losing weight is hard*… it is just a matter of willpower and is not difficult. (italics added)

Because of his limited scope, Travis viewed obesity as an issue that could be solved from a technocratic dimension (i.e., by going through surgeries). While lack of willpower may explain an energy imbalance from a technocratic dimension, it does not explain the global obesity epidemic. It was unlikely that our willpower has changed so drastically in a few decades to make it held accountable for the rapid surge in obesity. Also, the environment shaping our eating habit and lifestyle has indeed changed tremendously. Yvonne also believed that obesity was caused by a lack of willpower, although she had a different reasoning:

> I thought that *most of the obese cases are inborn and inherited*, as quite a lot of friends are suffering from this kind of genetic susceptibility… *There are really a lot of ways to lose weight*; for example, the most basic way is to exercise. Because so few people are affected by genetics, it is not an excuse, and willpower is important. (italics added)

Yvonne initially believed that genetics was the key reason for obesity, a view developed by observing her friends. She was surprised at the low percentage of people who were genetically susceptible to obesity, and she shifted her conception to lack of willpower as the key cause of obesity. She shared a similar view to Travis, and the solutions that she suggested (i.e., by dietary control and physical exercise) were dominated by her technocratic view about the causes of obesity.

Addressing the barrier. The attempt to use a single case (i.e., Travis' personal experience) or few cases (i.e., friends of Yvonne) to refute findings from statistics/epidemiology can be regarded as a reasoning fallacy. Thus, in our future teaching, we will introduce probabilistic reasoning (Osborne, Rafanelli, & Kind, 2018) to facilitate students' epistemic understanding of epidemiological knowledge and that generated from personal experience. The teaching involves the learning of math (M) contextualized in science and technology (S and T) This reasoning is context-generic and can be applicable in cost-benefit analysis of other SSIs (e.g., vaping ban and speed limit regulation).

Underestimation of the power of marketing

Underestimating the power of marketing was another possible barrier hindering participants from the expected conceptual change, as illustrated by the following interview excerpt:

> Travis: I haven't encountered direct-to-child marketing before. That is, you cannot say that just because chocolate is available at a shop and that is direct-to-child marketing; it's simply marketing. It's not like the river barge inviting kids to get on to promote junk food to them. I haven't seen this kind of marketing in Hong Kong before.
>
> Interviewer: How about the Happy Meals at McDonald's? Do you regard them as direct-tochild marketing? Travis: No, I don't, because it is just a meal. […] Kids can also choose regular meals. Including toys may make the meals more attractive to kids. No matter which meal that they buy, be it Happy Meals or regular meals, *they know that they are unhealthy*. Either is unhealthy, so it doesn't really matter.

Despite the use of various examples to illustrate how direct-to-child marketing is pervasive in the lives of children worldwide (e.g., in-school commercial activities, product placement, video games, the Internet, etc.) in the course, Travis was most impressed by Nestle's river barge that made junk food available to the isolated communities in the Amazon basin, especially to children. He appeared to hold the conception that only this kind of aggressive marketing to children could be considered direct-to-child marketing, and he thus believed that he had not personally encountered any direct-tochild marketing. Therefore, he was unaware of the profoundness of direct-to-child marketing and might not see it as one of the causes of obesity. Furthermore, Travis believed, "they (the children) know that they (Happy Meals and regular meals) are unhealthy" and seemed to assume that children were capable of making rational food choice. This assumption may not hold true, as children are not fully mature with regard to making informed decisions about what is best for their health, making this age group particularly vulnerable to manipulation by the food industry.

Addressing the barrier. This second barrier has context-specific implications for our future teaching. This suggests the need to develop students' awareness of the broader context of direct-tochild marketing that may facilitate a shift from a technocratic dimension to an emancipatory dimension of *marketing/advertising of unhealthy foods* in explaining obesity.

CONCLUSION

In sum, both Travis and Yvonne did not exhibit the expected shift towards the emancipatory dimension. Their strong adherence to the technocratic dimension in viewing obesity was problematic. First, it was inadequate to explain the rapid surge in obesity prevalence in recent decades. Second, it was likely to create more weight bias, creating more social injustice. This marks the importance of embracing the emancipatory dimension of obesity. Our findings for students who demonstrated limited change reveals barriers that have implications for both context-generic reasoning and context-specific strategies in our future teaching. These, in turn, may offer insight that informs the integration of a sociocultural perspective in STEM education.

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A STEAM-ORIENTED ACTIVITY IN A TAIWANESE ELEMENTARY SCHOOL: WHAT CHILDREN LEARN IN A GRADE 3 LANGUAGE CLASSROOM

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ABSTRACT

Science, Technology, Engineering, Art and Mathematics (STEAM) in Education could be a potential opportunity for educators and researchers from K-12 schools, universities, and colleges to refer to a variety of language teaching methods. However, few studies have shared and discussed innovative practices and research initiatives for Chinese language learners that may advance STEAM through language education. How teachers can integrate Science, Technology, Engineering, Art, and Mathematics dimensions into our actual practices remains a great challenge and is still unresolved. Some attention has been paid to exploring how project-based learning can help language learners develop their knowledge and skills in their classrooms. Language teachers could also believe that they play an important role in facilitating STEAM. In this study, a STEAM-oriented activity was designed and conducted in a Taiwanese elementary language course with 29 grade 3 learners. Also, learners' writing essays were collected for quantitative and qualitative analysis. The performances of high and low achievers in a STEAM activity were also investigated. The results indicate that a STEAM-oriented activity could enhance the young learners' writing performance. Moreover, it was found that the STEAM activity could improve low achievers' writing performance significantly more than that of high achievers.

Keywords: *STEAM-oriented teaching, Chinese writing, language education, elementary school*

INTRODUCTION

With the development of Science, Technology, Engineering, and Mathematics (STEM) education in the digital era of the 21st century, STEM education seems to be an important and potential curriculum reform in the next decade (Hwang, Li, & Lai, 2019). Hwang, Li, and Lai indicated that the goal and objectives of STEM education could provide a new teaching vision for teachers to help learners apply cross-disciplinary knowledge and cultivate abilities, such as communicative competence, and collaborative, problem-solving, critical-thinking, or creativity skills. When teachers design crossdisciplinary tasks or multi-disciplinary knowledge for learners to solve problems related to an issue in the learning process of creation, students could cultivate and improve their learning comprehension, learning performance and 5C skills under the guidance of STEM education (Ng & Chan, 2019). Some educators have investigated the effects of the use of robotics on learners' STEM performances and perceptions (Kim, Kim, Yuan, Hill, Doshi, & Thai, 2015). Stull, Fiorella, Gainer, and Mayer (2018) also analyzed the effects of using transparent whiteboards in STEM lectures. Moreover, some educators have focused on the factors affecting teachers and learners of STEM (Hwang, Li, & Lai, 2019). And some other educators have analyzed factors that influence behavioral intention to use mobile-based assessment in STEM courses (Nikou & Economides, 2019). However, only a few studies have been conducted to enhance students' learning outcomes or perceptions from different perspectives. For example, Wang & Degol (2017) also indicated that little is known about the relative effects of language interest and ability on STEM or STEAM education. They have also proposed recommendations for policy and practice to improve STEM diversity between gender gap, career preference, lifestyle value and other future research directions.

Therefore, this paper aims to provide STEAM design ideas and references for language teachers or language educators. A STEAM-oriented activity was proposed for stimulating learners' Chinese language development and writing performance. Moreover, an experiment was conducted in an elementary school language course to evaluate the effectiveness of the proposed approach by answering the following research questions:

1) Can a STEAM-oriented activity enhance students' writing performance? 2) What are the differences on the writing of the high and low achievers in a STEAM classroom?

LITERATURE REVIEW

Chinese Essay Writing

In the foundational skills of Chinese language learning, Chinese writing is tremendously important and challenging for Chinese language learners. Writing can not only reflect a writer's power of thought, but can also help the writer obtain language organization skills. If Taiwanese students want to enter a top university in Taiwan, it is critical that they master Chinese writing, but how can they write good Chinese essays? Law, Ki, Chung, Ko, and Lam (1998) pointed out that Chinese children are taught the proper sequence for forming the characters based on some rules when they begin to learn to write in Chinese. Shu (2003) also indicated that children could develop their reading and writing ability in the computer-assisted language learning system, in which they could be aware of the ill-formed structure early, and become aware of the well-formed structure as they grow older. Also, Yeung, Ho, Chan, Chung, Wong, and Cheng (2016) suggested that intrinsic motivation and identified regulation in Chinese written composition development are significant key factors among high school students in Hong Kong. However, the pedagogical instructions tend to place less emphasis on authentic writing goals and contexts. Yeung, Ho, Chan, and Chung (2017) even proved that when students pay more attention to spelling and oral narrative skills in Chinese writing, they will have better transcriptions skills. The scholars also found that sixth graders had better Chinese essay writing grades than fourth graders. Kubler (2018) also indicated that integrating technologies can enable students and teachers to make more efficient use of time by moving certain language learning activities out of the classroom. However, few studies have designed and conducted research initiatives for Chinese language students that may advance STEAM education.

The STEAM-Oriented Approach in the Classroom

Science, Technology, Engineering, Art and Mathematics (STEAM) is a multi-subject instructional approach designed to foster students' ability to effectively apply cross-disciplinary knowledge and skills to solve problems and perform better in one's daily life (Hwang, Li, & Lai, 2019). The theoretical considerations of this study are to apply learning for use and community-based learning environments for students to explore and experience a theme in the real world. Teachers design STEAM lesson plans, and scaffold students to complete projects or solve problems via collaborative learning from multiple disciplines, goal setting, project-based learning, and learners' participation (Hwang, Li, & Lai, 2019; Lin, Ha, Li, Chiu, Hong, & Tsai, 2019). In addition, Bell et al. (2018) also indicated that if teachers create a well-designed STEAM activity, students would be more encouraged, communicative, interactive and creative, and would engage in higher-order thinking. As a result, students may become more actively engaged, construct multi-subject knowledge, and have collaborative social experiences in the processes of STEAM learning (Hwang et al., 2019; Lin et al., 2019). However, in STEM education, most researchers and educators are from the fields of science, engineering, and mathematics (Hwang et al., 2019). Few studies have shared and discussed innovative practices and research experiments for STEAM language education, especially in a Chinese language course.

RESEARCH DESIGN

Participants

A total of 29 third graders from one Mandarin class at an elementary school in Taiwan participated in this STEAM-oriented activity. During the STEAM learning process, they were instructed by the one language teacher and one computer teacher, and they had minimal to zero relevant experience of STEAM learning.

A STEAM-Oriented Activity in a Language Classroom

The teaching experiment of the STEAM-oriented activity involved 2 weeks of lessons including Chinese, computer and mathematics classes and some break time (approximately 120 minutes). In the STEAM activity learning process, the teacher introduced the theme concept by telling a story to the students and explaining the basic Chinese writing structure, and then guided the students to actively explore the multi-disciplinary knowledge via collaborative learning with peers to complete the tasks creatively. The topic of this STEAM-oriented activity was "Mother's Day." During the STEAM tasks, students not only learned actively by remembering key concepts of how and why we should celebrate Mother's Day and understanding the STEAM tasks (science, technology, engineering, art, and mathematics), but also learned by applying the ideas, analyzing the tasks, being evaluated by the teachers, and eventually creating a written essay and a performance for this STEAM activity. The main goal of this STEAM-oriented activity was to help the students collaboratively communicate, discuss tasks, solve problems, and closely connect the classroom with the reality of life, enabling the students to apply what they had learned and to experience the fun of being a creator and a performer. Table 1 below shows the learning tasks and process of this STEAM-oriented activity in the language classroom.

Table 1. The STEAM-oriented activity (Happy Mother's Day Performance)

STEAM-oriented activity	Task	Procedure
Science (S)	□ All about carnations: Students learned about carnations: a small flower with a sweet smell, usually white, pink, or red in color.	(1) The teacher introduced carnations. (2) Students learned how to arrange flowers and created their potted plant using carnations.
Technology (T)	□ Students designed and created a personalized card in the computer room.	(1) The computer teacher introduced the template of card design. (2) Students created a Mother's Day card. They created a personalized card with a name, uploaded a photo, and added their own message for a special touch.
Engineering (E)	□ A young musical ensemble was organized by the teacher. The teacher coordinated all the STEAM tasks and guided the students to perform together.	(1) The teacher led the class as a young musical ensemble, consisting of three hosts, nine playing the flute, 15 singers, two playing the tambourine, and one playing the xylophone.
Art (A)	□ Students drew imaginative "door gods" on the card.	(1) The teacher explained the traditional Chinese story: Door gods (Menshen),
		who represent our mother and father to protect the family. Draw the card.
Mathematics (M)	□ Students learned time management, scheduling, and timetabling.	(1) Students learned how to manage time for all the STEAM tasks within 2 weeks.

Experimental Procedure

In this study, before the STEAM learning activity, the students had 3 weeks of Chinese lessons, two lessons per week, on the reading and writing units. The teacher introduced the reading passage followed by the paraphrasing. In the traditional Chinese writing classroom, the language class usually consists of four stages: 1) reading strategies, 2) writing tip strategies, 3) writing instruction and inquiry, and 4) guessing and prompting. The teacher instructed the students in basic concepts in order to learn how to write the essay. Following that, the students took a pre-test of Chinese essay writing to evaluate the prior knowledge of the class. The teacher then gave a 2-week, approximately 120-minute, orientation of the STEAM learning activity to the students, including all the STEAM learning tasks and project-based performance.

During the STEAM learning activities, the students were guided to follow the procedure of organizing, discussing, collaborating, and completing the tasks. Moreover, after the STEAM-oriented activity and performance, all the students took part in the post-test and wrote what they had learned and how they felt about the proposed STEAM learning activity, which is the Mother's Day celebration. After the STEAM learning activity, the teacher provided summative feedback and commented to the students to help them correct their Chinese essays.

RESULTS AND DISCUSSION

Table 2 shows the paired-sample *t*-test results for the class. They indicate that after participating in the STEAM learning activities, the students significantly improved their learning performance in the post-test (t = -5.78, $p < .001$). The means of the pre-test are 79.72, and the post-test is 94.14. That is, all the students, after learning with the STEAM learning activity had significantly improved their learning performance. Moreover, to further understand the effects of the proposed approach on the learning performance of the students with different degrees of improvement in their writing assignments, the students were classified into high and low achievers based on the ranges of their wiring scores in the post essay test. Moreover, high achievers and low achievers were also analyzed in the study. The reason to investigate the attributions of high and low achieving students about the proposed learning approach is to realize that the STEAM-oriented learning approach is helpful in providing a better learning method and guideline for low achieving students. Furthermore, this is also beneficial to practitioners such as teachers and researchers in the field of language education. Thus, the results demonstrated that the high achievers did not significantly improve their learning performance from the pre-test to the post-test. However, after the STEAM activity, the low achievers significantly improved their learning performance (t = -11.11, $p < .001$).

Consequently, it may be concluded that the students who learned with the STEAM-oriented activity seemed to have significantly better learning performance, especially for the low achievers. In other words, it could be testified that the low achievers could be motivated to engage more during the STEAM activity process and had significantly better learning performance compared with the high achievers. This finding complies with what has been expected and reported by Hwang, Li, and Lai (2019) and Ng and Chan (2019) that effective STEAM learning strategy could improve students' outcomes and learning performances. This also represents that the STEAM learning strategy could help the low achievers and guide their learning performance in the writing classroom.

Table 2. Paired-sample *t*-test results for the high and low achievers

Group		Pre-test		Post-test		*t*
	N	M	SD	M	SD	
All students	29	79.72	13.72	94.14	3.25	-5.78***
High achievers	13	92.46	3.62	94.46	3.43	-1.59
Low achievers	16	69.38	9.29	93.88	3.18	-11.11***

***$p < .001$

CONCLUSION

Science, Technology, Engineering, Art, and Mathematics (STEAM) is a multi-subject instructional approach which could be adopted to foster students' learning performance, engagement, subject construction, problem-solving, creativity, and relationships with others (Hwang, Li, & Lai, 2019). In this study, teachers created STEAM-oriented lesson plans whereby students could collaboratively learn by doing different tasks on an authentic issue and context related to their personal lives (e.g., Mother's Day) and which could impact the young learners' Chinese writing performance. During the STEAM-oriented activity, students completed interesting project-based tasks with peers, formed small groups to discuss and practice tasks assigned by the teachers, and eventually individually wrote a Chinese essay. Not only did the students learn goal-setting and participate in tasks to better understand the issues, but also the language teachers taught Chinese vocabulary, and provided grammar, sentence patterns and function words for the third graders to do the Chinese essay writing exercise at the same time. The STEAM multi-tasks not only helped the young learners perform different roles but also gave them more experiences to perform better such as learning performances. The students also had fruitful opportunities to practice social and communication skills as they learned to achieve the goal-setting project-based and supportive friendships with classmates (Lin et al., 2019) during the STEAM-oriented collaboration.

To sum up, there are two contributions to this study. First, it is found that the integrated STEAM-oriented activity could seem to benefit the students in terms of improving their learning performance in the language classroom. Second, it is found that during the STEAM tasks learning process, students seemed to use higher-order thinking, such as applying knowledge to deal with tasks and work collaboratively to complete the tasks. Therefore, in the future, it is worth conducting a series of experimental research with effective learning strategies and other research issues of designing a control group and an experimental group by taking into the 21st century competencies into the study, examining not only students' performances, but also perceptions from different perspectives (Hwang, Li, & Lai, 2019; Wang & Degol, 2017). On the other hand, there are some limitations to this study which should be noted. First, this study is only a single group pre-test and post-test design of research participants. The research design is not strictly experimental and there is no control group, and this inference would be uncertain. Also, in this study, the pre-test and post-test scores differ significantly, then the difference may be attributed to the independent variable, but and the difference may be due to extraneous variables towards the mean. Therefore, in the future, the most frequently used quasiexperimental research designs should be better pretested, given some treatment or independent variable manipulation, then post-tested. Second, there is only a small number of participants in this Chinese classroom. In future research, more groups and other digital learning strategy would be added to the STEAM PBL-based activities so as to engage students in more interactive and social learning environments to foster their thinking and writing competence, such as robotics, game design and so on (Leonard, Buss, Gamboa, Mitchell, Fashola, Hubert, & Almughyirah, 2016). It is believed that the STEAM-oriented approach aligns with language teaching and learning could be incorporated together and developed into schools' curricula to simultaneously promote academic and social gains for teachers and students in the future.

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PHILOSOPHY OF TECHNOLOGY FOR CHILDREN AND YOUTH II

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ABSTRACT

This unique contribution to philosophy of technology for children and youth camp (n=29). The key interview question is "what is technology?" We note that participants commonly characterize technology as popular devices but they also offer a range of unusual and contemplative responses. This paper focuses on these more unusual responses. The first section provides brief histories of philosophy in the schools and philosophy for children (P4C). The second section gives an overview of PT4CY and presents and analyzes qualitative data through conversational analysis. The paper concludes with recommendations for STEM educators and researchers by stressing the urgency of diversifying questions for PT4CY. (PT4CY) draws on a subset of data from interviews within the scope of a summer

Keywords: *philosophy of technology, children, tweens, and youth, P4C, PT4CY, STEM*

Although each generation of parents and teachers observe that children are growing up faster, it was not until the late 1960s that the phenomenon was pronounced. It is now common for cultural analysts to ask, "is 10 the new 15?" while pediatric analysts document increases in rates to puberty (Herman-Giddens, 2017; Irvine, 2006). If there once was a time when philosophies of childhood and education could determine what is age-appropriate for children and adolescents, those days are long gone. The gap or wedge between what teachers can teach— regulated as they are— and what children can learn has seemingly never been larger. Media and technology (M&T) are often given as reasons for this. In turn, children are stereotyped as 'heavy users' when it comes to applications (apps) but 'light thinkers' when it comes to implications of M&T.

Rather than theorize age-appropriate content and what children can learn, in this research we \asked a group of twenty-nine children and tweens what they know and think about M&T: we asked them to philosophize. The participants are variously categorized as Generation Z (otherwise classified as iGen, Gen @, and Generation Now), having unprecedented access to digital M&T. Their presuppositions are not *tabula rasa* and their understandings color what they desire, do, say, and see. In this way, we provide a unique contribution to the philosophy of technology for children and youth (PT4CY) (MacDowell, 2015; Petrina, 2020; MacDowell & Petrina, forthcoming). The first section provides brief histories of philosophy in the schools and philosophy for children (P4C). The second section gives an overview of PT4CY and transitions into data analysis. In this section, we profile a subset of participant interviews and voices. The paper concludes by emphasizing the importance of PT4CY along with critical analyses of M&T within Science, Technology,
Engineering, and Mathematics (STEM) Education. We stress the urgency of diversifying questions for PT4CY.

PHILOSOPHY FOR CHILDREN (P4C)

Studying and teaching philosophy have nearly always been justified as teaching to reason or think. In a Socratic sense, rather than philosophy, the emphasis continues to be on *philosophizing*. James (1892) said this simply means "an unusually obstinate attempt to think clearly and consistently" (p. 461). Ferm (1936) accentuates the point: "After all, it is not philosophy as such that is the big thing but the joy, the sport, the thrill of philosophizing. οϋ φιλοσοφία άλλά φιλοσοφείνν [Not Philosophy, but philosophizing, Plato advised]. Nothing shall stand in the way of the student's responsibility to think and to judge for [herself, theirself, or] himself, at every turn" (p. vii).

As progress was made to systematically introduce philosophy in the schools, the emphasis was on both "critical analysis" and "critical thinking." One advocate made a distinction by arguing that "to analyze is to include thinking critically but to think critically does not necessarily include thinking analytically" (Schievella, 1969, p. 3). For the most part, demands were coming from a new type of high school student emerging in the late 1960s. Duvall's (1969) extensive research on teens at the time concluded: "Our youngsters are asking far more candid questions and seeking more honest answers to life's dilemmas in terms of what is appropriate behavior, how do you feel, what are the goals and choices of life itself" (p. 285). As arguments were made for philosophizing with younger and younger students, skeptics countered that children were not yet mature enough. For instance, two countered that "the image of 10-year-old children engaged in philosophical discussions of marriage, death, unemployment, and personal relationships seems, as one colleague has put it, like a recipe for the production of neurotic children" (Jackson & Ott, 1980, p. 104). To be sure, critical analysis and thinking were common in schools through the twentieth century but philosophy courses were not, especially at junior high and elementary school levels (Petrina, 2020). To change this by creating curriculum for teachers and their young student, Lipman (1976) established an Institute for the Advancement of Philosophy for Children (IAPC) in New Jersey in 1974. His first P4C book for 10-12 year olds (grades 5 and 6), *Harry Stottlemeier's Discovery*, was drafted in 1969 and revised for field research in 1970-1971. Harry Stottle-meier (aka Ari-stotle) and friends reason through how statements can be twisted into truths or falsehoods. In one section, Harry's friend Tony exclaims that if a machine's parts were all small, "that wouldn't necessarily mean that it was a small machine. The parts could be light, and still it could be a heavy machine. So what's true of the part doesn't have to be true of the whole" (p. 66). *Pixie*, another P4C book published in 1981 for 9-10 year olds, explores ethics and freedom. Pixie is home alone with her older sister and sings "free, free, free! Everything's possible!" But big sister reminds her that "there are family rules, and they stay the same whether Mom and Dad are here or not" (Lipman, 2001/2009, p. 38). Used in classrooms, following reading aloud sessions and questions, children are challenged to discuss statements such as "family rules remain the same, whether or not adults are present" and "we are free if we think we're free" (p. 39). P4C "does not tell the child what to think: ultimately, that is up to the child" (Sharp, 2017, p. 26). By the mid 1990s, P4C diffused through 41 countries, from Argentina to Zimbabwe (Lipman, 1997). P4C demonstrates that children 10 years and younger can *think philosophically*, despite concerns (Kohlberg & Gilligan, 1971, p. 1072; Kitchenor (1990).

However much P4C advocacies and curriculum were developed for students facing tremendous technological changes since the 1960s, M&T has been overlooked (Petrina, 2020). Similarly, the philosophy of technology and design, engineering, and technology education have not accommodated P4C despite a wealth of children's literature with M&T content (Axtell, 2017). If "The Sorcerer's Apprentice" is a story of the seduction of technology, how might student philosophers relate this to their lives?

PHILOSOPHY OF TECHNOLOGY FOR CHILDREN AND YOUTH (PT4CY)

Of course, there are instances of PT4CY over the past few centuries. For example, in 1904, Dopp introduced an "Industrial and Social History" series of children's books and sustained their popularity through the early 1930s. "The removal of industrial processes from the home," Dopp (1904) says, deprived children from potent knowledge and compels us to "restore the educational factor that was in danger of being lost" (p. 9). The storybook format, in this case for 6-7 year olds, "is merely a literary device for bringing home to the child the truth that has thus far been ascertained regarding the fundamental steps in the development of our industrial and social institutions" (p. 133). A recent promising initiative in PT4CY is the "Philosophy Short Course" developed for Irish high schools (Canavan, 2014). Content for the "Philosophy of Science and Technology" strand includes guiding questions such as: "Does technology always advance human wellbeing?" and "Will technology be able to save our fragile earth" (p. 19)?

In our research, we address the core question of PT4CY: What does it mean for children and youth to *think philosophically about technology*? We explore how students and teachers can develop Socratic design, engineering, and technology (DE&T) classrooms, labs, and workshops. If we cannot yet say what characterizes this thinking or Socratic DE&T, we are able to provide insights into the challenges.

We recruited twenty-nine participants (ages 7-13 with mixed gender, ethnicity, and experience) for two intensive one-week gaming and robotics camps at the University of British Columbia. The recruitment flyer emphasized an exciting curriculum for children and tweens to "explore a world of creative possibilities with experienced technology teachers," and specifically to learn how to:

1. Design and program robots using Lego Mindstorms and NXT.
2. Design and make computer games and virtual worlds.
3. Design and produce digital video and still photography.
4. Be a technology researcher in a groundbreaking UBC study.

To ensure that no children were excluded for financial reasons, registration was complimentary (including nutritious snacks and lunch) and we were able to accept all the tweens (fourteen girls and fifteen boys) who registered for *101 Technology Fun*. Although gender was not the focus of the study, there were distinct differences in the girls' and boys' approaches to designing robots. We wanted to privilege the participants as authorities in their own right, so they were placed in important roles as co-researchers (Goldman-Segall, 1998; Haynes, 2008). For the duration of the camp, instructors and participants were actively involved in videotaping technology interactions, recording field notes, and conducting interviews with each other. Popular interview questions discussed during our recorded conversations include:

1. What are some of your favorite games and what do you enjoy about them?
2. How do you learn to play new games?
3. Tell me your memories of the first game that you played.
4. If you could rid the Earth of one game, which would it be and why?
5. Do you have any stories to tell me about designing with LEGO Robotics?

An immediate challenge for PT4CY is contradicting conventional wisdom (Petrina, 2020). We were especially curious about participants' insights into technology that differed from the conventional wisdom popularized in the media and various textbooks. As the participants were partnered for other activities in the camp, we mobilized them for small group interviews (2-5 participants). We asked them to think and talk about what technology is and means to them. Predictably, some immediately characterize technology as devices but less predictable are the unusual descriptions, which to us indicate serious thinking about the meaning of technology. For example, Jeremy thinks natural beings and things can embody technological features, but Jeff and Darren disagree. Anne and Marie then elaborate on the counter-argument:

> **Jeremy**: Technology can be living cuz some animals have electricity in them, like stingrays and electric eels.
> **Jeff**: No, not anything electric is technology.
> **Darren**: It [technology] has to be [hu]man-made and cultural. Animals are not cultural and can't be technology unless they are a scientific test-tube thingy trying to create life.
> **Jeremy**: [smacking on a wad of gum] My bubble gum is a technology of candy.
> **Darren**: Gum is just a piece of a rubber tree.
> **Anne**: Tree, rock and sun are Nature's technologies and Mother Nature's beauty is just there, not [hu]man-made, as there is no plug to plug-in to make nature grow. Did you notice that every technology is made out of nature? The [hu]man-made things use nature to make [hum]man-made things, and then use other man-made things to make more [hu]man-made things.
> **Marie**: Chicken laying eggs is like technology: the white egg is like technology eggs cuz you don't know what's inside growing and it's like, "how did this chicken come out of an egg?" If you didn't know about that then you'd think someone must have made the chicks. Kind of like the culture technology stuff the boys are talking about.

Although their values toward technology vary, many participants identify technology as celebratory and positive. For example: "it's sooooo amazing" (Ayako), "technology has done many things to improve our lives" (Tina). According to Alan, "technology makes things easier in life: the car is easier to travel, the broom is easier to clean and with a phone you can call people… technology helps you to learn and you can take online classes if you can't get to school." Responses from each child and tween differ and most are initially puzzled, caught by surprise, and unable to instantly contribute their thoughts to the simple question: "What is technology?"

This suggests the participants do not necessarily pause to consider the meaning of commonplace and pervasive M&T. Expressions of ambiguity reflect their immersion, not naiveté. Their views are strongly influenced by branding, marketing, and perspectives of friends; hence we are concerned by a noticeable absence of parents or teachers in participants' conversations. Certainly, there is a range of differences between the 9-10 year old children and 12-13 year old tweens. Raywin, with her superior store of 9 year-old knowledge, reflects, noting "when I was like 7 or something I was like technology, when you really think about the word, it sounded so boring like with too much complicated stuff so it won't be any fun, but now I know it's really fun to learn how to do stuff." Her level of analysis and observation is advanced, as she notes that "some people walk around like cavemen [and women] not knowing what to do without technology. We use technology every single day without noticing it, but without it we would be like, 'what are we doing' and we'd have to make our own stuff." The group of younger girls, working as coresearchers, elaborate:

> **Tina**: They should make them [hybrid cars] and sell them at regular car price cuz no one can afford them. They can make it in three easy payments like on the home shopping channel [giggles]. Actually, we need less things, not just cheaper, to help global warming, otherwise everyone would buy more if cheaper and that would pollute the earth. They should only make solar cars [pauses] except then only the rich people would have them.

Raywin: It would be really cool in the future if we could start off all over again, except not at caveman time, but when people started figuring out how to make technology and cars. We wouldn't make the same mistakes like global warming and cigarettes. People liked the smell and thought they tasted good, but then got addicted. Now we keep making smokes even though they are poison.
Ayako: And pollution. If someone threw a cigarette on the ground when I was born, it would still be there cuz it takes twelve years for it to totally degrade or whatever until it's totally gone.

These girls demonstrate a complex understanding of a good/bad technology continuum as they deliberate opportunities, risks, and appropriate use at home and school. Further, they show their capacities to willfully engage in contemplative dialogue and inquiry, when given the time and space to think about and question technology. What is the impact of PT4CY? Fast forward to 2035 when the participants of this study are old enough to have children of their own, will they look back with dignity or indignity for what technology is, how it evolved and what we made it to be? After deliberating these questions with the researchers, the group of student philosophers were further challenged to address their concerns through design-based thinking.

Paula (First Author): What if we make a game, and in this game we are able to start off fresh and re-imagine the world differently, to create a place like the one that you are talking about?
4 Girls: [in unison] Yeah! Oh Yeah! That would be so much fun! Totally Cool!
Raywin: If people play this kind of game and are having fun, then they might think that: "Whoa, maybe we can actually do this!" And the more people who play this game, the more people who will think about taking care of the planet. And maybe in the future sometime, they will actually start doing it.
Chani: Or maybe in the game you get to make something that helps the earth or fights pollution in the world.
Ayako: With technology that is better for the earth, not just what we want and we need and everything like that. Better technology where before we do something, we really have to think twice, to think more about everybody, not just yourself or a few people, but everybody and everything.

CONCLUSION

This is a unique contribution to PT4CY and its core question: What does it mean for children and youth to *think philosophically about technology*? We report on research with a group of children and teens, focusing on how they philosophize M&T within a learning environment where their ideas, reasons, and ways of thinking are valued. We present and analyze data collected through small group interviews that addressed the question, "what is technology?" We note that participants are quick to characterize technology as popular electronic devices, including, a camera, cell phone, computer, Game Boy, PSP, Wii, DDR, wristwatch, and Xbox. We presented the more unusual responses that suggest they are seriously thinking about what else technology might mean. While the depth of participants' desire and enthusiasm for consumption of brand-specific commercial technologies is troubling, the small group interviews reveal that they are philosophizing M&T in complex and unexpected ways. We try to capture the diverse and subtle ways that children and tweens generate meaning of M&T. While these selected examples do not tell the whole story, educators and researchers need to address concrete examples of M&T constraining, mobilizing, and tempting children and youth (MacDowell, 2015; Petrina, 2017). It is equally important to listen to how they philosophize M&T using argumentative skills, reasoning, and questioning. Questions directed to each other were quite complex. Inasmuch as their questions show inquisitiveness, they are as important as the answers provided (Nye, 2006).

It is notable that the children and tweens enjoyed philosophizing M&T. The tween boys' conversation about technology lasted for over an hour and they were surprised and somewhat disappointed to find out that we had run out of time. There were spontaneous exclamations: "That was so fun!" "Do we get to listen [to the recording]?" and "I really enjoyed that." Thinking philosophically about M&T can be as fun as building robots and playing popular entertainment games. STEM educators can effectively utilize youth interest in philosophical inquiry to ignite engagement in the significance of STEM curricula. Youth can figure out for themselves the meanings, reasons, purposes, and values without over-reliance on course texts. They can learn from the diverse perspectives of peers, as well as come to know that they have the ability to negotiate and change their views over time. This meta-cognitive course of action requires awareness of one's thinking and deliberate self-examination of what it thought, which encourages learners to develop their philosophies of STEM education, and their ways of thinking about STEM in the world. The goal is for children and youth to develop philosophical habits of mind that contribute to being and becoming thoughtful, reflective, empathetic, and reasonable citizens.

Key challenges for PT4CY and STEM education include diversifying questions and answers that draw from, for instance, African, Chinese, Indian, and indigenous philosophies, traditions, and wisdom. How can PT4CY help make wisdom teachable and learnable (Van Norden, 2017)? However much we are challenged to design STEM curriculum for "Traditional Ecological Knowledge and Wisdom" (TEKW) we are doubly challenged by Traditional Technological Knowledge and Wisdom (TTKW) (Turner, Ignace, & Ignace, 2000). One of our participants (Dan) insightfully reasoned that "90% of people in Ghana use firewood to cook, and for them that is a new technology if 90% of them are still using it." Whether this or that technology is old or new for Ghanaians is not quite what the tweens were debating. More profound is the fund of Ghanaian philosophies of M&T that might inform DE&T and STEM education.

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IMPACT OF MATHEMATICS CENTRE INTERVENTION AT A SOUTHAFRICAN UNIVERSITY OF TECHNOLOGY

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ABSTRACT

In 2012 the Centre of Academic Development (CAD) at a University of Technology (UoT) in South Africa started a Mathematics Centre (MC) to help the UoT Mathematics 1 and Mathematics 2 students with mathematics tutorial problems. This was to address the problem of bad performance in mathematics. Literature survey seems to attach tutorial approach – size, frequency of tutorial classes etc. – to performance success. This paper looked at impact of intervention within the scope of tutorial processes followed at the UoT. Examination results of the students in the pre-intervention years (2010 and 2011) and intervention years (2012 and 2013) were analyzed. The 2010 to 2013 years were chosen to minimize the impact of other variables on the intervention (e.g. *change of* syllabus, lecturers, number of periods per week etc.). Quantitative method was used. The examination averages, and corresponding pass percentages, of the pre-intervention and intervention were compared in both first and second semesters. The results showed that in Mathematics 1, the first-semester intervention average and pass percentage were higher than those of pre-intervention examination, while the trend for both was reversed in second semester. In Mathematics 2 the pre-intervention averages and pass percentages were higher than those of the intervention period, both in first and second semesters. This established the need to revisit the tutorial intervention processes at the UoT. What can be learned from the investigation is that intervention is not enough – how the intervention is done is of paramount importance.

Keywords: *examinations, peer tutors, performance, tutorials*

INTRODUCTION, GOALS AND OBJECTIVE

In a certain South African University of Technology (UoT), an attempt made to address the problem of low performance in mathematics was the introduction of a Mathematics Centre (MC), by the Centre of Academic Development (CAD), in 2012. CAD appointed mathematics tutors to help Mathematics 1 and 2 students having difficulty in solving mathematics tutorial questions they received from their normal mathematics classes. Tutorials were compulsory for all students, but there were no consequences for non- attendance of the tutorials. Students had access to the tutors daily. Topics covered in Mathematics 1 and 2 included using different techniques to differentiate functions and their inverses, solutions of ordinary differential equations, matrix algebra and statistics.

The goal of this paper is to investigate whether the intervention had any impact on the mathematics performance of the students. It is within Boud *et al.*'s (1999) assertion that a poor design of peer tutoring in tertiary education can damage the potential positive contribution of the tutoring, that we establish the impact of the tutorial intervention at this UoT. This gives rise to the following question:

Research questions: What was the impact of the intervention of the MC in the mathematics performance of the students? The following are the associated sub-questions:

1.1. How did the pre-intervention mathematics examination results compare with the intervention examination results in the first semester?

1.2. How did the pre-intervention mathematics examination results compare with the intervention examination results in the second semester?

Before answering these questions, we look at the literature that deals with tutorials**.**

LITERATURE SURVEY

South African rate of university graduation is, at 15%, among the lowest in the world (Lekseka & Maile, 2008). This, according to Pandor (2006), is a case for concern. Among several interventions to improve student performance are tutorial programmes.

This paper establishes how the use of tutorials can help address the problem of low performance with a specific focus on mathematics. Senior students with at least a BTech qualification with Mathematics 3 pass are hired by the UoT as mathematics tutors. A study by Fouche (2007) explored whether senior student - facilitated tutorials improved tertiary students' academic literacy course marks. The focus of a statistical analysis was on the impact of the tutorials on performance of students attending academic literacy course tutorials 10 times or more besides normal lectures. It was found that attending the tutorials did not improve students' Test of Academic Literacy Levels (TALL) marks, but the tutorial attendance seems to have positively impacted on the students' writing ability (Fouche,2007).

Consistent with this finding was Hutcheson and Tse's (2006) finding that attending tutorials regularly led to improved examination results. Kirby and McElroy (2003) found that students sometimes attended the tutorials more than lectures, benefitting from the smaller tutorial classes that resulted in better grades because of more active learning. Van der Merwe (2006) found that better-performing students showed more commitment to seeking tutorial task help.

Van Veggel and Amory (2014), in a study to investigate the impact of small-group math tutorials on first-year Animal Science student performance, found that small - group tutorials improved the students' academic math performance. Horn and Jansen (2009), investigated the Stellenbosch University first-year economics student tutorial programme, and found that tutorial attendance contributed positively to academic performance. Molepo and Mothudi (2014) investigated how face-to-face tutorials impacted first semester 2011 College of Education (CEDU) student performance at Unisa's Ekurhuleni Centre. They found that tutorials had a positive contribution on the performance.

Schoer and Shepherd (2013), in their investigation, started a tutorial programme that ran parallel to normal lectures. Students who obtained below 50% in the examination were obliged to attend the tutorials. The tutorials were optional for the other students. It was found that the compulsory tutoring improved the student performance. Johnston *et al.* (2000) focused their investigation on effect of a collaborative, problem solving (CPS) approach to tutorials in a second-year macroeconomics course. No consistent positive impact was observed for local students.

THEORETICAL FRAMEWORK AND LIMITATIONS

The teaching philosophy of the UoT under discussion is the one underpinned by the principle that knowledge cannot be passively transmitted from lecturer to the student, that the students need an opportunity to actively construct their knowledge subject to socially accepted norms. A socio-constructivist approach to teaching and learning was adopted at this UoT. Tutors, out of conscious effort to observe the philosophy, intended to use students' solutions to establish what prompting questions to ask to identify the student knowledge gap and guide the student solution. Unfortunately, there were stumbling blocks to adhering to the UoT philosophy.

There were two contexts in which the tutorial sessions were run. The first context involved the time-tabled tutorial session, where the whole class was attending. Because of the usually big classes – about 60 students per class – tutors identified the most common problems the students encountered and solved them on the whiteboard. This limited the tutors' ability to comply with the teaching philosophy of the UoT. There was no provision for seating arrangements that could facilitate the formation of group work. Lecture rooms were characterised by non-removable chairs in fixed rows.

The second context of the tutorial session involved a one – to – one contact between the student and the tutor. This is where compliance to the UoT teaching philosophy is attempted, depending on the number of the students on the queue to be helped. Unfortunately, because of lack of time management, majority of students waited till late to utilise the tutors' help. This again limited the tutor's attempt to adhere to the UoT philosophy.

RESEARCH METHODOLOGY

Research design

The research design was quantitative. Figure 1 gives a summary of the design

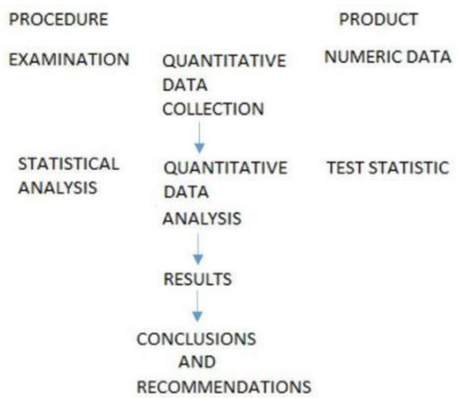

FIGURE 1: QUANTITATIVE DESIGN OF THE PAPER

What Figure 1 briefly shows is that quantitative data (examination results) were analysed and their means (test statistics) compared. Conclusions and recommendations were then drawn from the comparison.

Sample

The sample was a purposive sample. In this paper two populations – pre-intervention population and intervention population – are compared. The use of the relatively old data was prompted by the ease of comparing data of years close to the starting of the intervention – avoiding other variables like change of number of periods per week, change of lecturers and possible change of syllabus – all of which subsequently happened at the UoT.

Data collection instrument.

Data consisted of examination marks of 2010, 2011, 2012 and 2013.

Validity/ Reliability of the instrument

A tool is reliable if its results are reproducible. A ruler is a good example of a reliable tool, as the results of ruler measurement could be replicated time after time.

A tool is valid if it yields the intended measurement. Validity is all about genuineness of the research, whereas reliability is repeatability of outcomes.

a) Main examination mark as an assessment tool within the reliability and validity contexts.

The following steps were taken to ensure the reliability and validity of the main examination:

- A study guide given to each student at the beginning of the term specified not only the topics covered during the term but also clearly defined goals and objectives of each topic. Lecturers and tutors were guided by the goals and objectives when teaching or tutoring.
- The main examination was set by the assigned examiner for each level, and then moderated internally by another assigned colleague. The purpose of moderation is to ensure adherence to goals and objectives specified in the guide, adherence to the syllabus and consistent marking.
- The main examination was written by all students. Scripts were distributed among different lecturers for marking (numerous lecturers at this institution taught the same level mathematics, for instance, 8 lecturers taught Mathematics 1, 10 lecturers taught Mathematics 2 etc.), resulting in a lecturer not necessarily marking the scripts of his/her students. Student numbers rather than names were written on examination scripts, making it difficult for the marker to know whose script it is.

b) Semester comparison within concepts of reliability and validity

Semester 1 results were compared together, so were and semester 2 results. The pre-intervention 2011 first-semester Mathematics 1 results were compared with 2012 intervention first-semester Mathematics 1 results.

Furthermore, first-semester examinations could not be compared to second-semester examinations because the first semester was generally longer than the second semester, despite the same content being covered during both semesters. In this UoT by Maths 1 or Maths 2 we mean the mathematics content covered in one semester. A student would register for Mathematics 1 in January and Mathematics 2 in July of the same year.

c) Choice of the main examination mark as a tool.

The main examination mark was chosen for comparison in place of overall semester mark (consisting of class test, 2 semester tests a fourth mark (50%) and the main examination (50%)). The exclusion of the other components was prompted by the fact that, for instance, the fourth mark (quizzes, assignments) were set by individual lecturers. The class test was also set by the individual lecturers.

Data Analysis

The statistic used in the data analysis was the mean. The performance means (averages) of the two groups (pre-intervention group versus intervention group) were compared subject to statistical significance ($p < 0.05$). The pre-intervention and intervention examination pass percentages were also compared.

RESULTS:

Maths 1:

a) First semester 201101 versus 201201

TABLE 1.1: MATHS 1 FIRST SEMESTER 201101 VERSUS 201201

	201101Maths1	*201201Maths1*
Mean	43.3002681	47.57934509
Variance	270.7966935	316.1128641
Observations (N)	373	794
Hypothesised Mean Difference	0	
df	782	
T Stat	-4.035924947	
P(T<=t) one-tail	2.98668×10^{-5}	
t Critical one-tail	1.646804505	
P(T<=t) two-tail	5.97335×10^{-5}	
t Critical two-tail	1.9630022	

Table 1.1 shows that the pre-intervention students ($\boldsymbol{N} = \mathbf{373}$) got a mean of 43.4% as opposed to 47.58% of the intervention group ($\boldsymbol{N} = \mathbf{794}$). This is consistent with the fact that 7.7% of preintervention students obtained at least 50% in the examination as opposed to 44% of intervention students (See table 1.2 below). In the subsequent sections performance tables (like table 1.2) will be left out because of space.

TABLE 1.2: MATHS 1: PERFORMANCE IN THE ACTUAL EXAMINATION

201101 Opportunity 1 Maths 1	**Frequency**	**201201 Maths 1**	**Frequency**
0 - 9	0	0 - 9	0
10 - 19	24	10 - 19	44
20 - 29	51	20 - 29	72
30 - 39	69	30 - 39	128
40 - 49	104	40 - 49	198
50 - 59	72	50 - 59	164
60 - 69	28	60 - 69	104
70 - 79	13	70 - 79	44
80 - 89	10	80 - 89	32
90 - 99	2	90 - 99	7
100	0	100	1
Total	373	Total	794
Number of passes	**25**	**Number of passes**	**352**
Pass %	**7.7**	**Pass %**	**44**

b) *Second Semester Mathematics 1 results:*

TABLE 1.3: MATHS 1 SECOND SEMESTER 201102 VERSUS 201302

	201102Maths1	*201302 Maths1*
Mean	53.90831919	41.48255814
Variance	299.7874987	196.4499864
Observations (*N*)	589	172
Hypothesized Mean Difference	0	
df	338	
t Stat	9.670136518	
P(T<=t) one-tail	5.45629E-20	
t Critical one-tail	1.649374276	
P(T<=t) two-tail	1.09126E-19	
t Critical two-tail	1.967007311	

Table 1.3 shows that the pre-intervention students ($\boldsymbol{N} = \mathbf{589}$) got a mean of 53.9% (examination pass% = 61%, table left out because of space) as opposed to 41.48% (examination pass% = 30%,) of the intervention group ($\boldsymbol{N} = \mathbf{172}$).

Mathematics 2 results

a) First Semester Mathematics 2 results:

TABLE 2.1:MATHS 2 FIRST SEMESTER 201101 VERSUS 201201

	201101Maths2	**201201Maths2**
Mean	39.12237762	36.32085561
Variance	222.8011096	171.189725
Observations	572	561
Hypothethised Mean Difference	0	
df	1117	
T Stat	3.361296418	
P(T<=t) one-tail	0.000401015	
t Critical one-tail	1.646218928	
P(T<=t) two-tail	0.00080203	
t Critical two-tail	1.962090037	

Table 2.1 shows that the pre-intervention students ($\boldsymbol{N} = \mathbf{572}$) got a mean of 39.12% (examination pass% = 22%), as opposed to 36.32% ($\boldsymbol{N} = \mathbf{561}$) (examination pass% = 16%,).

b) *Second Semester Mathematics 2 results:*

TABLE 2.3 MATHS 2 SECOND SEMESTER 201002 VERSUS201302

	201002Maths2Opp1	*201302 Maths2Opp1*
Mean	51.81265823	41.24311927
Variance	262.9990791	292.6733395
Observations	790	218
Hypothesized Mean Difference	0	
df	332	
t Stat	8.165645184	
P(T<=t) one-tail	3.37095E-15	
t Critical one-tail	1.649456205	
P(T<=t) two-tail	6.7419E-15	
t Critical two-tail	1.967135057	

Table 2.3 shows that the pre-intervention students ($\boldsymbol{N} = \mathbf{790}$) got a mean of 51.8% (examination pass% = 62%) as opposed to 41.2% ($\boldsymbol{N} = \mathbf{218}$) (examination pass % = 29%, of the intervention group.

CONCLUSION, DISCUSSION AND SIGNIFICANCE OF THE STUDY

Conclusion and discussion

The 201101 versus 201201 Maths 1 results indicate an improvement as a result of the intervention, while 201002 versus 201302 results show a remarkable decline in performance from the pre-intervention period to the intervention period. It can be concluded that the Maths 1 impact of the intervention is inconclusive. On the other hand, the Maths 2 results seem to indicate a decline in performance from the pre- intervention period to the intervention period. The 201101 versus 201201 results show a decline of about 3%, which is not much difference. The 201002 versus 201302 results, surprisingly, show a sharp decline from the pre-intervention period to the intervention period. It appears generally, from the data, that the intervention, overall, did not have a positive impact on the performance of the students. What makes it difficult to conclude, on the contrary, that the intervention negatively impacted on the student performance is that students may have used the availability of the tutors as a false sense of security – waiting until too late to seek help. Helping an anxious student prepare for the examination because of the student unpreparedness does not necessarily mean what you do to help is not good. It is therefore recommended that the real cause of decline in student performance be investigated.

Significance of the study

This study offered the UoT an opportunity to introspect. Was the UoT intervention done right? What can be done to facilitate successful intervention? Further research is needed in this regard. Secondly, the tutorial intervention had the potential to isolate lack of time management as a culprit in the student performance. Students could have been distracted by the knowledge of availability of tutoring help, focusing on other subjects and running to the tutors on the eleventh hour. Should the student counselling be involved in helping students with time management? The results of this study can help the UoT to structure their tutorials in a way that will maximise the student potential – addressing items that contribute towards student failure. One must acknowledge that lack of intervention positive impact does not necessarily imply that the intervention itself has failed. The results further highlight interesting trends that require further research. The second semester **d**ifference in performance between the pre-intervention and intervention groups is quite large in both Mathematics 1 (53.9% versus 41.4%) and Mathematics 2 (51.8% versus 41.2%) groups.

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A NEW 21st CENTURY QUANTIATIVE LEARNING THEORY FOR IMPROVING STEM EDUCATION IN BOTH FACE-TO-FACE AND ONLINE MODE

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ABSTRACT

The learning theories in use today such as Constructivism and Behaviourism were developed in the 20th Century. They are qualitative and hence subjectively open to interpretation. This can result in wide variations in learning outcomes. A problem exacerbated when teaching and learning are online. In order to address this problem, Cognitive Load Optimization was developed. This Science of Learning method is simple to use and provides a quantitatively defined optimum learning path that is used as the basis of instructional design and teaching. Published work to date has shown that using this method, in the college and university sectors, results in significant improvements in learning outcomes for a wide range of STEM disciplines in both face-to-face and remote online modes. Preliminary results suggest CLO is applicable to teaching STEM in the school sector. However, further work is needed.

Keywords: *cognitive load optimization, science of learning*

INTRODUCTION

Learning theories explain how learning occurs and hence provide guidance on how to improve teaching and learning outcomes. The dominant ones in use today such as Constructivism and Behaviorism were developed in the 20th Century. They are best classified as 'soft' science because they are predominately qualitative. As such the methodologies are subject to different interpretations which may result in less than optimal learning outcomes. This problem is exacerbated when delivery is in remote, on-line mode when all teacher-student interactions are synchronous (aka simultaneously) and asynchronous in which there are inherent delays. This presents a more difficult learning environment which is reflected in student attrition rates which are typically much higher for distance education compared to the traditional face-to-face mode of teaching (Angelino, 2007). There is a case for a learning theory based on 'hard' scientific principles.

SCIENCE OF LEARNING – A REVIEW

There have been numerous international research initiatives in the Science of Learning (SoL). The Australian Science of Learning Research Centre (SLRC) was established to improve educational outcomes at all educational levels by developing scientifically based strategies and associated tools (Centre, 2020). The SLRC developed twelve principles based on Psychology, Education and Neuroscience (PEN). For example, PEN principle #1 *Written text and spoken word don't mix*. However, none of the PEN principles can be classified as 'hard' science. They are guidelines only. The US National Science Foundation (NSF) funded six Science of Learning Research Centres. It was concluded that much needs to be learnt about the Science of Learning. In order to assist teachers in the application of SoL the Deans for Impact defined six key questions and the corresponding cognitive principles that could be applied in the classroom such as '*A well sequenced curriculum is* *important to ensure that students have the prior knowledge they need to master new ideas*.' (Impact, 2015). However, they are guidelines only.

Significantly, the goal of SoL is optimized learning for all. This can only be achieved with a learning theory based on 'hard' scientific principles.

COGNITIVE LOAD THEORY

Cognitive Load Theory (CLT) is based on cognitive science principles, namely: schemas, Short Term Memory (STM), Long Term Memory (LTM) and automation (Bannert, 2002; Valcke, 2002). A schema is how knowledge is stored in LTM; it is a pattern of relationships that confers understanding. The process of learning is the construction of schemas in LTM mediated by STM. However, STM (aka working memory) has only limited capacity and retention time. Hence it can easily be overloaded. By contrast LTM does not have these handicaps. The learning process consists of new knowledge being presented to STM which is then assimilated with existing knowledge (schema) resident in LTM. Given the limitations of mediating STM this can be problematic as it can easily be overloaded. One measure of this load is called Intrinsic Cognitive Load (ICL) which is a function of the complexity of the knowledge to be taught. By definition complex knowledge consists of many interdependent elements that cannot be understood in isolation. Hence complex knowledge has a high ICL which can overload STM therefore handicapping learning. By contrast simple knowledge has a low ICL and easily learnt. An alternative taxonomy to Bloom (Anderson, 2001; Biggs, 1982; Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956) is the Structure of Observed Learning Outcomes (SOLO). Excluding the initial pre-structural and extended abstract levels, the SOLO taxonomy consists of three levels.

- Relational – learner has integrated subject into a coherent whole
- Multi-structural – learner focuses on several relevant aspects but they are disconnected
- Uni-structural - learner focuses only on one relevant aspect

The first two low order learning levels are essentially rote learning i.e., memory without understanding which has a low ICL. By contrast relational knowledge means that the student has established an understanding based on the relationships in the subject matter. According to Halford, '*Arguably, relational knowledge represents the core of higher cognition*.' (Halford, 2010). However, according to some measuring ICL in CLT is problematic (de Jong, 2010). In order to apply optimization techniques, it essential to have a reliable, quantitative method for measuring ICL.

COGNITIVE LOAD OPTIMIZATION

Cognitive Load Optimization (CLO) is based on scientific principles and hence is quantitative and objective (Maj, 2018). Significantly, CLO provides a reliable, quantitative method for measuring ICL thereby addressing the problem with CLT outlined above. To illustrate, using CLO it is possible to create the simplest learning path (with the lowest ICL) for a complex concept such as the equation $y = Asin(\omega t \pm L)$. This equation consists of attributes such as degrees, radians, amplitude etc. The attributes are organised from the simplest to the most complex and used to create a sequence of progressively more complex sub-concepts (Table 1).

Concept 1, $y = sin\theta$ has the attributes of degrees and radians. Concept 2, $y = Asin\theta$ inherits the attributes of degrees and radians but also has the attribute of amplitude. This results in a hierarchical predecessor/successor sequence of concepts. The concept/attribute matrix is used to create a concept attribute diagram (Figure 1) which is the basis of instructional design and teaching.

Table 1. Concept/attribute matrix

Attribute	Deg	Rad	A	L	$p\ \theta$	ωt
Concept						
0. $sine\ wave$ $(prerequisite)$	0	0	0	0	0	0
1. $y = sin\theta$	1	1	0	0	0	0
2. $y = Asin\theta$	1	1	1	0	0	0
3. $y = Asin(\theta \pm L)$	1	1	1	1	0	0
4. $y = Asin(p\theta \pm L)$	1	1	1	1	1	0
5. $y = Asin(\omega t \pm L)$	0	1	1	1	0	1

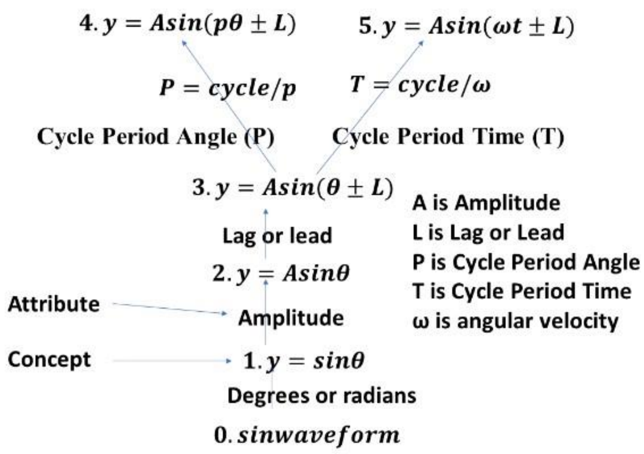

Figure 1. Concept/attribute diagram

There are different CLO metrics for measuring ICL, the simplest is the number of attribute changes (8) divided by the number of concepts (5) i.e., 1.6. According to Maj,

> *The CLO concept-attribute matrix and map represent the simplest and easiest learning path because each concept is presented sequentially to STM from the simple to advanced concepts in a logical, incremental sequence. Because of inheritance each attribute need only be taught once, but is reinforced by the subsequent concept thereby reinforcing 'new' existing knowledge. Learning new knowledge is therefore automatically contextualized. In effect subject material with a high ICL, and hence difficult to understand, can be converted to material a low ICL. Hence, when used as an instructional design method it reduces (minimizes) the STM load. This has the potential to significantly improved learning outcomes.* (Maj, 2020)

Using CLO, analysis of textbook material resulted in an incomplete and inconsistent matrix with a higher ICL (10/5 = 2). Again, according to Maj, *In effect a ‘gap’ represents an ICL. If a learning sequence has gaps students are forced to come to their own conclusions which may be incorrect. The resulting student schema could be incomplete, inconsistent and incorrect. This schema is the basis of learning more advanced material, and if incorrect has the potential to handicap further learning. Given that a schema is resident in LTM early learning tends to be persistent and hence may be hard to correct.*

Published work to date has shown that using this method, in the college and university sectors, results in significant improvements in learning outcomes for a wide range of STEM disciplines in both face-to-face and remote online modes.

CLO based distance learning – engineering mathematics

According to Maj, CLO can be used to significantly improve teaching engineering mathematics in distance learning mode resulting in 100% pass and retention rates, whist still achieving the objective of students acquiring complex relational knowledge. In this experiment teaching materials based on the CLO method were used to teach first year engineering mathematics in distance learning online mode. According to Maj, learning was considerably facilitated because as there were no cognitive gaps student questions typically anticipated the next concept. Feedback from all 10 participants based on the Likert scale (1 lowest, 5 highest) resulted in a score of 5 (highest) for every question. In this paper student comments were:

I found our Monday tutorial sessions to be the perfect blend of instructional teaching, challenging questions and most importantly thorough explanation.

So far this math unit is the best unit I have ever been in ever, I thoroughly enjoy our teaching and methods with interaction to make sure we are all learning. I also really enjoy how you can keep students active in the topic to help learning, and not like many other teachers, including one I had to drop out recently, that just read the content and answer questions quite vaguely. I would personally love if you could teach more units or if XXX could possibly get other teachers to adopt your teaching curriculum method. (Maj, 2018)

CLO based distance learning – teaching STEM to business students

A business degree in disciplines such as IT technology management requires students to study units in STEM technical subjects such as IT infrastructure, cybersecurity, secure information systems etc. These are technically complex subjects; however, business students often do not have a technical background. To address this problem CLO was used to teach three topics (computer technology, network technology and security technology) to non-native Englishspeaking post-graduate students in remote online learning mode. Three 6-hour presentations were given that included complex technologies such as: hash functions, integrity, encryption, decryption, Diffie-Hellman key exchange etc. Feedback from the 33 students was conclusive that teaching based on the CLO method (referred to as the ‘depth’ model) resulted in significantly better understanding of the topics (Maj, Nuangjamnong, 2020). Student comments regarding the CLO method included:

Able to understand the concept and how does it work. In this way you will be able to identify the issues when it happens because you are understand how does it work.

Understand deeply in all topic.

Understand the knowledge will last long than remember them.

By contrast student comments regarding the standard method of instruction included:

But lack of deep understanding of each topic. Sometime you don't really know your understanding is correct or not.

When asked if they would remember in 3 months' time what they have been taught using the CLO method student comments were: *Of course I will.*

Yes I still remember it because they explain and give an example.

Sure, I prefer this method because I can have a full understanding. I like the way I can think of something not remember it.

CLO based learning - Introduction to programming

A commonly used method of teaching programming is Greenfoot which is an integrated development Object Oriented Programming (OOP) platform designed for educational purposes with the target user groups being school children (circa 14 years of age) (Kolling, 2010, 2016). The high-level design goals of Greenfoot are to facilitate student learning by means of: ease of use; discoverability, quick feedback loop etc. Significantly one teaching principle is to avoid cognitive overload. An analysis of the Introduction to Programming unit, based on Greenfoot, for first year university students was conducted (Maj, 2020). The material was representative of complex relational knowledge as all the major concepts were taught such as: classes, objects, return types, inheritance etc. It was taught using the same material at three different geographical sites by different lecturers. However, at each site the pass rate was consistently less than 30%, on every campus, every semester. It should be noted the university has a rigorous recruitment policy and only hires lecturers with the appropriate knowledge and teaching experience. Significantly, when half of the programming unit content was taught based on the CLO method and delivered on one site there was a 60% increase in the pass rate compared to the other two sites.

CLO based learning - Network technology

The Cisco Network Academy Program (CNAP) is the world's largest technology curriculum that was developed by educational experts at an initial cost of circa $35 million. About 10,000 colleges and universities are CNAP academies with global enrolments of circa 300,000 students. The Cisco Certified Network Associate (CCNA) course was rewritten using the CLO method and the concept-attribute diagram used to develop an eLearning tool called State Model Diagrams (SMDs). In a direct comparative evaluation of the CCNA and CLO implementation, the CLO method resulted in significant improvements in learning outcomes achieved in considerably less time. There was also substantial evidence that learning was resident in LTM (Maj, Kohli, Fetherston, 2005; Maj, Veal, 2007)

CLO BASED STEM - IN THE SCHOOL SECTOR

Using the CLO method, the Australian curriculum for 12-14 years olds in digital technologies was evaluated (Grover, 2017). In chapter 4, Understanding Networks, there are clearly identifiable cognitive gaps and hence the material has a high ICL. Using the CLO method, a concept-attribute matrix was developed for the concepts of dedicated line, shared line, logical addressing, physical addressing etc. Hence the concepts were logically related from the simplest to the more complex by attribute ownership. This matrix represents the optimized simplest learning sequence with the lowest possible ICL and hence no cognitive gaps. Optimization can be done manually (simple and sub-optimal) or algorithmically (optimal). The associated concept-attribute map was used as the basis of instructional materials and delivery.

A cohort of 21 school children attended a one-day session on a university campus using a dedicated network teaching laboratory. Each pair of students was allocated two PCs, one hub, one switch and one router along with all associated cables. The workshop consisted of a series of short lessons interleaved with the associated practical exercise in which students established connectivity directly between the PCs, via a hub, via a switch and then connectivity through the router. During the lessons and workshops students were asked questions to evaluate their learning. Questions such as: can you unicast when in half-duplex mode? what does a switch table do? how does a switch enable unicast to work? All students managed to complete all the exercises. It was deemed inappropriate to ask the students attempt an exam. This experiment was monitored by a member of the university education department who deemed: throughout the exercise students were fully engaged; learning occurred and did not exceed their abilities; all learning objectives were meet. Further work is needed.

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SUPPORTS AND BARRIERS FOR TEACHER PROFESSIONAL LEARNING AND GROWTH

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ABSTRACT

The focus of this paper is to report on the supports and barriers teachers experienced while engaging in a year-long sustained coaching model of professional development. A grounded theory methodology was used to support theorizing about the effectiveness of a specific teacher professional development model. Data was collected from interviews (both pre- and post- the professional development sessions). Major findings have concluded that in order for the professional development to be sustainable, barriers to engaging in the professional development are to be minimized while supports need to be provided for teachers so that they can fully engage in the sessions. The study highlights that there needs to be a recognition of the complexity of the factors influencing a teacher's interaction with professional development. This complexity provides a lens with which to consider the potential for teacher change and effectiveness of teacher professional development programs.

Keywords: *teacher professional development, teacher growth, coaching, mathematics*

INTRODUCTION

Effective teacher professional development that contributes to a change in teacher beliefs and practice is a topic that has garnered much attention in the research literature for over 20 years (eg. Loucks-Horsley & Matsumoto, 1999; Netolicky, 2016). Traditional models of one day professional development sessions with no follow-up have been shown to be ineffective in impacting teacher practice and that long-term support is needed for teachers to begin to change practice (Gallagher & Bennett, 2018; Glazer & Hannafin, 2006). The coaching model of professional development used in this project draws on the elements of professional development that have been articulated in the literature (e.g. Avalos, 2011; Chaaban & Abu-Tineh, 2017) and has been implemented successfully with secondary mathematics teachers (Marynowski, 2014) as a way to influence teacher beliefs and practices with respect to assessment and classroom instructional strategies in the mathematics classroom.

Teacher professional development is considered crucial as teachers might not possess an educational background in the course they are teaching (The National Commission on Teaching and America's Future, 1996). Teachers need to be knowledgeable in the area they are teaching as teacher expertise is often related to improvements in student learning. When teachers are able to develop a deep understanding of the content they are teaching, they are more efficient in facilitating student learning, as they have a deeper understanding of how students learn (Loucks-Horsley & Matsumoto, 1999). They may be more likely to utilize deep learning questions in the classroom that stimulate critical thinking and problem-solving skills, while ultimately enhancing student learning overall (Hattie et al., 2016). Professional development should place more emphasis on the learning process itself as a way to enhance the understanding of how individuals learn (Knight, 2002).

Challenges to teacher growth

Despite the importance of teacher professional development, challenges can arise when learning and implementing new teaching practices in the classroom. For instance, teaching new practices can be a timely process and involves a lot of unlearning of current practices and beliefs (Loucks-Horsley & Matsumoto, 1999). In order to incorporate different practices, teachers need to be convinced that the new practices are going to be more beneficial to student learning than their current practices. Teachers are often faced with time constraints, which can create barriers in participating in professional development opportunities, as well as implementing what they have learned into practice (Rhodes & Beneicke, 2002). Teachers may face challenges in developing a deep understanding of the content they are learning due to a lack of time, and as a result, they may not be able to effectively explain the content they are teaching to their students if they do not possess a deep understanding of the content themselves (Loucks-Horsley & Matsumoto, 1999).

In order to create effective learning experiences and to implement change, change should be implemented gradually, teachers should be flexible with their techniques, teachers should be provided with the choice of what techniques to implement, teachers should be held accountable to implement the changes, and they should be provided with ongoing feedback and support (Timperley, 2008; Wiliam, 2007). The coaching model of professional development used in the current study aimed to achieve each of these stated goals.

RESEARCH QUESTIONS

The main research question guiding this study was: Can year-long engagement in a sustained coaching model of professional development change the beliefs and practices of teachers with respect to instructional and assessment practices in mathematics? A secondary question was: What processes within the sustained coaching model supported or proved to be a barrier to teacher change? The focus of this paper are the supports and barriers that teachers experienced while engaging in a year-long professional development series.

THEORETICAL FRAMEWORK AND DESIGN

This research project used qualitative research methodologies to respond to the main research question exploring teacher change through engagement in a year-long professional development series. Constructivist grounded theory (Charmaz, 2006) framed the research processes and was used to theorize about teacher professional development. Constructivist grounded theory allows for the articulation of a theory regarding a process that draws on participants' experiences through engaging in the process under investigation. Timmermans and Tavory's (2012) process of abductive analysis with respect to theorizing within a constructivist grounded theory methodology, which allows for the development "generating novel theoretical insights" (p. 174), was used as the basis of the analysis of the qualitative data. Bronfenbrenner's bio-ecological model of human development (Marynowski, Mombourquette & Slomp, 2017; Bronfenbrenner, 1999; Bronfenbrenner & Morris, 2006) was also used as a way to frame elements of teachers' personal ecosystems that influenced the degree of change a teacher was able to accept or endure. Teachers do not live and work in a vacuum, their ability and readiness to make changes to practice are influenced by their personal and work lives as well as the economic and political climate that they work within (Marynowski, Mombourquette & Slomp, 2017). The bio-ecological model of human development honors the complexity that exists in the ecology of one's life that either works to support or inhibit change.

PROJECT CONTEXT

The professional development sessions took place in a small rural school division in Alberta, Canada. The focus of the project was to support middle years mathematics teachers: grades 6 – 9. The majority of the schools in the school division have one class of each grade level at the middle years level and one mathematics teacher in the school. The schools in the school division are geographically spread apart and opportunities for teachers to engage in conversations and professional development with colleagues teaching the same course or grade level is rare.

Participants

Ten teachers and one consultant agreed to engage in the professional development with seven of those also agreeing to engage in the research components of the project. Of the seven participants, three had more than 15 years teaching experience, three had between five and 15 years of teaching experience and one had less than five years of teaching experience. Each of the teachers was teaching mathematics to students in at least one of the grades 6 – 9. One teacher was teaching mathematics to a single grade while the rest were teaching multiple grades, often in the same class. The consultant's role was one of assessment support for all teachers within the division. In addition, one of the teachers were trained as a mathematics teacher, five of them were trained as science teachers, and one was trained as a social studies teacher. One of the participants was also the principal of the school that he was teaching at. All 11 teachers engaged in all aspects of the professional development.

DATA COLLECTION

Data that is included in this paper consist of individual interviews with participants. Interviews were approximately 20 minutes in length. All interviews were conducted by the coach/researcher at the teacher's school at a time that was convenient for the teacher. The first interview for each participant focused on having the teacher describe specific characteristics of professional development that are important to that teacher, what that teacher hoped to get out of engaging in the professional development series, and what barriers the teacher has experienced in engaging with professional development in the past. The second interview asked the teacher to identify what, if anything, was most impactful for him throughout the professional development sessions, what barriers were experienced throughout the year, and what supports the teacher experienced that helped him engage in the sessions.

DATA ANALYSIS

Grounded theory methodology and abductive analysis was used to systematically conceptualize categories within the interview data (Timmermans & Tavory, 2012). The interviews were analyzed to produce rich data to support an in-depth exploration of emerging ideas, categories, and comparisons, and to ultimately enhance the understanding and interpretation of the participants' experiences (Charmaz, 1996; Charmaz, 2008). A simultaneous process of transcribing the interviews and analysing the interview data was implemented (Charmaz, 1996). For instance, the interviews were transcribed while listening for emerging categories, while preliminary memo writing was used to explore emerging thoughts about the data, as well as emerging categories (Charmaz, 1996). Transcriptions were revisited and reviewed using a line-by-line coding process to create initial codes for each idea conveyed throughout the interview (Charmaz, 1996). The codes were then revisited to rethink different perspectives, interpretations, and explanations of the data (Timmermans & Tavory, 2012). When new initial codes emerged during subsequent interviews, previous interview transcriptions were revisited and reviewed to determine whether this initial code emerged at an earlier time (Charmaz, 1996). The initial codes were then transformed into more concrete categories by comparing the data between participants, interviews, and additional categories found within the data (Charmaz, 1996; Mills, Bonner, & Francis, 2006).

Once the categories were revisited and reviewed for each interview, they were narrowed down into specific concepts to better interpret and explain the overriding themes found within the data (Charmaz, 1996). The concepts were also compared with existing concepts found within the research literature (Timmermans & Tavory, 2012). The concepts were calculated to determine their prevalence and verbatim material from the interviews was included to lend further support to the final concepts (Charmaz, 1996). The categories and concepts were interpreted as closely to the participants' experiences as possible (Charmaz, 1996). The goal was to develop a deep understanding of how the participants construct and make sense of their own experiences (Charmaz, 2008) related to their participation in this research project.

RESULTS

Within the sustained coaching model of professional development, there were several characteristics that were deemed to support teachers while others acted as a barrier. The characteristics of a sustained coaching model of professional development that were deemed most relevant in supporting teachers to change their practice were: a) being able to collaborate and learn from a consistent group of people; b) being held accountable for both doing the readings and for trying out something between the sessions; c) that there was an aspect of practicality to the sessions; d) that the sessions were held over the course of the year; and e) that the professional development sessions were being supported by both the school division and the principals. With respect to barriers present in the process the following elements were evident a) time away from the classroom; b) time to implement new strategies; c) the availability of substitute teachers; and d) the readiness of the individual to engage in and try out ideas.

Each of these supports and barriers carry different weight with different participants in the study. As such a professional development program needs to ensure that it is attentive to as many elements of support as possible and to remove as many barriers as possible. Though the elements identified here are not exhaustive, they represent the main components identified by participants in the current project as being key elements to influencing their beliefs and practices. Of the barriers that were noted, access to substitute teachers was a unique factor that has not been fully explored in relation to considerations in professional development. The access to quality support to teach one's class and not have to lose instructional time while attending a professional development session was a major consideration for teachers in this project.

Mills, Bonner, and Francis (2006) identify that an element of grounded theory analysis includes "integrative diagramming, illustrating the complex interplay between the different levels of conditions" (p. 30) at play in the articulation of theory development. As such, combining both Bronfenbrenner and Morris' (2006) bioecological factors and integrative diagramming, the following illustration, Figure 1, was developed to demonstrate the complexity of factors involved with professional development and teacher change.

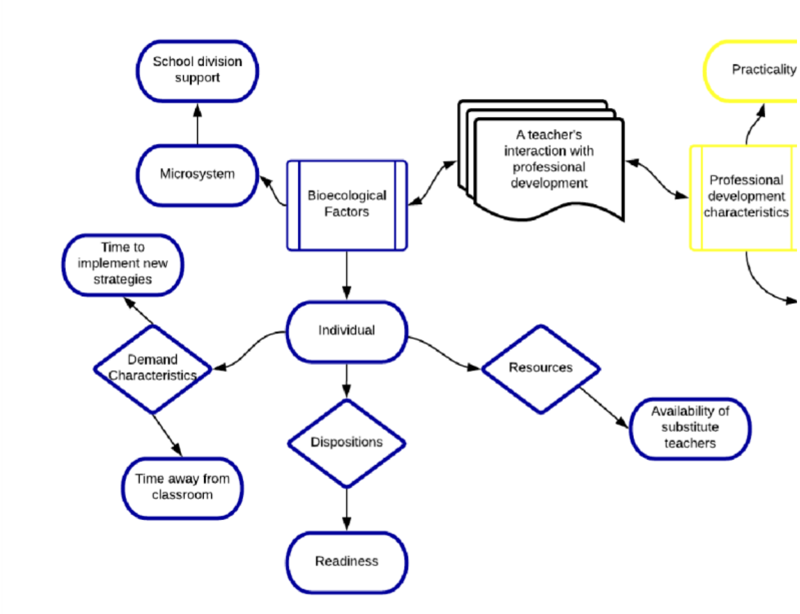

Figure 1: Illustration of the factors influencing teacher interaction with professional development.

Figure 1 illustrates the factors that are closest to the teacher that can be seen as influencing his or her interaction with the professional development and its potential to influence a change in beliefs or practice. At any given time for any teacher each of these elements could be more or less of an influence than another. In addition to each of those factors, there are macrosystem and chronosystem factors like the social conditions at the time, the political climate, and the era of accountability within the education system that have influence on teacher change and interaction with professional development (Marynowski, Mombourquette & Slomp, 2017). Four of the seven characteristics noted by the participants as being supports for their professional growth fall under the category of professional development characteristics, while the other three are bio-ecological factors. Additionally, each of the barriers that were noted by participants are bio-ecological factors rather than professional development characteristics. Elements that did not surface through this project, yet have been considerations in other research include the teacher's past professional development experiences and their relative successes in influencing that teacher's practice, past teaching experiences, and one's identity as a teacher (Kelchtermans, 2009; Rex & Nelson, 2004; van Zoest & Bohl, 2005).

CONCLUSION

This one-year study of the professional learning of a cohort of middle years mathematics teachers documents the professional development sessions and the bio-ecological factors which resulted in the changes of beliefs and practices of the participants. The richness of experiences of project participants not only inspires change in how we approach professional development, but the data yields substantial implications for how we structure it. Key characteristics on the success of this model include establishing an authentic community of teachers, including "commit to try" strategies over time, and a balance of theory and personalized, practical support for teachers. By using a combination of effective practices in professional learning, the impacts on teacher practices and beliefs can be deeper and more enduring.

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STEM-BASED INITIATIVES IN AN INFORMAL LEARNING CONTEXT: STARTING THE JOURNEY

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ABSTRACT

STEM has become a central focus in many countries, not only in educational practices, but also in an informal learning environment which provides various opportunities for young people to experience STEM outside of the classroom setting. This quantitative study of 92 participants focuses on students' motivation in attending STEM-related activities offered at Qatar National Library and the relevance of these activities to their favorite school subjects and future career plans. Students' insights into how a public library could improve future programs to further support STEM-related initiatives in the community, particularly for young learners, are also examined. Data was collected via a paper-based survey of library patrons with various nationalities during a series of STEM programs conducted from August to October 2019 as part of the Young Adults' department's library programs. Using descriptive statistical analysis, the findings show that young learners expressed a great interest in STEM topics. Findings also revealed that students indicated a preference for future STEM-related careers and are likely more interested to participate in various STEM activities offered in the library because of this interest. Students recommended that the library should organize more hands-on activities and programs related to STEM topics. This paper seeks to contribute to the growing body of research on STEM in informal learning environments, particularly those studies on organizing STEM-related concepts to enable users' exposure to authentic and practical learning experiences.

Keywords*: STEM, public libraries, informal learning environment*

INTRODUCTION

Many studies recognize the needs for STEM education in various institutions, particularly across education and information systems (Baek, 2013; Subramaniam, Ahn, Fleischmann, & Druin, 2012). In Qatar, several government agencies, institutions, universities, and schools have established campaigns to engage students in various STEM activities (Bukhari, 2018). One of these is the Qatar National Library, which has three functions: a National Library, a University and Research Library, and a Metropolitan Public Library.

In April 2017, Qatar National Library was officially opened through the initiative by Her Highness Sheikha Moza bint Nasser, Chairperson for Education, Science and Community Development.

Since then, the library has achieved various milestones: 900,000 visitors, 150,000 registered library members, and more than one million resources. Additionally, the library has hosted 1,300 events related to Information Literacy and Reading, Health and Wellbeing, Arts, and STEM.

Young adult librarians have implemented several STEM-related programs for young adults. Library programming is one of the core responsibilities of the department, and staff members organize monthly programs. STEM activities have included robot building, MaKey-MaKey, Ozobot, lego challenge, coding and programming, experiments, building roller coasters, Robot building, wave creation, building blocks, and hydraulic activity. The programs are free and open to all young adults, who register online through the library website.

This paper highlights the role of the public library in addressing and meeting young people's STEM related needs with these objectives:

1. To identify school-aged library users' motivations in attending STEM-related activities in a public library;
2. To determine users' favorite school subject and their preferred future career;
3. To gather insights on how a public library could improve future STEM-related programs.

LITERATURE REVIEW

Public libraries, informal learning, and STEM

Several international organizations and professional associations in library and information science highlight the roles of public libraries in promoting STEM and address how the library can serve as a platform for communities to experience authentic learning experience on STEM initiatives (Australia Library and Information Science, 2017; Young Adult Library Services Association, 2013). Roberson (2015) claims that STEM-based library activities are in demand by a wide range of library users. It is believed that libraries are part of a "STEM learning ecology" that provides invaluable resources, particularly for children and families, to cultivate their learning and development (Lopez, Jacobson, Caspe, & Hanebutt, 2019, p. 9). Duncan and Murnane (2014) identify libraries' roles in fostering STEM within the community through various events such as makerspaces, exhibitions, and children- and family-oriented activities that provide opportunities for attendees to learn STEM concepts (as cited in Lopez, Jacobson, Caspe, & Hanebutt, 2019, p. 5) . Similarly, Dusenberry (2013) argues that having STEM programs in libraries creates more opportunities to engage users, particularly in science and technology. Lopez et al. (2019) explain that public libraries link formal and informal environments while providing opportunities for children and young adults to collaborate with their families.

Many studies indicate that public libraries are considered an informal learning environment (Fenichel & Schweingruber, 2010; Institute of Museum and Library Services, 2009; (Kuhl, Lim, Guerriero, & van Damme, 2019). Informal learning environments are defined as places where activities occur outside of a school-based setting (Yao & Mohr-Schroeder, 2019). They can be categorized into three settings: "everyday experiences," "designed settings," and "programmed settings" (Kotys-Schwartz, Besterfield-Sacre, & Shuman, 2011). Because public libraries provide various activities that are wellplanned and facilitated outside of schools, they considered programmed settings (Denson, 2015). These settings enable learners to engage and focus on their own interests in a flexible and dynamic space, where they can learn independently (Young Adult Library Services Association, 2016).

Informal learning environments (ILEs) have many advantages in promoting STEM concepts within the community. The use of informal learning in STEM initiatives has been shown to effectively increase students' interest in STEM (Mohr-Schroeder et al., 2014) and influence students to choose STEM careers (Kitchen et al., 2018). Denson et al. (2015) claim that informal learning environment has been an effective tool to empower students' STEM knowledge and skills.

Informal learning environments also support students' learning needs outside of the school curriculum. Yao and Mohr-Schroeder (2019) note that ILEs "supplement and complement the work being done in schools" (p. 148). ILEs provide opportunities beyond traditional activities at K-12 schools by offering experiences that may not be available in K-12 schools. According to Yao and Mohn-Schroeder, schools face limitations including lack of time, limited resources, and lack of expertise. In this learning ecosystem, after school activities play an important role to support students' success (Belle et al., 2009). Therefore, public libraries and other ILEs play an indispensable role in promoting and fostering STEM-related initiatives (Dusenbery, 2013).

Theoretical Framework

This study adapts the situated learning theory to examine learning activities outside of the classroom based environment. As defined by Clancey (1995), situated learning theory supports the idea that when students are exposed to authentic and actual learning experiences, they engage in a better learning process. Situated learning theory "suggests that learning takes place through the relationships between people and connecting prior knowledge with authentic, informal, and often unintended contextual learning" (Northern Illinois University, 2018, p. 1). Situated learning theory is commonly used to address the relationship between informal learning and STEM concepts (Larkins et al., 2013), as well as relationships between learners and their environments (Brown et al., 1989). Since programs organized at libraries are considered a community practice, they provide opportunities for participants to experience authentic learning, which is one of the characteristics of successful STEM programs in informal learning environments (Prentice, 2011).

RESEARCH DESIGN

Ninety-two library patrons (N = 92) from Grades 3 to 10 completed a paper-based survey after participating in a STEM-related library activity from August to October 2019. These activities included: Makey Makey, Robotics Building, STEM for Young Adults, and Makerspace (see Figure 1). Paper surveys were distributed after each program to all participants. Those users who had difficulty understanding survey questions were assisted by their parents or an assigned library employee. This study modified question from a study by Roberts et al. (2018). This paper created three questions:

"What does STEM mean to you?", "What is your favorite subject?", and "What do you want to be when you grow up?" (p. 5). Additionally, users were asked how they found out about the program, stated their satisfaction with the content and registration experience, and indicated their reason for attending the session.

Figure 1: Sample STEM activities that were held at Qatar National Library.

RESULTS AND DISCUSSION

Demographic Profile

In all five STEM activities that were conducted by the library, the majority of attendees were in Grade 7 (27 %, *n* = 25), Grade 8 (26 %, *n* = 24), and Grade 6 (18%, *n* = 17). There were also attendees from Grade 3 (9%, *n* = 8), Grade 5 (8%, *n* = 7), Grade 4 (5%, *n* = 5), Grade 9 (4%, *n* = 4), and Grade 10 (2%, *n* = 2). Among the participants, there were more than males (74%, *n* = 68) than females (25%, *n* = 24) in all sessions.

Surveyed patrons' nationalities included British (12%, *n* = 11), Canadian (5%, *n* = 5), Egyptian (22%, *n* = 20), Filipino (1%, *n* = 1), French (2%, *n* = 2), Hungarian (2%, *n* = 2), Indian (26%, *n* = 24), Jordanian (4%, *n* = 4), Pakistan (2%, *n* = 2), Palestinian (2%, *n* = 1), Qatari (8%, *n* = 7), South African (1%, *n* = 1), Sri Lankan (5%, *n* = 5), Syrian (2%, *n* = 2), Turkish (2%, *n* = 2), and Yemeni (2%, *n* = 2).

Source of Information about the Program

When participants (N = 92) were asked how they found out the program, the majority (80%, *n* = 74) mentioned the library website, and 14% (*n* = 13) selected word of mouth. Five respondents (5%, *n* = 5) did not provide any information about it. This indicates that the library website has become an effective tool to market STEM-related library programs and attract school-aged users to attend these sessions. Since Qatar a small country with many non-native residents, word of mouth may be an effective form of information gathering for this population.

Users' perceptions about STEM

This determined users' understanding about STEM by asking them about their ideas about the term "STEM." More than half of the surveyed students (63%, *n* = 58) defined STEM as Science, Technology, Engineering, and Mathematics. A small number (10%, *n* = 9) mentioned that STEM is about Technology, and the same number (10%, *n* = 9) said that they do not know anything about STEM. Moreover, four respondents (4%, *n* = 4) indicated that STEM is about "Education." Two respondents (2%, *n* = 2) related STEM to plants that have roots and carry water. Only one user (1%, *n* = 1) described STEM as a "complicated" topic. Other respondents (10%, *n* = 9) provided unrelated terms about STEM. Further exploring users' perceptions could help educators, librarians, and other domain experts identify the level of users' awareness about STEM, which might be a preliminary step to organize informal learning activities on STEM in the future.

Users' reasons for attending the public library's STEM programs

The study examined users' motivations for attending the library's STEM programs. A majority of users (58%, n = 53) expressed that they are interested in STEM and want to learn new information about it. Almost a quarter of survey participants (23%, n = 21) mentioned that they are influenced by their parents to participate in this kind of library program. A small number of respondents (17%, n = 16) indicated that they wanted to experience a new activity in the library. One percent (1%, n = 2) said they attended to be with friends. These findings indicate that young learners view the public library as a place to gain knowledge about STEM topics.

Users' favorite subject in their schools

Since the target of the library's STEM programs are K-12 students, it is important that the library activities are attuned to students' academic preferences and personal growth. Of all respondents, 29% (n = 27) noted that Math is their favorite subject, followed by 24% (n = 22) who indicated it was Science. Fifteen percent reported English (n = 14) and Physical Education (n = 14) as their preferred subjects in school. Only 10% (n = 9) of them indicated Arts, History 3% (n = 3), Geography (1%, n = 1), French (1%, n = 1), and Chemistry (1% , n = 1). Overall, a significant number of K-12 library patrons' favorite subjects are STEM topics, which could indicate that these users have strong preference for STEM activities, and therefore it might be useful for the library to organize STEM programs to serve these patrons' subject interests.

Users' long-term career plan

One of the goals of the library is to further support their users' long-term career plans. When asked about their future professional career plans, most of the respondents (33%, n = 29) indicate that they wanted to become an engineer. Eighteen percent (n = 17) reported that they see themselves working in a medical field. Nine percent (n = 8) wanted to become football players, pilot (n = 8), and teacher (n = 8). Eight percent (n = 7) of students said that they will become a scientist. Four percent wanted to become an artist (n = 4), and geographer (n = 4). Two percent sought to become astronauts (n = 2) or computer programmers (n = 2), and two percent (n = 2) were uncertain which future profession they wanted to pursue. These findings indicate that a majority of the respondents are currently interested in a STEM-related career. Based on this finding, the public library should continue to foster STEM-related initiatives in the community.

Users' feedback on future STEM-related library programs

Figure 2, created with an online word cloud generator, shows the list of users' feedback terms that were generated from the survey. A large number (n = 42) of patrons commented "more" when they were asked about what kind of STEM activities they preferred to see in the future library programs. Some of the respondents did not indicate any comments, while others preferred to see robot-related and art activities in the library. This word cloud helps show that library patrons are eager to see more STEM related activities in the library. This preference might be a good indication that K-12 users satisfy with the current library programs or expect the library to deliver these kinds of activities to provide for their learning needs. Additionally, findings presented here present the foundation for in-depth analysis on how STEM-related activities in a public library could impact the learning experience of library users, as well as address the effectiveness of these programs in meeting users' expectations for coverage of STEM topics.

Figure 2: Users' feedback on future STEM-related library programs

CONCLUSION

The study shows that many young learners perceive the role of a public library as not only a physical space, but also as an arena for providing access to and resources for STEM topics within authentic and practical learning experiences. As Dusenbery (2013) states, "Informal education environments, such as libraries, are now seen as an untapped STEM" (p.2). The preliminary findings presented here provide a new perspective of the important role public libraries play in the continuous growth of STEM education. Survey results that explored library users' insights can help other libraries leverage the STEM learning needs of their student-aged patrons and provide authentic learning environments that fit the library's objectives. By understanding library patrons' perceptions of how a public library can help their STEM educational needs, this research contributes to the development of STEM-related conceptual programming in informal learning environments. Questions such as "How do educators and librarians design their STEM-based programs?", "How do these programs impact users' development?", and "How does a public library maximize resources to support STEM needs within the 21st century learning environment?" could inform future studies. With STEM educational needs continuing to grow, this newly built public library will continue to foster STEM skills in the community. Similar studies of its future initiatives could inform other library programs around the world.

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SCAFFOLDING CRITICAL REASONING AND ARGUMENTATION IN STEM LITERACY TEACHING

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ABSTRACT

Science Technology Engineering and Math (STEM) has been a popularized yet diversely interpreted set of disciplines in education for over a decade. One aim of STEM education is to equip 21st Century students with the critical reasoning skills to participate in democratic discussion on contentious social scientific issues such as climate change, genetic engineering, population growth, and factory farming. STEM literacy and 21st century communicative competencies need to go hand in hand. However, a lack of pedagogical integration across the disciplines has contributed to difficulties in applying the knowledge and skills learnt in different disciplines to the tasks of understanding, explaining and reasoning about social scientific issues. Our research study focuses on the challenges faced by students in understanding, explaining and applying knowledge of the theory of evolution by natural selection, in an undergraduate biology course to develop warranted arguments on a contentious issue in human biology. A combination of the Premise-Reasoning-Outcome (PRO) cognitive scaffolding (Tang, 2015) approach along with the use of dialectal maps (Niu, Sharp & Nesbit, 2015) were used.

Keywords: *STEM, theory of evolution, argumentation*

INTRODUCTION

For the last decade, the term STEM has made its way across many K-12 classrooms in North America (Kennedy & Odell, 2014). As discussed by Macdonald (2016), STEM education was aimed at encouraging more students, especially female students, to pursue STEM subjects to increase the number of students entering STEM-based careers and ensuring those students were well prepared to engage in the work force.

Researchers have found that the different subjects in STEM education are often seen as separate silos lacking the necessary integration between disciplines (Ashgar, Ellington, Rice, Johnson, & Prime, 2012). Teachers often utilize explanation styles of practice that do not give students the opportunity to use their own reasoning skills and participate in dialogic learning. Therefore, it is important for teachers to re-configure their practice in order to integrate new meaningful ways of learning (Hallström and Schönborn, 2019).

One such method in the science classroom involves argumentation. "Argumentation is a central goal of science education because it engages students in a complex scientific practice in which they construct and justify knowledge claims (Berland & McNeil, 2010, p.765). According to Jimenez-Aleixandre, Rodriguez, and Duschl (2000), argumentation includes linguistic propositions that involve creating, justifying and explaining knowledge claims and beliefs.

GOALS AND OBJECTIVES

This study investigates an alternate way of teaching the theory of evolution to post-secondary biology students. An area of study that is of particular difficulty for biology students, is the fundamental concept of evolution by natural selection, as much of the terminology, such as fitness, also conveys everyday concepts. Confounding every day and scientific meanings of evolutionary terminology may be due to students' lack of understanding of scientific conceptions. In addition, some students feel that their religious or cultural beliefs prevent them from accepting evolutionary concepts (Basel, Harms & Prechtl, 2013). We propose that by integrating an explanation genre, specifically the *Premise-Reasoning-Outcome* (PRO) Approach (Tang, 2015), we can offer students and teachers a new method to learning critical evolution theory. This cognitive discursive scaffold takes into account three features of scientific explanation; the principal fact or premise, the reasoning behind the principal, and the explanation of the outcome or result of the phenomenon (Tang, 2015). The idea of PRO is that it helps to scaffold students' construction of a theory-based explanation. We have chosen to modify the PRO instructional framework (Tang, 2015) by combining the Phenomenon (P) and Reasoning (R) steps and by including aspects of a dialectal argumentation, specifically using a dialectal map (Dmap), which was established by Nesbit and Hui (Nesbit, Niu & Liu, 2019). The dialectal map is a web-based schema that responds to a specific science related statements with a pro and con binary, along with a space to discuss evidence, warrants and conclusion arguments. However, by using a dialectal map on its own, students may still lack the scaffolding to develop theory-based and evidence-based explanations. For the purpose of this study, the structure of the scientific explanation will comprise of three primary components (a) Problem/Phenomenon and evidence, (b) Reasoning, which includes the accepted knowledge that provides the basis of the explanation and the logical sequences that follow from the premise and the warrant for evidence, (c) Outcome, which includes evidence that contributes to the phenomenon. We refer to this modified PRO based theory as PRO_Map. It is anticipated that this approach will help students to reduce their misconceptions regarding the topic of evolution and natural selection. The PRO_Map explanation strategy will improve students' knowledge-based reasoning skills when discussing contentious STEM-related social scientific issue and the framework will help them to provide evidence to support their claim.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

In creating clearer competencies for STEM education, STEM literacy outlined more concrete guidelines. STEM literacy includes all four disciplines working as an integrated system to solve real world problems that cannot be solved using a single discipline (Bybee, 2013; Jackson & MohrSchroeder, 2018)

Bybee (2013) established four basic tenets of STEM literacies as:

- Knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues.
- Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry and design;

- Awareness of how STEM disciplines shape our material, intellectual, and cultural environments;
- Willingness to engage in STEM-related issues and with the ideas of science, technology, engineering and mathematics as a constructive, concerned, and reflective citizen." (p.101).

It is not enough to look at STEM literacies in isolation. One must also consider 21st century reasoning and communicative literacies as an integrated part of the future of learning and teaching practices. Many of these competencies are intertwined with STEM literacy. As outlined by the Partnership for the 21st Century (2008), three areas of skills are emphasized: learning skills, literacy skills and life skills. A key factor that is highlighted in 21st century skills, but is missing from STEM literacy, is the idea that other non-science related disciplines play an important role in achieving STEM education competencies. For example, in their study on Information Communicative Technologies (ICT), van Laar, van Deursen, van Dijk, and de Haan (2017) discuss the importance of not overlooking the human factor when considering these skills. Although 21st century competencies feed the globalized economy, a human's ability to solve problems in the ever changing globalized climate is critical, "How someone thinks, solves problems, and learns, has a greater impact on a person's ability to function in a technologically rich society than just being knowledgeable about specific software" (p.578). In order to incorporate these critical reasoning and communicative literacies into a STEM literacy framework, it is important to consider a shift in teaching practices to include reasoning skills.

As mentioned in the 21st century skills, students need to acquire the ability to solve real world scientific problems, and these skills require an integrative approach. In many science-based classrooms, explanatory teaching practices are paramount. However, it is important to incorporate a form of practice that explores reasoning skills and that can further develop an understanding of content and problem-solving skills. Argumentation theory is a form of teaching practice that incorporates scientific principles with reasoning skills. There are three types of argumentation: analytical, dialectal, and rhetorical. Analytical arguments revolve around logic and involve inductive and deductive reasoning to reach a conclusion; Dialectal arguments involve discussions that lead to premises that may or may not be true and the synthesizing of information; Rhetorical arguments involve the persuasive presentation of an idea by using knowledge and discursive techniques (Jimenez-Aleixandre et al., p.760). For the purpose of this study, we will focus on dialectal argumentation. According to Nielson (2013), dialectal argumentation refers to the "features that are operative when students collaboratively manage (potential) disagreement by providing arguments and engaging critically with the arguments provided by others" (p.372). Dialectal argumentation offers advantages in the science classroom. These include building the skills necessary to participate in scientific debate and allow for a co-construction of disciplinary knowledge by incorporating different perspectives and world views. It is important to note that argumentation practices are not separate from explanation practices. Berland and Reiser (2008) found that these teaching practices can be considered complimentary. "First, explanations of scientific phenomena can provide a product around which the argumentation can occur, while proponents of an explanation attempt to persuade their peers of their understandings. Second, argumentation creates a context in which robust explanations—those with which the community (the students) can agree—are valued" (p.28). Dialectal maps also play a useful role as a study tool. Niu, Sharp, and Nesbit (2015) conducted an experiment in which students were placed into random groups, including a dialectal map group, argument group and a no-training group, in order to examine how student's write about their ideas. There was a notable difference in the active engagement of the Dmap group in regard to studying. The results indicated that the group that used Dmap as a study tool were able to better retrieve information from their long-term memory and were able to make meaningful connections.

A challenge for science teachers involves changing their explanatory teaching practice to include an argumentative style. In order to shift this teaching practice, we have opted to use the PRO approach to help students construct explanations and reasoning skills. In his study, Tang (2015) found that the PRO approach helped students understand the specific content but acted as a scaffold to support the students in their reasoning skills. Tang found that students gained content knowledge from using the PRO strategy, but they were also able to improve their scientific reasoning skills "while the emphasis of using PRO was initially targeted at learning the specific content and phrasing answers for written examination at the beginning of the year, the emphasis gradually shifted towards getting students to think about the logical sequencing of the explanation (p.7). Tang (2015) describes the PRO approach by stating the following: P-premise refers to the law like generalization that has been established; Rreasoning refers to the logical steps that follow the main principle or premise; O-outcome refers to the result of the sequence of logical steps (p.4). Therefore, the PRO method is transferable to a variety of scientific topics, including evolution for natural selection. For example, the teacher could discuss the theory of evolution by natural selection and students would work toward generating an explanation for the reasoning and outcome of the particular topic related to evolutionary change in human population. However, it must be emphasized that process is a co-construction between the instructor and researcher.

RESEARCH DESIGN

Methodology

In this Design-Based Research Study, our aim is to investigate ways to incorporate an argumentation style of teaching practice, by using aspects of dialogic and dialectal argumentation as complementary skills that pertain to critical evolution theory in an undergraduate biology course. In combining the PRO approach and Dmap, we will use a new framework, which we refer to as PRO_Map. In addition, a quasi-experimental design with student pre- and post-tests will also be utilized. Based on the objectives, our research questions are:

(1) When discussing critical concepts in the theory of evolution by natural selection, how accurately do students express their knowledge of content and their reasoning skills?

(2) When introduced to the PRO_Map approach, how accurately do students demonstrate an understanding of the content and provide logical reasoning and explanations for the outcome, as it pertains to critical concepts of evolutionary theory?

(3) How do the instructors feel with a shift in teaching style from a more explanatory practice to an argumentation and dialogic practice?

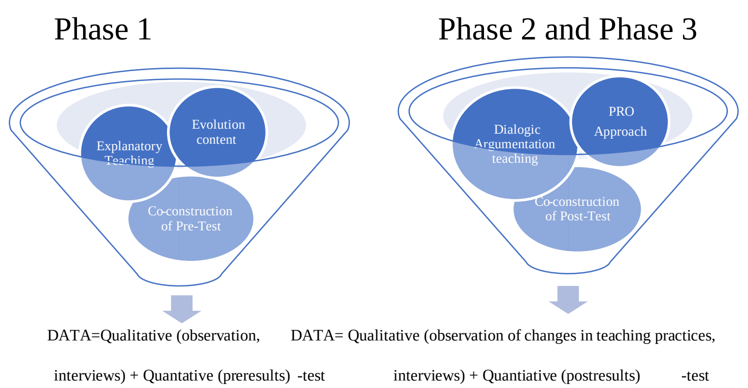
The design-based research is divided into three phases (see Figure 1.1):

Phase 1: Involves an ethnographic approach, where naturalistic observation and student interviews are conducted. There is a collaboration between the instructor and researcher in terms of identifying the problems related to the theory of evolution by natural selection. A pre-test is co-constructed.

Phase 2: In this phase the instructor and researcher co-construct 5 weeks of modules, where the PRO_Map approach embedded in the teaching practices. After the 5-week module, a post-test is coconstructed, as well as student interviews (open-ended interviews).

Phase 3: In this phase, the instructor will be interviewed (using open-ended approach) as to his/her perspectives on the different teaching styles.

Figure 1.1: Research Design



The data will be collected using video classroom recordings, field notes, interviews with students and instructors, pre and post test data (which includes the student's written data). The participants in this study will include 230 students and one instructor from an introductory biology class, in a postsecondary university. The school is located in Metro Vancouver.

ANTICIPATED RESULTS AND DISCUSSION

In analyzing the data, including the classroom video recordings, field notes and pre and post test data, we anticipate there to be a qualitative and quantitative difference in the way students understand and are able to explain and provide reasoning to questions related to critical concepts about evolution by natural selection. It is anticipated that students who scored higher on the post-test were able to engage critically with the material and were active participants in the argumentative and dialogic style of learning.

In this study, we aim to analyze student's argumentation skills by using the framework of PRO_Map style of teaching, as related to critical concepts in evolution theory. Although, we have not yet conducted this study, it is our projection that upon analysis, students will show an improvement in their argumentation skills on the post test. It is also our projection that the instructor will prefer using the PRO_Map approach and argumentation style, when teaching the theory of evolution by natural selection.

CONCLUSION AND SIGNIFICANCE

One of the overlapping premises of STEM literacy and 21st century skills is the idea of a concerned reflective citizen who is able to solve problems. To be a truly reflective citizen, a dialogic perspective is integral. In order to solve problems and be reflective, we need the ability to reason, explain and share our own knowledge and experiences. These factors are critical in the ability to participate in meaningful ethical-onto-epistemology. We define ethical-onto-epistemology as honouring the everyday assumptions or experiences along with scientific knowledge and content. Each individual's experience and life history play a part in how they interpret content. Therefore, it is critical for educators to create a space for this dialogic perspective.

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USING INTEGRATED APPROACH TO TEACH SCIENCE: A FIJIAN CASE STUDY

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ABSTRACT

Visual and culturally appropriate methods are gaining focus in teaching and learning of science. An exploratory, qualitive study used learning space observation of fifteen Grade 5 students from Fiji to investigate the effectiveness of the use of drawings and *Talanoa* (a culturally appropriate method for informal discussion) to teach science. The study unpacked that the use of integrated approach of drawing and *Talanoa* helps the students to describe their feelings fairly easily, encourages collaborative meaning-making as it allowed the students to give voice to what the drawing was intended to convey, and articulate feelings that had been implicit and were hard to define. Although this study is limited to small sample size, it argues that drawings and culturally appropriate methods of teaching and learning science offer a rich and insightful in science education.

Keywords: *qualitative inquiry, drawing, Talanoa, integrated approach, visual, culturally appropriate*

INTRODUCTION

Providing students with the means to communicate their thinking through visual and verbal representations in a supportive environment is crucial in maximising the benefits of teaching and learning (Van Meter, Aleksic, Schwartz, & Garner, 2006). Educators around the world acknowledge the need for culturally appropriate ways to communicate to students to understand and explore their understanding of the world around them and students being able to express ideas and information clearly in many different ways (Farrely & Nabobo-Baba, 2012; Halapua, 2008; Vaioleti, 2006). Literature reveals that there is little research on the use of drawings (Brooks, 2012; Van Meter et al., 2006) and culturally appropriate methods (Farrelly & Nabobo-Baba, 2014*;* Vaioleti, 2006), to teach science.

Fiji being a multicultural country with rich cultures was used as the context to investigate the approach of using drawings and *Talanoa* for science teaching and learning. Fiji's classrooms are diverse in terms of culture, ethnicity, experiences, and religion which encourage the use of context specific and culturally-relevant curriculum and pedagogies to enrich meaningful experiences for students as they learn (MoE, 2013). The Fijian curriculum encourages teachers to draw on and provide learning experiences that link scientific concepts to their community, enabling a sense of ownership in learning. The curriculum also promotes social aspects of learning by encouraging learning together in small teams, thus requiring negotiation, mediation and sharing experiences (MoE, 2013) as well as drawing on students' prior experiences, skills and ideas which helps them to learn about new topics (Worth, Duque, & Saltiel, 2009). In light of this, the connection between science and culturally appropriate teaching and learning strategies could be used in classrooms. Hence, this study tried to use drawing and *Talanoa* to teach the topic of climate change, hence, the study was to draw conclusions whether drawing and *Talanoa* is an effective methodology to teach Fijian students.

LITERATURE

A range of researchers have explored the power of visual representations, such as drawings. Drawings are a valuable tool for meaning-making in science because they mediate between the visual representation of ideas and scientific concepts (Van Meter et al., 2006). Drawings can also facilitate the communication of ideas and enhance problem-solving (Lee & Fradd, 1996). They provide a gateway from abstract learning to a creative, hands and minds on approach to science. If scaffolded appropriately, drawings could be used to identify misunderstandings or gaps in learners' knowledge as it could unpack rich authentic ideas. When combined with dialogue to interrogate the participants'' scientific thinking, drawings can lead to in-depth information, reasoning and conceptual understanding of the students.

Ainsworth, Prain and Tytler (2011) suggested that having students explain the meaning of a diagram is an effective metacognitive tool that can assist them to develop a deeper understanding of the concept. Drawings can help children to collaborate and develop competencies with visual representations, interpretations, orientations and interpersonal relations. The representation of ideas through drawings helps students to work at a more metacognitive level, when exploring their thoughts about complex ideas, phenomena and questions about the world in which they live (Tytler, Prain, Hubber, & Haslam, 2013). Re-examining, revising and reflecting on their drawings helps students to make connections and develop their story (Gijlers, Weinberger, Dijk, Bollen & Joolingen, 2013). So, when real world science-related experiences through drawing and communication are woven into cultural context, students conceptual understanding and reasoning are strengthened (Ainsworth et al. 2011) which could help in the teaching and learning of science. *Talanoa*, a culturally appropriate method for informal discussions is rooted in oral communication and recognised in Pacific island countries such as Samoa, Tonga and Fiji (Nabobo-Baba, 2006: Otunuku, 2011; Prescott, 2008; Vaioleti, 2006). Talanoa is also considered as a way to engage in dialogue or storytelling (Halapua, 2008). Halapua (2003, p. 18) describes *Talanoa* as 'having an open dialogue where people can speak from their hearts and where there are no preconceptions." *Talanoa* can be either formal or informal conversation. However, Johannson-Fua (2009) described *Talanoa* as an informal conversation in which knowledge is socially constructed. *Talanoa* sessions could happen between a two people or a small group of participants. *Talanoa* is considered a contextually and culturally relevant method to share personal and lived experiences.

METHOD

As part of the research ethics, approval were sought from the University of Tasmania, Fiji Ministry of Education Research and Ethics Council and later from the participants. The learning space observation involved fifteen Grade 5 students from a rural primary school in Fiji. The students were divided into three groups of five. Each group was asked to make three drawings which represented their understanding of climate change: the *cause* of flooding in their local context, the *effect* of it on the local environment; and possible *solutions* to reduce flooding. Each group was provided some blank A4 pages, HB pencils, as well as two 12-color sets of crayons. The groups took approximately two hours to complete their drawings. The teacher moved away from the students while they were drawing, but remained in the room. After they had drawn the three drawings, they were asked to interpret their drawings. These interpretations provided the context and served as a guide for the *Talanoa* . With the prior consent of the school, teacher, students and their parents, the *Talanoa* session were digitally recorded so that all discussions could be captured and transcribed accurately. The *Talanoa* sessions were analysed using a thematic approach based on open coding, axial coding and selective coding for the development of themes (Miles, Huberman, & Saldana, 2014).

FINDINGS

The student's drawings were used to facilitate the *Talanoa* sessions. One of the group's drawing is given in Figure 1.

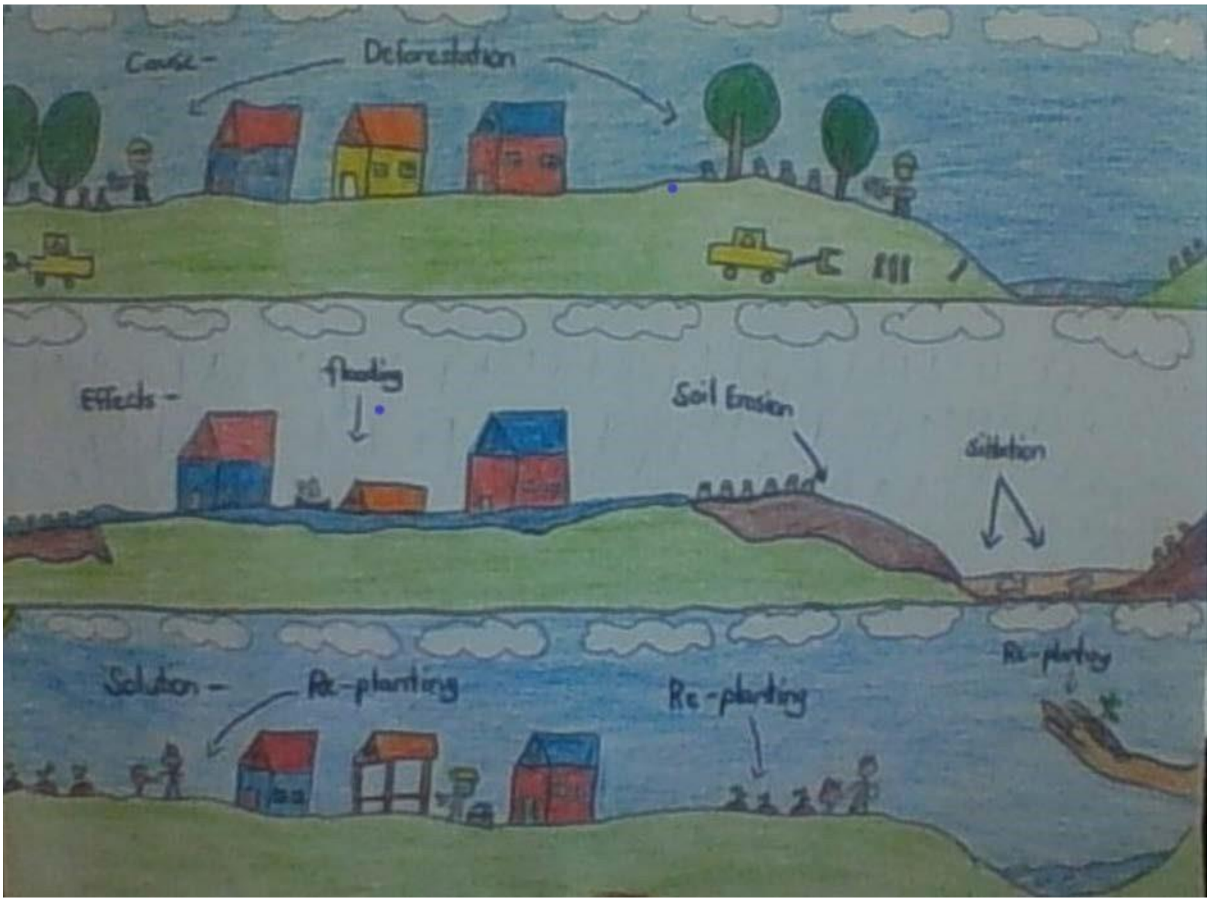

Figure 1. Drawing showing *cause*, *effect* and *solution* of climate change

Student's understanding of climate change in response to the drawings was revealed in the *Talanoa*, as described below:

Teacher: What causes climate change? I can see you have drawn houses, trees, fallen trees, people and other things which you may be able to explain to me better?

Student A: The people in my village cut trees for building houses, making space for planting cassava, dalo and yagona. Some use heavy machines to put down trees to make roads and playgrounds. This is what causes climate change and it causes flooding.

Teacher: What does cutting down of trees has to do with flooding or climate change? Please can you explain?

Student B: You know when people cut down trees, there is no roots to hold the soil when it rains. Due to the heavy rain, the soil gets washed away and gets to rivers as you can see in my drawing. The river gets shallow and it easily gets flooded. Last year all our cassava and dalo plantation was under water in the heavy rain. We lost all our crops. I saw my grandfather crying. Daily, he used to wake up early in the morning and go to the plantation and bring us food, but all was gone. It was very hard for us.

Teacher: What about the fish? Do you have fish in the river?

Student C: Yes, before my grandfather used to tell us that we had plenty of fish and prawns in the river but slowly the number is decreasing. He said because before the river was very deep but now it is shallow. Also, I have seen that the water before was very clean but now sometimes when we go for a swim we see that the water is muddy because of the rain up in the mountains. That's what is soil erosion, the soil is washed down in the rain and comes to the river.

Teacher: So, do you think it affects the organisms that live in the river?

Student D: Yes, that is why we have less fish and prawns now. Can you see I have drawn water around our house?

Teacher: Yes, I can see it is even going in the houses and one house is partly under water.

Student A: I wanted to tell you that due to flooding, once our house was under water, I was just 7 years old I think, we all had to spend the night on the roof. That time I didn't know why all this is happening.

Teacher: So, do you have any idea how we can avoid flooding and climate change?

Student E: Yes. If we can avoid cutting down of trees, or in case we have to cut down any tree for some reason, we must make sure that we plant another one or two. This way we can have plenty of trees around us which will give us shade and fresh air. I believe that we should educate our people in our community we live, to keep our environment healthy by planting lots of trees and avoid cutting it down. If everyone does this, we can help avoid climate change. We can all live happily.

The findings indicated that the students understood the reasons behind increased flooding in the community. The student's reasons for increased flooding drew on the prior experience and knowledge from within the social context of their community. This was evident through the student's verbal explanations where they contended that the cutting down of trees for building houses, making space for playgrounds and plantations, and making roads. All the students who participated in the study were able to contextualise the phenomenon based on the experience and observation in their village. It was also revealed that students were interested in drawing out their understanding as students were seen smiling while drawing and participated in the *Talanoa* session happily and effectively. Students chose to use diagrammatic representation to show the effect of flooding on the local community using a visualisation of a village on the riverbanks. The students clarified the positioning of each component on the drawing. Though students understood the reasons for flooding and used labels in their drawings, the description could be seen as a little ambiguous, but students supported it orally explaining the impact of flooding in *Talanoa*. The teacher's comments and questions provided a platform for students to refine their understanding of key concepts. It was also found that drawings play an important role in initiating *Talanoa* (talks or discussions) hence, drawings are useful for *Talanoa* methodology as it keeps the discussion focused on achieving the desired outcome. When examining the solution for flooding or climate change, replanting of trees, it was clear that students had a detailed understanding of the re-planting process. The students contextualised that it needs the effort of the local and the global community to keep the environment healthy; hence, emphasising on the collective effort to tackle climate change.

DISCUSSION

Drawings followed by *Talanoa* provides a gateway from abstract understanding to a creative, hands and minds on approach to data collection which is important for participants of primary aged students. If managed appropriately, drawings can be used to identify misinformation or gaps in students' understanding and allow teachers to dig-deep through *Talanoa* to get all the information from the students. When combined with dialogue to interrogate the learners' scientific thinking, it was found that drawings lead to deeper reasoning and conceptual understanding of the concept. It is argued that teachers in primary schools give priority to those strategies that has cultural connectedness to build likeness of the strategy before scaffolding their students to in creating complex multi-modal representations (Waldrip & Prain, 2012a). The use of student generated representations allows students to engage in different types of reasoning (Waldrip & Prain, 2012b) which can be enhanced with the guidance of teachers (Tytler et al., 2013). Similarly, through culturally relevant tools, teachers can take control of the conversation which could help to ascertain rich knowledge.

The findings demonstrated that the students interpreted information about the flooding phenomenon in the drawings to include the "cause, effect and solution". This allowed the systematic arrangement of components for better meaning-making. The breaking of phenomena down into components, analysing and synthesising the vital information to construct representation, leads to reasoning through the organisation of perceptions (Tytler et al., 2013). The construction of appropriate and logical diagrams, the inclusion and placement of trees, machinery, river, logs, soil erosion, and community, showed the student's ability to convey their mental representations on each drawing. Student reasoning happens when students make representational selections and decide appropriate size or how to put together different components (Tytler et al., 2013).

The findings also demonstrated that the students identified replanting of trees as a possible solution to reducing flooding in their community and extended their contextual solution to broader community. The application of representations into new contexts in this way, could lead to students reasoning (Tytler et al., 2013). Through the drawings the students justified to the teacher during discussion on the choice of each element on their drawing which helped in getting unrevealed information out of the students.

Finally, the findings revealed the existence of link between the use of drawing and *Talanoa* in teaching and learning. Keeping in mind the rich cultural connection of using drawing and communication, it could provide a new direction to science teaching in Fiji.

CONCLUSION

Using students produced drawings is more likely to accurately represent students' experiences which are reliable and authentic (Kearney & Hyle, 2004). However, if the teacher does not give the structure or clear direction to the students, the drawing produced may not relate to the content in focus and be of little use. Therefore, follow up *Talanoa* between the teacher and student could most likely promote effective teaching and learning. The drawings create an opportunity for students to demonstrate their feelings and emotions which leads towards unpacking of their experiences, creating an opportunity for more meaningful and honest discussion; hence, it could be concluded that drawings supplements *Talanoa* and *Talanoa* supplements drawings. However, broader studies are needed to determine whether the combination of drawing and *Talanoa* (talks/conversations/storytelling) contribute positively to the existing teaching methods.

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TEACHER'S PERCEPTIONS ABOUT TECHNOLOGY INTEGRATION IN UGANDAN SCHOOLS

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ABSTRACT

This paper examines teacher's perceptions on technology integration in teaching in selected secondary schools in Eastern Uganda. Data was generated through a case study employing mixed methods in the form of a survey questionnaire, face to face interviews and class observations. 250 secondary teachers from Mbale, Uganda participated in the survey and nine from this pool participated in interviews and were observed teaching. The quantitative phase was the major component and enabled identification of factors related to technology use in teaching. The qualitative phase was the minor component and built on quantitative findings. Exploratory Factor Analysis was used for quantitative data, and open coding and thematic analysis for qualitative data. Findings show that the teachers had a positive attitude towards technology use but were limited by skills and infrastructure relating to technology integration in their teaching. This was largely due to lack of proper training and limited resources to use technology in the teaching and learning process. These findings are key to shaping school, government and non-governmental organizations' efforts in supporting technology use in schools not only in Uganda but also in other parts of Africa.

Keywords: *technology, TPACK, PCT, competencies, perceptions, disposition.*

INTRODUCTION

The 21st century students are using technology be it cell phones, computers, iPads etc. In Uganda, students are increasingly expressing themselves on Facebook, using emails, through twitter, WhatsApp, blogs and other platforms. All these changes have implications on how teachers communicate and share information as well as engage in the teaching and learning processes (see (UNDP, 2010; United Nations, 2014). Teachers can no longer ignore the demands these changes are putting on students' approaches and perceptions to learning as well as teacher's perceptions about teaching and learning. In developed nations such as Canada, teachers have tried to keep up with these changes amid existing challenges. Voogt, (2010) suggested that teacher's support and attitudes have a significant effect on successful implementation of technology in the classroom/school. Consequently, teachers have to learn to shift and evolve their knowledge from different domains (Bisaso, Kereteletswe, Selwood, & Visscher, 2008; Shulman, 1986) including knowledge of student thinking and learning, knowledge of subject matter, and increasingly knowledge of technology. In spite of these recommendations, research has shown that technology integration in schools is happening slowly and therefore affecting or compromising students' learning (Howley, Wood & Hough, 2011). In African contexts, as an example, Ramorola (2013) noted that lack of technology policy, insufficient technology equipment, a lack of teachers qualified in technology integration, and maintenance and technical problems affect meaningful integration of technology in South African schools. In Uganda, the use of technology in classrooms is a recent phenomenon that needs to be examined so as to understand how teachers can successfully integrate this key resource in their work, hence this study.

THEORETICAL GROUNDINGS

This work draws on the framework of Technological Pedagogical Content Knowledge (TPACK) and Perceptual Control Theory (PCT) to understand teachers' perceptions of technology use in Ugandan classrooms. Kohler and Mishra (2008) present a TPACK framework that is informed by Shulman's (1986) work on pedagogical content knowledge to help us understand how educational technologies interact with pedagogical content knowledge. The fundamental principle of TPACK is that a teacher's knowledge regarding technology is multidimensional and that the best mix for the classroom is a balanced combination of technology, pedagogy, and content (Harris, Mishra & Koehler, 2008; Koehler & Mishra, 2009). In their framework, Mishra and Koehler (2009) evoke the significance or understanding the impact of technology on one's practices, in this case, the teaching and learning process, if educators have to come up with meaningful technological tools that will be valuable in the classroom.

In the same vein, Powers (1950)'s Perceptual Control Theory presents a system model that explains human actions based on negative feedback. The theory maintains that humans behave the way they do by invariably comparing their perceptions to perceptual reference standards (goals) within their senses rather than external stimuli (Kuhn & Powers, 2006; Powers, 1973). Therefore, from a PCT perspective, three conditions are necessary for teachers to use technology: (1) the teacher must believe that technology can effectively meet a higher-level goal than what has been used. (2) The teacher must believe that using technology will not cause disturbances to other high-level goals that [teachers] consider to be more important than the one being maintained. (3) The teachers must believe that they will have sufficient ability and resources to use technology.

Therefore, educators have to also understand that the use of technology will vary based on content. Further, the authors suggest that limitations in use of technology can also offer opportunities for newer ideas and therefore call for flexibility in its implementations. Drawing on TPACK and PCT thus is useful in understanding the perceptions and challenges teachers in Uganda face when using technology as well as limitations and possible solutions they present.

METHODS AND DATA COLLECTION

This study employed a mixed method approach (survey questionnaire, face to face interviews and classroom observations). The study sought to address two key questions: i) How do secondary teachers in Uganda perceive use of technology in the classrooms? and ii) What are the limitations of implementing technology in the classroom. Survey questionnaires were sent to 250 study participants in Eastern Uganda after which the researcher conducted 9 face to face interviews and also observed 9 classes of teachers who volunteered to participate in the study. Additionally, educational and government policy documents were analysed to corroborate the findings from the interviews, observations and survey questionnaires.

FINDINGS

Results from the study show that the teachers in Uganda lacked technology skills because training in technology was low. Teachers' attitude towards using technology was majorly influenced by the presence technology resources. Schools that had sufficient technology infrastructure had many of their teachers using technology, whereas, those that had moderate to low technology experienced some form of resistance in using ICTs.

There was no explicit policy around use of technology in schools either from the ministry level or from the school district levels. It meant that individual schools and teachers made choices on when, what and how to use technology which turned out to be inconsistent given the varied levels of experience, knowledge and competence they had. Moreover, the qualitative data revealed that the leading hindrance that inhibited teachers from preparing technology enhanced lessons was the urgency to complete the syllabus and prepare students for exams. In-service and preservice training for teachers is key to promoting use and integration of technology in schools.

CONCLUSION AND SIGNIFICANCE OF THE STUDY

This research offers important recommendations to schools, teachers and the government when considering technology integration in schools. Curriculum developers, school managers and teachers will benefit in terms of understanding some of the key effort teachers are making to live up to the much revered technology use as an important 21st century learning skill. It also provides insight into the many challenges teachers are facing. Stakeholders can evaluate the ICT adoption programs and how they have impacted on teachers and [students] and determine which areas need to be strengthened to bring about the desired outcomes. This study will also provide the participants [teachers] with the space to reflect on the call by government to integrate technology into teaching and learning activities. In a way, this may impact on their perceptions and in turn influence their competency levels.

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INVESTIGATING KENYAN PRIMARY SCHOOL TEACHERS' STEM TEACHING THROUGH A GIRL CHILD'S CULTURAL EXPERIENCES/KNOWLEDGE FRAMEWORK

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ABSTRACT

In Kenya, student performance in sciences and Mathematics is still low compared to art oriented disciplines. The poor performance has affected not only the *Girl child's* interest in these disciplines but also the number of girls that take STEM oriented programs at tertiary levels. Several mitigating measures have been enacted in the form of STEM teacher *pedagogy*. But, despite these efforts, the situation has not changed much. This study was to investigate the extent to which Kenyan teachers integrate their female students‟ cultural knowledge and experiences in science learning discourses so as to improve the Kenyan girls‟ performance in science at the primary school level. The study employed a crosssectional descriptive design that adopted both qualitative and quantitative data collection methods. Data from structured questionnaires were analyzed using Statistical package for social sciences (SPSS Version.20. Findings were summarized using descriptive statistics (frequencies). Qualitative data was analyzed as themes. The study revealed that science subjects that could be linked to specific *girl child's* social activities included health education, Biology and Math. Most teachers (90%) are aware of girls‟ rich socio-cultural backgrounds and related Science activities that could link to STEM subjects. Less than half (40%) reported to link the social activities and knowledge with the science *concepts*. Collaborative teaching involving parents, members of community and the children themselves to explain traditional activities related to identified science topics could be the way forward.

Keywords: c*urriculum, girl child, concept, pedagogical*

INTRODUCTION

BACKGROUND OF THE STUDY

The Government of Kenya recognizes the importance of science and math in the realization of its vision 2030 to become a globally competitive and prosperous country by the year 2030 (Republic of Kenya, 2012)**.** This is reflected in the amount of resources both human and otherwise that are channeled towards enhancing the teaching and learning of science and math at all levels of education in Kenya (MoE, 2005; Government of Kenya, 2007). However, this high input does not seem to be reflected in the performance (Sammons, et al., 2008; UNESCO, 2002)**.** Recent research shows a continuous decline in science and Math performance. As well, the numbers of students who choose to study science subjects in high school and later pursue scientific careers have also continued to decline (Maundu, 1986; Osborne, Simon & Collins, 2003; OECD, 2005). The poor performance and decline in science and math is more pronounced with the girl child as compared to the boy child. In the Kenya system of Education, primary school science curriculum includes many topics dealing practically with everyday life and the immediate societal environment (Abeti, 1987; Knamiller, 1984; UNESCO, 2017). The curriculum is arranged such that many important scientific concepts are introduced to pupils at an early stage in primary school and therefore it is possible that what is reflected as poor performance at secondary school level could have a root at lower levels of education. Today, most primary school children are enthralled by the world around them and are therefore inquisitive about events that occur in their everyday life (Abeti, 1987). Unfortunately, teachers with the social sciences background are often ill-prepared for the increasingly complex questions that primary school children raise. When teachers‟ confidence and enthusiasm with which they respond to such questions proves lacking, children‟s eagerness to enquire gradually diminishes. Alongside this, also children‟s interest (Jennifer, 2014) in science related concepts declines and eventually disappears (Derek, 2018).

OBJECTIVES

MAIN OBJECTIVE

To investigate the extent to which primary school teachers integrate the girl child cultural knowledge and experience in Science Learning Discourse.

SPECIFIC OBJECTIVES;

1. To identify the science topics in grade five that could be linked to specific girl child social activities

2. To assess teachers‟ awareness of the girls‟ rich social-cultural background and related science topics.

3. To establish the extent to which teachers integrate female students‟ cultural knowledge and experience in science learning discourses.

THEORETICAL FRAMEWORK

Our research is grounded on Constructivist approaches towards learning in science**.**

STEM subjects are mainly practical in nature, constructivist theory is used to develop a curriculum which is competency based, one which promotes exploration in learners (girls) and inculcates critical thinking, innovation and problem solving skills (Bales & Taylor, 2015).

In the classroom, the constructivist view of learning can point towards a number of different teaching practices. In the most general sense, it usually means encouraging students to use active techniques (experiments, real-world problem solving) to create more knowledge and then to reflect on and talk about what they are doing and how their understanding is changing. The teacher makes sure she understands the students' preexisting conceptions, and guides the activity to address them and then build on them. Constructivist teachers encourage students to constantly assess how the activity is helping them gain understanding. By questioning themselves and their strategies, students in the constructivist classroom ideally become "expert learners." This gives them ever-broadening tools to keep learning. With a well-planned classroom environment, the students learn how to learn (NRC 2007).

METHODOLOGY

THE STUDY AREA (KISUMU COUNTY-WESTERN KENYA)

Kisumu County is one of the 37 counties in the Republic of Kenya. It is located on the shores of Lake Victoria to the Western part of Kenya, far from the national capital Nairobi. The county has 8 sub counties; Kisumu East where the study was taken is one of them.

SELECTION OF SCHOOLS FOR THE STUDY

The study schools were purposively selected. Eight rural public primary schools were selected. The bases for selection of schools were on schools with a purely rural population. The children brought up with cultural norms have a rural background where culture still plays a major role in a child"s upbringing

RESEARCH DESIGN AND METHODOLOGY

This was a descriptive survey research that employed mixed method. The study used simple random sampling to sample one sub-county, out of eight (8). For ease of data collection, purposive sampling was then used to select study schools, 2 from each village in Kisumu East Sub County. A total of 8 schools were selected for the study. The total number of participants was 70.

RESEARCH INSTRUMENTS

The study utilized both primary and secondary data. The main instrument for primary data collection was the questionnaires. It consisted of both structured and unstructured questions which allowed for the collection of both quantitative and qualitative data (Mugenda & Mugenda, 2003). Secondary data was obtained from primary school science syllabus that was in use in the school, grade five science and math text books, teachers lesson plan books, record of work books, student exercise books, end term and end year performance records.

PRELIMINARY SCHOOL VISITS

Visits were made to all the eight schools to observe in order to have first-hand information on certain key issues relevant to the study. The preliminary visits were beneficial to the researchers because they used the visit to interact unofficially with heads of science department and math and all the science teachers in school including those teaching senior classes. The main goal of the research was made known to them. Arrangement was made on how to collect data with little interference with the learning process.

QUESTIONNAIRE

The questionnaires were administered to all science/math teachers who had handled or were handling grade five classes in the study schools.

FOCUS GROUP DISCUSSIONS (FGDS)

The researchers arranged for and had separate FDG, with the science teachers and with grade five girls in all the schools visited. Focus groups can be used as a data collection method in their own right but in our case, it was utilized to complement other methods.

INTERVIEWS

In this study, heads of STEM subjects and standard five science teachers were interviewed on their views about teaching grade five science /math topics, and the general performance of the girl child compared to boy child.

OBSERVATION

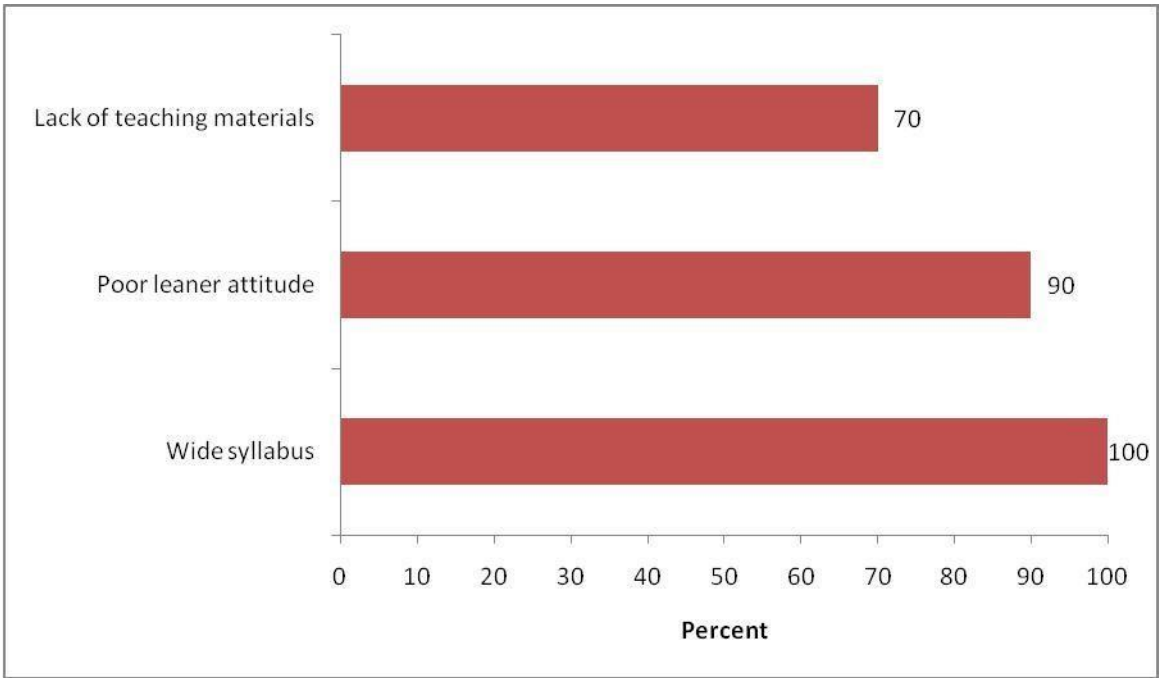
For the purpose of this study, the nonparticipant observation was adopted. In the nonparticipant observation, the observer is only a spectator and not an actor that is the observer is detached from the group, though the group is aware of the presence of the observer (Kothari, 2004). In all the eight schools the researchers visited, observations were made on the state of the classrooms, teaching methods employed by teachers in teaching science topics in standard five, availability of teaching and learning materials, whether the available materials if any were being used and how they were used, and finally any other materials/facilities used in teaching STEM related subjects. The researchers also observed the girls‟ physical appearance in uniform and comfort in class with respect to sitting arrangement. Thus, researchers**,** looking reserved and quiet were taken to mean some discomfort or frustration on the girl child.

RESULTS

MAIN PROBLEMS ENCOUNTERED BY SCIENCE TEACHERS

Among the problems encountered by teachers during the teaching of science and mathematics; were wide syllabus (100%), poor learner‟s attitude (90%) and lack of teaching materials (70%). In addition, it was reported that some topics were difficult for the learners, figure 2.

Fig 1: Problems Encountered During Teaching



Those who reported girl as poorer in science, they explained that boys get the concepts faster and their participation and contribution during the lessons is very good while girls tend to be conservative.

SCIENCE TOPICS THAT COULD BE LINKED TO SPECIFIC GIRL CHILD SOCIAL ACTIVITIES

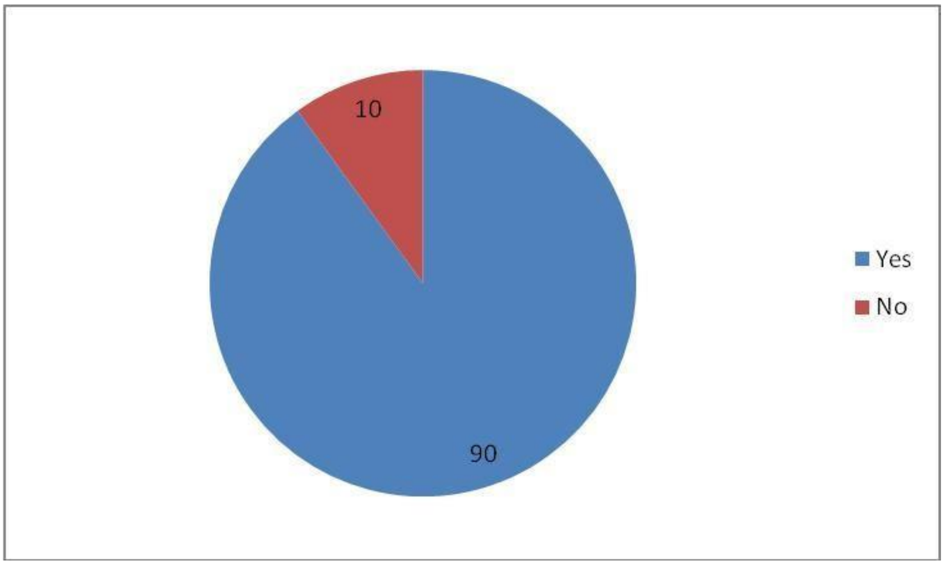
The Science and math's topics that could be linked to specific girl child social activities as reported by the teachers are indicated in table 1.

Table 1: Some identified key standard V Science, mathematics topics that could be linked to Kenyan Girl Child social background. (Source; Standard V Science Teacher)

Subject	Topic	Related activity, household chores and game
Science	Food and nutrition	Cooking, washing hands before eating, sharing meals
	Proper storage of medicine	Keeping medicine out of reach of children
	Separating mixtures	Purifying well water for domestic use
	Health education	HIV/AIDS, Cause, prevention, maintenance of victims, effects of the disease on families.
	Environmental	pollution, prevention, remediation
Mathematics	Fractions	Sharing food,
	Numbers /budgeting	Taking positions in a game so as to win, counting during rope jumping, buying and selling and getting balance
	Operations	Game of arranging and counting items

TEACHERS' AWARENESS OF THE GIRLS' RICH SOCIAL-CULTURAL BACKGROUND AND RELATED SCIENCE TOPICS.

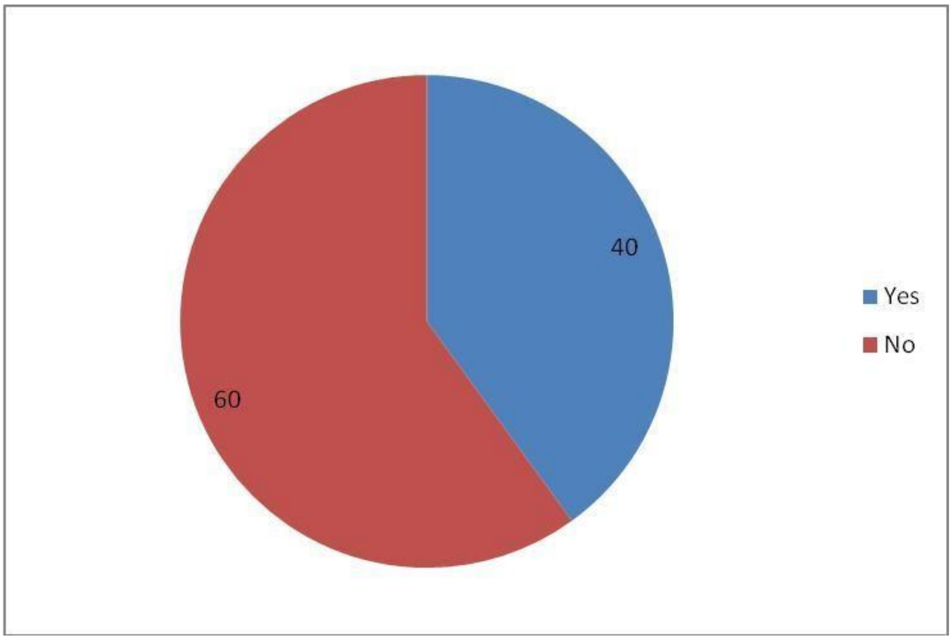
Fig 2 : Awareness of girls' rich social-cultural background and related science topics



Almost all the teachers (90%) were aware of the girls" rich social-cultural background and related science topics (Figure 3).

EXTENT TO WHICH TEACHERS INTEGRATE FEMALE STUDENTS' CULTURAL KNOWLEDGE AND EXPERIENCE IN SCIENCE LEARNING DISCOURSES

Fig 3: Integration of female students' cultural knowledge and experience in science learning discourses



Among the teachers that were observed, 60% of the lessons were lively but only 40% were linked to specific girl child social activities. The linkage was through examples correlating the topic to cultural events. Only 40% of the teachers integrated female students „cultural knowledge and experience in science learning discourse.

DISCUSSION

Finding revealed that the teachers are aware of the science topics related to specific Girl child cultural activities and all, 100 % of the participants do the necessary link while teaching. We therefore decided to carry out this second study just to confirm this claim of, "Yes we are aware and we are doing the link". We administered questionnaire but this time it was followed by class teaching observation and thorough checking of lesson plans, schemes of work teaching aids and other relevant teaching materials to STEM teachers in a nearby Kisumu County, still in Western Kenya. There was one FGD per school, one with the teachers teaching standard five classes and one with standard five girls. A significant number of primary school teachers in Kisumu County are aware of the Kenyan Girl child socio-cultural activities that can be linked to specific science concepts in standard five syllabuses (Kelonye et al, 2018). Most teachers used the class text book to lecture on a topic for a large portion of a lesson and then questioned students to see what they were able to absorb or recall. There was minimum inter pupil interactions or discussions during class time (Levin and Nolan, 2013).

Field visits, out of class activities, group work class experiments or teacher demonstrations were completely missing from teacher‟s lesson plans.

Teachers have been found to evaluate girls‟ ability in mathematics at a lower rate than boys‟ ability, even when they are performing at similar levels. With regards to teachers‟ attitude toward female students in the science class, the findings indicated that teachers‟ attitude toward boys tend to be more positive than it is toward girls (UNESCO, 2017). The girls told us their favorite‟s topics in STEM which include, Nutrition, Environmental Science, Biology and selected topics in in Mathematics. Apart from changing the pedagogical approach to teaching STEM subjects, I wish STEM teachers could reduce the issue of absenteeism if they are keen in quality science teaching.
To support this argument, (Kamuri in 2013) reported that teacher‟s absenteeism hurts classroom learning and reduces pupil‟s interest in a subject. Teachers should also pay attention to the contexts, subjects or Science topics which are known to favor girls understanding and interest as suggested by (Bian, et al., 2017). Gender differences in STEM education participation are more apparent as soon as subject selection becomes available, usually in upper secondary education and become worse as the level of education increases (Kelly, 1988). Negative attitudes towards science by the girl child was another obstacle to teaching as claimed by the teachers during the interview.

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

Generally, a number of issues explain why girls shy away, perform dismally in STEM subjects and are therefore under-represented in mathematics and science fields. These include deductive against exploratory approaches to teaching; failure or little effort to contextualize the concepts learnt by use of examples or illustrations from real life; little interactions in lessons as opposed to learnercentered practices; un-approachable and distant teachers. From our findings, Socio-cultural, socioeconomic and school based factors are affecting the teaching and learning of science in public primary schools in Kisumu County, Kenya and this is affecting the girl child‟s Education and carrier right from grade five.

The findings and recommendations of the study may also be useful to the management and principals of schools. This may lead to the change in science teaching strategies for improved performance of girls in STEM subjects and better representation in STEM disciplines at tertiary levels.

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SOUL (SLOW ONLINE AND UBIQUITOUS LEARNING)

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ABSTRACT

This paper addresses an experimental and innovative pedagogy and philosophy: Slow Online and Ubiquitous Learning (SOUL). Since 2011, the co-authors have implemented SOUL as a pedagogy and philosophy into the online courses they teach at a university level. Pedagogically, SOUL is a pragmatic temporal regulation that limits and paces course commitments for students and instructors. Philosophically, SOUL is an intervention into the conventional wisdom that portrays online learning as a limitless exchange of ideas 24/7. This paper reviews relevant research on time, provides a theoretical framework that underwrites SOUL, and analyzes instructors' and students' experiences and self-study data.

Keywords: *instructional time, slow movement, online learning, ubiquitous learning, instructional design*

Defined and premised on time, online learning "means technology enabled online real time (synchronous) interaction between the instructor and the student, near time (asynchronous) interaction between the instructor and the student, or any combination thereof" (California Legislature, 2008, SB 1437, chap. 718). Yet ironically, time is one of the most neglected variables in research on online learning and teaching. Empirical challenges of research include reliable documentation and records of instructional time and learning time. In self-reporting data, instructors and students may be unprepared or too embarrassed over the volume of time expended and pace clocked to provide accurate accounts. If accounted for at all, some researchers transform a quantitative problem of "how much time is expended?" to a qualitative problem of "what is the variability of time allocated?" or a problem of polychronicity (Bluedorn, 2002; Martins & Nunes, 2015). When the amount of time expended in learning and teaching is addressed, the pace of time is typically neglected.

In this paper, we take the increase in demands or pressures on instructional time and learning time as given (Spector, 2005; Szollos, 2009). First, we provide a theoretical framework for temporal regulation in online courses. Rather than demonstrating how a course or learning management system (CMS, LMS) or virtual learning environment (VLE) can be configured to regulate time, we demonstrate how users can self-regulate. Designers and vendors tend to stress maximizing time in the LMS and some students stress minimizing time. We stress moderating time in the LMS. Second, we summarize self-study and narrative data derived from our experiences (n=3 instructors) with SOUL in an online course (i.e., Foundations of Educational Technology) we designed taught since 2011. We address instructional time *and* learning time throughout but in the data analysis we focus on instructional time. Our intent is analysis first and advocacy second.

The course is a requirement within a "for-profit" educational technology graduate program within the University of British Columbia (Petrina, 2005). The business model of the program necessarily intensifies the pace and hours of instruction but this is not the only relevant intensifier. How can designers effect a healthy, sustainable amount and pace of time in an online course? How does SOUL regulate the amount and pace of instructional time and learning time? Learning and instruction take time and require pacing but what is healthy or sustainable?

THEORETICAL FRAMEWORK

Slow online and ubiquitous learning (SOUL) was founded under conditions and circumstances similar to the Slow Food movement (Massoud, 2019). Down-shifting to slow or steer the juggernaut to more healthy or organic paces and volumes, e-learning and educational technology (ET) with SOUL adds to the concerns of slow food with the health and well-being of individuals, the collective, and the planet, a concern for learners and teachers. What does it mean to be an e-learner or i-teacher in the 21st century?

Intensifiers in online courses include business models that maximize enrollment and minimize instructional costs, omnipresence of media and technology, and increasingly unhealthy patterns of work in the creative industries and higher education. Technological changes mark occupations in the creative industries and higher education, wherein workers routinely report "chronic time pressure" (CTP) or feelings of "*being rushed*" and a "*shortage of time*" (Szollos, 2009, pp. 332-333). In the creative industries and education alike, unsustainable hours and crunch time pressures are often dismissed as love of the project and task or commitment to clients and students (Menzies & Newson, 2007; Samuel & Kanji, 2019; Thompson, Parker, & Cox, 2016). "It's very important to just bust the myth here that longer hours equals productivity," Harriss (2019) clarifies. She continues, noting that educators teaching creatives and, for this paper, online instructors, are "making permissible forms of labour exploitation, and creating work-life balance that often triggers mental health" problems (quoted in Block, 2019, p. 1). Summarizing reports of CTP, Wills (1996) concluded that faculty members are "battling to keep going as best as they can, but in the longer term the damaging effects of long working hours upon social activities, family life, health and welfare, may be more difficult to ignore" (p. 296). As one faculty member confessed, "I'm absolutely flat out now and if the treadmill revolves faster, I will be unable to cope" (p. 298). Media and technology erode boundaries between home and work and, making matters worse, online courses move the workplace to the domestic space and cafés provisioned as a "post-geographic office" (Conline, 2006).

Advocates of flexible time would have us believe that the political economy of time is merely applicable to 19th and 20th century factories and offices. In the 1990s, coinciding with the rise of the "course management system" (CMS) for online learning, "smashing the clock" became a common refrain across business and higher education. The unspoken policy for "this post-face-time, location-agnostic way of working is that people are free to work wherever they want, whenever they want, as long as they get their work done" (Conlin, 2006). As 21st C reality goes, most flextime workers clock many more hours through unpaid overtime, driving down their hourly wages, while managers' salaries and rates of profit skyrocket (Chung & van der Horst, 2018; Lott, 2018). At universities, middle management has bloated, employee paychecks stagnated, and part-time contract faculty populated the labour pool, especially for online education (Petrina & Ross, 2014; Petrina, Mathison, & Ross, 2015). Importantly, online instruction directs attention to Marx's (1867/1967) conclusion: "what is a working-day, presents itself as the result of a struggle," in many ways here a struggle between the instructor and manager's means of production (i.e., a CMS) (p. 235).

Derber (1983) acknowledges that "professionals do not punch time-clocks" but "they work according to the imposed rhythms of the organization and procedures and technology subject to administrative approval and review" (p. 310). He continues, professionals are proletarianized through a "lack of control over the process of the work itself" or by submission to "a rhythm or pace of work which they have no voice in creating" (p. 313). Who or what controls total hours of work in online courses? Who or what controls pace of work?

To understand learning time and instructional time, we have to dispense with the naïve assertion that "learners determine the time and pace of instruction" (Piccoli, Ahmad, & Ives, 2001,

p. 404). This derives from false distinctions between objectivist and constructivist theories of online instruction. Theorists assert that in objectivist courses “the instructor controls the material and the pace of learning” while in constructivist courses “the frequency and intensity of student processing of cognitive input, rather than the instructor’s agenda, drives the pace of the learning process” (Arbaugh & Benbunan-Fich, 2006, pp. 436, 437). In theory, this may be the case but it is readily contradicted by facts of technological production and empirical reports.

REVIEW OF LITERATURE

Rohland-Heinrich’s (2016) study reported the scope of online instruction as involving but not limited to: “professional, pedagogical, social, evaluator, administrator, technologist, advisor/counselor, and researcher” functions (p. 100). One online instructor reported that “many of the functions remain the same whether I teach online or in the classroom" (p. 100). Another reported that these functions are “complex as it is a challenge to remain engaged and available” (p. 101).

CTP is nonetheless a neglected variable in online educational research and learning analytics. For instance, the *Handbook of Research on Educational Communications and Technology*, in 894 pages, refers to time (hours, pace) only peripherally (Spector, Merrill, van Merriënboer, & Driscoll, 2008). Similarly, the *Handbook of Learning Analytics*, in 355 pages, overlooks learning and instructional pace and time except for a chapter on time given for the preparation of writing assignments (Lang, Siemens, Wise, & Gašević, 2017).

Tallent-Runnels et al.’s (2006) survey of research in online teaching is an extensive engagement with time but overlooks pace. They make an effective distinction between “engaged time, or time on task,” and total time expended on courses but the focus is on learning time, not instructional time (p. 99). They note that some researchers suggest “that the quality, rather than the quantity, of the time spent in online courses might be a more accurate index of students engagement” (p. 100). Of course, quality is important as an index of engagement. However, Tallent-Runnels et al. make the common mistake of transforming the quantitative problem of time into a qualitative of problem of engagement. Time, especially instructional time, is extremely important, albeit commonly finessed away or overlooked.

Some report that instructional time is excessive in comparison to F2F courses (Song, 2016; Spector, 2005) and others report that time spent is about equal in comparison (van de Vord & Pogue, 2012). In an extensive analysis of instructional challenges, Song (2016) acknowledges the heavier workload as “instructors tend to see online course as time-consuming work” (p. 709). Certainly in the first author’s experience and data, instructional time is much greater (i.e., 2x-4x) in quantity and demanding in urgency than in F2F courses. The course under analysis is a 3 credit course (13 weeks), which with long established conventions for F2F courses suggests that learning time ought to be 6-9 hours per week for student preparation (i.e., 9-12 hours/week including class time) (Roberts, 2001, p. 22). Professorial or instructor preparation time is conventionally 6 hours per week for a 3 credit course (i.e., 9 hours/week total) (Kahn, 1973, pp. 480-481). Online courses are asynchronous and do not pivot around weekly F2F class meetings. Analogy with F2F conventions should nonetheless hold as the workload is reasonable. Instead, online courses can require from instructors 2-4 hours per day on average (i.e., 14-28 hours/week). Demands on time from the LMS are often relentless.

That said, there is little to no research on interventions for regulating time, including LMS or VLE design interventions. Accounting for time means accounting for the LMS, which consistently affects hours and pace. Briefly, a LMS is an application that delivers and manages instructional content, allocates access and assignments, including discussions, identifies and assesses individual progress, and collates data for analysis (Watson & Watson, 2007, p. 28). In exploring LMS effects, researchers consistently overlook demands on time, especially on instructional time. For instance, in an otherwise helpful review, Coates, James, and Baldwin (2015) fail to mention how the LMS affects instructional time. Some researchers explore time necessary to learn how to use the LMS (Kim, 2017; Song, 2016) and others account for LMS effects on evaluations of Instructors (Lan, Tallent-Runnels, Fryer, Thomas, Cooper, & Wang, 2003; Lonn, Teasley, & Hemphill, 2007; Tallent-Runnels et al., 2006). Lopes (2009) underplays LMS demands on time and instead concludes that, at least for her, "information management is much more difficult these days than time management" (p. 13). She says the LMS "has been helpful in helping me to organise and manage" information (p. 13). However, we have found that LMS's (i.e., WebCT, Blackboard, Desire2Learn, Moodle, Canvas) intensify the flow of information and demands on pace and time. Most basically, the LMS's are clunky to use and slow to load. More germane to this research, for example, LMS's register quantity of discussion posts, which is then configured as an indicator of student activity (i.e., the greater the posts, the more active the student). Granted, the "time-independent" attribute of online learning is an asset yet neither students nor instructors escape the pressures of time. Hence, we reject notions that this era of polychronicity and multitasking decimates concerns with time and instead argue, via SOUL, that these characteristics of work necessitate attention to healthier perspectives on time.

SOUL INTERVENTION

We necessarily assume that instructors and students are "time poor," in the way Honoré (2004) describes. Individually and collectively, Honoré (2004) notes, we are "straining to do everything faster— and paying a heavy price for it…. We are driving the planet and ourselves towards burnout. We are so time-poor and time-sick that we neglect our friends, families and partners" (p. 274). Since 2011, in two online courses we teach, we have implemented the following regulation (in varying forms):

> Pragmatically with SOUL, in courses such as ETEC 531 at UBC, we stop or pause from Canvas for two days each week— Mondays and Tuesdays (Vancouver PST as common time zone) (i.e., 0 posts except private posts for planning). We also expect a conventional weekend pause, although we also anticipate that weekends may be the best times for some of you to contribute. In effect, the pause means a pause in access, including discussion posts (limit to sparse posts only for assignments) for working on the readings and thoughtful engagement with the assignments. For all participants throughout the term a second mode of moderation entails quantitatively fewer posts and qualitatively better posts. This means about one or two messages or posts per week for each student and teacher as co-respondents in conversation. This also means a thoughtful engagement with the readings, modules, assignments, and discussions each week.

Regulation of time on task or time online can be self-imposed (i.e., I'll time myself and spend two hours in the online shell), technologically-controlled (i.e., LMS configuration closes access to all users Mondays and Tuesdays), or rule-based and consensus-based (i.e., As a rule, we agree that will avoid going online or curb our activity at these times). SOUL is a rule-based and consensus-based intervention in that, as a class or group, we commit to staying out of the course shell or curbing our activity on Mondays and Tuesdays. We also commit at the beginning to slower in pace, fewer in quantity, and higher in quality messages and posts throughout the term.

SELF-STUDY METHODOLOGY AND DATA ANALYSIS

This paper draws on narrative and self-study data and methodologies to ground and explore SOUL in action. Self-study is an "insider" methodology wherein practitioners "critically examine their actions and the context of those actions as a way of developing a more consciously driven mode of professional activity, as contrasted with action based on habit, tradition, or impulse" (Samaras & Roberts, 2011, p. 43). Self-study is paired with narrative, which creates order out of experiences. For this research, we define narrative as a representation of experiences. Narrative analysis is a way of making sense out of these ordered representations (Connelly & Clandinin, 1990; Hendry, 2010). In general terms, narrative analysis addresses two questions: "What is the story?" and "Why is the story told" (Franzosi, 1998, p. 532)? Data for analysis include course analytics and anonymous student comments, unsolicited and submitted through end of term course evaluations. Our data are limited to Blackboard Connect and Canvas reports; regrettably, we did not reliably document our instructional time in the course while offline (e.g., planning, reading, marking papers).

At the start of each course, we open SOUL up to discussion and throughout the term receive a range of comments and insights. In addition, we periodically receive research papers (assignments) from students that focus on dimensions of SOUL (e.g., Christen, 2013). The vast majority (i.e., 10:1) of student responses to SOUL can be described as advocacy— students advocate for SOUL. For instance, one student volunteered at the end of the course in 2013: "I appreciated SOUL; I think it helped me hang onto my sanity this semester. It was refreshing to see people value quality over quantity re: posts." Another wrote in 2014 that they liked SOUL "so much that I emulated it for my own classes. But I call it SUIL instead (Slow Ubiquitous Inquirybased Learning)."

At the same time, there are students who are critical of SOUL, noting the unexpected regulation of time and access. For instance, a student commented at the end of 2013:

> while I agree with the SOUL principle in theory, enforcing it in a top-down manner is pretty disrespectful to adult learners - many of whom have jobs, families, professional obligations, etc. Being told to 'not post on Mondays/Tuesdays, during reading week, or more than twice per week' limits the ability of many people to post.

For various reasons, online courses developed over time by playing on anticipations of deregulation and liberty of access. Some students are certainly frustrated with the disincentives and regulation of online interactions. They report that they enrolled in an online course so they could be online "any time" or just-in-time. In this regard, SOUL affects asynchronicity and polychronicity.

Minimalizing or suppressing course activity works, but what of faculty experiences? What of the regulation of demands on instructional time? What of the regulation of the intensity of pace of instructional time? In the balance of this section, we focus on our experiences as instructors and primarily on how SOUL shapes the quality and quantity of our instructional time.

Our experiences vary, quite differently in many ways depending on our work patterns or rhythms. Of course, like the students, our perspectives on the intervention differ but we also have to model the curbing or suppression of course activity on the SOUL days. We realized a time savings on these days but was there a total reduction of instructional time overall for each of us? As we realized a time savings, did SOUL slow the pace of the course? Monday-Tuesday SOUL days provided a means of slowing the demands and response burden over the weekends. We realized mixed results in balancing work lives and personal lives. We differed in reductions of time *and* effort. The next phase of SOUL challenges us to develop labour-driven apps for monitoring instructional time.

CONCLUSION

By and large, we found students advocating SOUL throughout the course. Exceptions counter with expectations of deregulation and liberty of access in online learning. Our own advocacy is inherent in the intervention. In this paper, we focused on an analysis of SOUL rather than advocacy. SOUL is a reality check on self-organized learning environments (SOLE) (Mitra et al., 2010). While the tongue-in-cheek Slow Internet Movement (SIM) and itinerant 'slow netters' challenge current carriers' and service providers' infatuation with speed, SOUL offers a mode of being with slowness (NPR, 2011). And although SOUL and SOLE are philosophically compatible in being rule-based and consensus-based, the latter tends to neglect the problem of time in children, students, and teachers. SOLE overlooks the implications of hyper-learning, hyper-teaching, and hyper-parenting (Honoré, 2008).

In the final analysis, we stress that instructional time and learning time, or total educational time, have a variety of superficial and profound implications for individuals, collectives, and the environment. In the chapter on the workday and overwork in *Capital*, Marx offers a hypothetical comment by an employee to an employer: “What you gain in labor I lose in substance” of life (p. 234). Repeated as a mantra, it is a reminder to online educators that a healthy length of the workday begins with a containment of time allocated to each course.

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DOES SCHOOL MATHEMATICS SUPPORT STEM EDUCATION? – EXPLORING SPECIALIZED MATHEMATICS KNOWLEDGE FOR STEM EDUCATION

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ABSTRACT

Transdisciplinary approaches to STEM education emphasize innovation and address issues in different contexts related to culture, environment, and social justice. The connections of these approaches to school mathematics are commonly taken for granted. In this paper, we address this assumption elaborating on specific examples in the context of teacher education. We specifically address the following questions: (1) What types of mathematics are involved in different educational settings related to STEM education? (2) What specialized mathematical knowledge is required for teaching in this context? We draw from qualitative analyses of different sources of data involving teachers' designs of learning tasks, including two graduate courses for teachers, one undergraduate course for teachers in preparation, and a professional learning series for teachers, adding to a total of 79 participants. Our findings focus on specific mathematical content not addressed explicitly in the mandated program of studies or in common resources for teachers. This mathematics includes: images and metaphors for numbers and arithmetic operations; dynamic geometry; spatial reasoning; networks and flow diagrams; and specific elements of coding. These results extend to the body of knowledge on teacher education and task design in the transdisciplinary approach to STEM education.

Keywords: *mathematics, teacher education, integrative approach, geometry, coding, sustainability*

INTRODUCTION

There is an increasing interest in incorporating STEM into school settings around the world, which often involves a focus on teaching mathematics and science or promoting enrolment in STEM related career paths. We, however, are interested in promoting participation and innovation. From our perspective, learning means participation and involves engaging students as active contributors to exploring complex problems and alternative solutions to global issues (Davis, Francis, & Friesen, 2019). This perspective is consistent with other approaches to STEM education, such as the *combine* approach identified by Bybee (2013) and the *transdisciplinary* approach described by Vasquez, Sneider, and Comer (2013). With this approach in mind, it is reasonable to wonder whether there is a need for additional mathematics, or mathematics learned in a different way, that would support this perspective on STEM education.

In this paper, we explore the mathematical knowledge related to STEM tasks designed by teachers as part of teacher education programs. We focus on mathematics that are not included, or at least not explicitly included, in the mandated mathematics programs of study. Although the analyzed tasks come from the education context in Alberta, Canada, the results can be generalized as such mathematics are not commonly included in programs of study around the world. We analyze data from four teacher education projects, including graduate and undergraduate courses and a professional learning series. We conclude with some implications for teaching, teacher educators, curriculum design, and research.

THEORETCAL FRAMEWORK

We draw from two theoretical perspectives for this study: the specialized knowledge for teaching, and an embodied perspective on what it means to learn mathematics.

Specialized mathematical knowledge for teaching

Since Shulman's (1988) prompt to pedagogical content knowledge, many scholars have debated what teachers need to know to teach mathematics. Prominent in this debate is the pedagogical content knowledge described by Ball, Thames, and Phelps (2008): While knowledge about curriculum and general pedagogical strategies is important, knowledge for teaching mathematics is specialized and require understanding mathematics in ways that can support learning: including key representations or models for relevant concepts, development of mathematical concepts across the curriculum, and students' common misconceptions. We extend this idea of specialized knowledge for the integration of the STEM transdisciplinary approach into the classroom. In doing so, we also consider a particular perspective on learning mathematics that stresses the role of the human experience in the world.

An embodied perspective on mathematics learning

Authors with different perspectives on embodied cognition share a focus on the body with respect to learning (Gerofsky, 2016). From an embodied perspective of cognition, the role of the human experience in the environment shapes the way we learn, including culture and language. Two particular mathematical concepts are relevant examples of the role of the embodied perspective on learning for our study: number and geometric transformations. Lakoff and Núñez (2000) elaborated on how mathematics can be constructed from grounding metaphors based on bodily experience of humans in the world. They offered four different grounding metaphors for arithmetic operations regarding particular meanings of number, namely: object collection, object construction, measuring stick, and motion along a path. The later metaphor for arithmetic corresponds to the number line, which had historical relevance in the conception of number, as Lakoff and Núñez posited: "Conceptualizing all (real) numbers metaphorically as point-locations on the same line was crucial to providing a uniform understanding of number" (p. 73). Regarding geometric transformations, Thom, D'Amour, and Preciado (2015) described how students made sense of transformation through experiences with their body, gesturing, and manipulating furniture to describe rolling, staking, and sliding.

This enactive perspective permeates though several topics, including those related to coding and robotics. As most of the images in computer graphics refer to some aspect of the physical world, even in their representation in two dimensions, the geometry involved in graphic manipulation has a direct connection to human experience in the world, as stressed by Francis, Khan and Davis (2016).

METHODOLOGY

The results presented here draw from two different studies, both based on design-based methodology and focused on improving mathematics teacher education. One of the studies corresponds to an eight-session professional learning series, and the other to an undergraduate and two graduate courses in education, as described in Table 1. The table also indicates the number of participants in each study. Although the data corresponds to different learning settings, teachers' task designs, along with reflective narratives, and online discussions, were analyzed in each case, providing a common ground for integrating the data set as a whole. The analysis of these data not only reflects the focus and content of each teacher education modality, but also provides specific details of teachers' decisions and challenges in designing learning environments.

Table 1. Research participants per cite

Teacher education modality	Population	Participants
Professional Leaning Series	Experienced teachers	50
Courses		
Geometry in Nature, Art and Computer Graphics	Same graduate students	
Mathematics for Sustainability	for both courses	7
STEM Education	Undergraduate students	22

We elaborate on each data source in this section, including contextual features, instructional approaches, and specific mathematical content involved.

Professional Learning Series

Addressing the need for an: "increased availability and access to high-quality professional development and training opportunities specific to the teaching of Mathematics" (O' Connor, de Vries, Goldie, Beltaos, Bica & Lagu, 2016, p. 8), the University of Calgary, in partnership with the Galileo Educational Network Association, and a school district in Alberta designed an eight-session professional learning series for elementary teachers. This project placed a particular attention to the meanings of number; in particular, there was a deliberate focus on number lines and bar models, which are fundamental for understanding the concept of number (Norton & Alibali, 2019). The project also involved elements of computational thinking. The purpose of the project was to enrich student learning opportunities and stimulate systemic growth in mathematics teaching and learning through the professional learning series.

An analysis of student samples that teachers brought to the sessions, as part of the activities in the series, showed a lack of attention to representing number using the number line, which was a main focus for the learning series. Lessons observed as part of this project also showed a lack of critical representations of number. This is consistent with our review of curricular materials, including textbooks and programs of study, that place minimal attention to this representation, and instead focus mainly on number as quantity (cardinality).

Geometry in nature, art and computer graphics

The course *Geometry in Nature, Art, and Computer Graphics* is the third component for the fourcourse graduate program *Contemporary, Emergent Mathematics*, co-developed and co-taught by the Werklund School of Education and the Department of Mathematics and Statistics of the University of Calgary. This program is based on the premise that contemporary branches in mathematics have a variety of applications that, with the aid of digital technology, are increasingly common in our society. This graduate program introduces teachers to contemporary mathematics and a range of current applications. The purpose is to explore mathematical topics, applications, and implications to society that could complement and enrich mathematics education at K to 12 levels.

The course, targeted for teachers and educators from K to 12, focuses on the mathematical ideas around shape and symmetry in nature, in contemporary and classical art, and in computer graphics, including algorithms for image representation and manipulation used for diverse applications such as virtual reality and media communication. Teachers enrolled in the course were required to design of three learning activities for the classroom, commonly reported as lesson plans.

Geometry for computer graphics can be described in terms of the relationships between geometry and programing, in particular with respect to the manipulation of virtual images. This also includes programing for robotics, with involves spatial elements.

Mathematics for sustainability

The *Mathematics for Sustainability* course is also a part of the Contemporary, Emergent Mathematics program. This course applies mathematical tools through a look at sustainability issues from a mathematical perspective, asking fundamental questions such as: How large? How fast? How risky? How connected? Key ideas and topics for this course include ways in which information can be represented numerically, ways of studying systems changing over time, ways of quantifying risk and uncertainty for decision making, and ways to think mathematically about complex, large-scale systems, including the complex behavior that arises.

The course also requires teacher to design tasks for their classrooms based on the content of the course, which followed the book with same name written by Roe, deForest and Jamshidi (2018). This book focuses on using mathematics for studying issues of sustainability and concludes with a chapter with case studies, which have the purpose of inform a real decision or a path of action. Participants in this course were required to create similar case studies.

STEM Education

The *STEM Education* course is a mandatory component of the undergraduate program of education at the University of Calgary. The course is informed by a transdisciplinary approach where inquiry transcends each specific discipline. The intent of the course is to foster an understanding of how STEM can inform and be used to shape teaching and learning across grade levels and subject areas. Course assignments include designing STEM learning environments that incorporate robotics.

RESULTS AND DISCUSSION

Through an iterative process of discussion and review of the data, we identified common themes across data sources and elaborate on each one in this section with a focus on mathematics not explicitly included in program of studies.

Embodied Mathematics (Images and Metaphors)

We identified tasks that require students to move in connection to the notion of number (distance) from the learning series and angle (rotation) from the Geometry in Nature, Arts and Computer Graphics course. While the concepts of number and angle are explicitly introduced in the Alberta Mathematics Program of Study, we notice that number is mostly presented in the context of counting objects. Angle is introduced in the context of two intersecting lines. We found that the dynamic approach to these two concepts provided students with enactive meanings suitable for agent-based programing and robot design. Similarly, the Mathematics for Sustainability course placed an emphasis on communicating quantities in human terms, as opposed to just give numbers that due to their very large or very small size, that may be detached of meaning to people. Teachers in this course stressed this point in the tasks they designed as part of the course.

Spatial Reasoning

Spatial reasoning also relates to the perspective on embodied mathematics, but there were very specific examples in this category. Examples of spatial reasoning from the STEM Education course include building the basic tank from the EV3 manual, which requires the following abilities: understand a 2D representation of a 3D object; mental rotation. Also, agent-based programming, addressed both the STEM Education course and the Geometry in Nature, Arts and Computer Graphics course, requires navigation skills not addressed on program of studies.

Geometry and Transformations

Both the Geometry in Nature, Art and Computer Graphics course and the STEM Education course include elements of geometry, such as transformations, angles, use of vectors in coding, proportion, and coordinate systems (Preciado Babb, 2020). While these topics are in the Alberta Mathematics Program of Study, their use in the courses extended beyond the regular requirements, including the utilization of 2D and 3D vectors for image transformation and animations (e.g. creating an animation of the solar system), which also included different coordinate systems for the plane and the space, such as polar and cylindrical coordinates.

Many learning environments designed in the STEM education course required nuanced descriptions of robot rotations, including the position of the centre of rotation based on the differences in speed and direction of each of the motors.

Computational Thinking in Mathematics

Coding was particularly relevant for the STEM Education course and the Geometry in Nature, Art and Computer Graphics. In particular, the use of iterations such as loops and repeat commands is important to start creating some codes. Additionally, the principle of recursion in mathematics and programing was addressed through fractal generation. These iterations were particularly difficult for the teachers enrolled in the course. Some teachers included a pedagogical strategy to address this difficulty in their design: first code the agent (a robot or the turtle in Logo) to do a series of steps, without the iteration; and then write the corresponding code with a repeat, a loop or a recursive approach, which are relevant for computational thinking.

Elements of computational thinking were evident in some of the tasks designed by teachers in the Professional Learning Series and Geometry in Nature, Art and Computer Graphics course, such as: breaking down a problem into smaller pieces; creating and abstract model; and designing an algorithm or procedure. Many of the tasks designed by the teacher addressed computational thinking in contexts that did not required a computer, which helped to focus on the process of addressing the problems.

We consider it important to attend to the way computational thinking is described, as a general approach to problem solving. As such, computational thinking does not necessarily involve mathematics. Our analysis of the tasks designed by teachers in Professional Learning Series highlighted the need to embed computational thinking with STEM contexts with an explicit attention to mathematical reasoning.

Networking and Flow Diagrams

Networks and flow diagrams were important for applications to sustainability that included, for instance, a model for the greenhouse effect. Some teachers included these in their learning design environments in the Mathematics for Sustainability course. While this topic does not represent advanced concepts, it is not commonly included in mathematics program of studies.

CONCLUSIONS

The mathematical content identified in this paper is not addressed explicitly in the mathematics programs of study, nor in common resources for teachers. This result suggests that current program of studies lack specific mathematical content required to address STEM tasks that focus on transdisciplinary and innovation.

Images and metaphors are more than representations or instantiations of a mathematical concepts; they are fundamental to understand mathematical concepts at more abstract levels. In this paper we started to identify some of this content, which can inform the design of tasks for the classroom and the content for teacher education programs. However, we are just starting to identify such knowledge, including pedagogical implications, and more research is necessary to gain more insights on the specific mathematics involved in the transdisciplinary approach to STEM, and the strategies for teacher professional learning.

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COTEACHERS INTERACTIONS FOR PROFESSIONAL LEARNING IN A FIRST GRADE CLASSROOM MOVING TO STUDENT-CENTERED SCIENTIFIC INQUIRY

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ABSTRACT

Scientific literacy is vital to understanding critical environmental concerns. One essential aspect of scientific literacy learning involves doing science investigations that begin with students' questions. Although it is important to start such experiences in primary schools, primary teachers often do not have the science background to support this. This study is part of a larger study that focuses on primary teachers professional learning through coteaching with an expert teacher using a support framework called the *Steps to Inquiry* framework. This study focused specifically on coteacher interactions between a first-grade teacher and the expert teacher supporting him as he led the children through their science investigations using the framework. The study used video recording of all activities in the classroom and micro-analysis. It indicates five categories of coteacher interactions and shows that interactions occurred on average every one to two minutes. Interactions involved organizational talk and talk about student work. Interactions helped keep the primary teacher on track supporting students' investigations with the *Steps to Inquiry* framework. Implications for practical support of primary teachers is discussed.

Keywords: *student-centered scientific inquiry, coteaching, primary science education*

INTRODUCTION

In a world where an understanding of public issues (e.g. climate change) is so vital, scientific literacy is critically necessary (NRC, 1996). It requires skills and understanding gained through *doing* science. For this reason, school science curricula around the world recommend some provision for student-centered scientific inquiry (SCSI) where students have opportunities to be 'question askers'; to learn to *do* science by *doing* science' (Hodson, 2014, p.2547 italics added). This learning needs to begin early in primary schools (e.g. Harlen, 2018) however primary teachers often do not have the science background to support children doing SCSI. One way to support them is through coteaching. In coteaching two or more teachers work together to plan, implement and reflect upon lessons and units (Roth, Tobin, Carambo, & Dalland, 2004, 2005). This study focuses on coteaching for SCSI in a first-grade classroom where an expert teacher is supporting a teacher new to SCSI using a framework called the *Steps to Inquiry* (*SI*) framework. The aim is to examine ways that teachers interact, the content of these interactions and how they relate to the SCSIs and the *SI* framework. The research questions addressed are *"In what ways do coteachers interact with each other during coteaching in a classroom where SCSI is being introduced?* and "*What do the teachers talk about in their interactions and how does it relate to SCSI and the* SI *framework*"?

LITERATURE REVIEW

Student-centered scientific inquiry (SCSI)

Scientific inquiry refers to the practices of observing, thinking, investigating and validating that scientists use in their work (AAAS, 1993). SCSI, is led by students' questions and involves students designing and conducting investigations. It is a recommended part of curriculum in many countries around the world (e.g. BC new curriculum 2015; Next Generation Science Standards, 2013; Rocard Report, 2007), because it is only through *doing* science that students can understand the practices that scientists use to find answers (e.g. Kuhn, Arvidsson, Lesperance & Corprew, 2017).

Supporting student-centered scientific inquiries

Although we recognize that experimentation is but one type of scientific inquiry, this study focuses on supporting SCSIs that involve experimentation. Although children often naturally pose singlevariable questions, they need guidance with understanding control of variables (Lazonder and Kemp, 2012). Even students in higher grades in high school need support in basic aspects of designing experiments. For example, they need support with understanding dependent, independence and controlled variables (Arnold, Kremerk & Mayer, 2014).

Steps to Inquiry (*SI*) Framework

The *SI* framework was created by a team of teachers to be used by teachers to support them and their students conducting SCSI (e.g. Rees, Pardo & Parker, 2013; Alexander, Pardo, Lindsay & Rees, 2018). Influenced by the Inquiry Boards of Buttemer (2006) and the work of Goldsworthy and Feasy (1997), the *SI* framework utilizes a series of interactive posters that guide teachers and students through the logical steps of planning and conducting their own experiments. It begins with collecting students' observations and wonderings about an event, and supports them identifying variables, phrasing testable questions, designing procedures, and conducting investigations.

Coteaching

In this study, SCSI with the *SI* framework is introduced through coteaching. This is an example of coteaching for professional learning, which has been studied before in the context of initial teacher education (e.g. Murphy & Beggs, 2005; Roth et al, 2004, 2005; Scantlebury, Gallo-Fox & Wassell, 2008). Research in the literature commonly focuses on self-reports from coteachers, with studies involving direct observation and video recording being rarer. Previous research utilizing video recording in classrooms indicates that in coteaching, teachers create and use resources; they pick up each other's styles and habits; and they learn from each other when they directly step in and out of the lead role, often seamlessly from the point of view of the class. (Roth et al, 2004, 2005).

RESEARCH DESIGN

This qualitative research study of teacher interactions is part of a larger case study that focuses on teacher professional learning during coteaching for SCSI. A first-grade teacher new to SCSI teaching is learning to implement it using the *SI* framework, introduced through coteaching with an experienced teacher over a one-year period. This is a microanalysis that aims to develop understanding of the specific ways that the teachers interact in the classroom during coteaching. It focuses on one student-centered inquiry which took place over three days (117 minutes of class time).

Participants

Mr. Wise (all names are pseudonyms), the teacher experienced with SCSI, has a bachelor of science degree, a master's degree in education, and has worked at the school (a public school in a small city in BC) for eight years. He has been conducting SCSI for four years in his own classroom. Mr. Holmes' the first-grade teacher chose to be part of the study due to his interest in SCSI. He has little background in science beyond high school and his teacher education program. He has a bachelor of arts degree. The 17 first grade children in the study include nine girls and eight boys. The children range from six to seven years of age. Invitations to participate in this study followed university research ethics board guidelines.

Data Sources and Collection

Data sources include video and audio recordings of the classroom during coteaching, collected over three days (117 minutes of class-time). Three cameras were operated simultaneously to capture the whole class from different perspectives. One camera was fixed for a wide-angle perspective of the classroom, while two cameras focused on the teachers and students. Audio recorders were carried by the teachers. All relevant written documents (artefacts) that participants engaged with during activities were photographed. For analysis of video recordings and audio recordings, the researchers completed verbatim transcription as soon as possible following the events.

Data Analysis

To identify events going on in the classroom, we created 'event maps' (Crawford, Kelly, & Brown, 2000) of all video recordings. The event maps were chronological representations of the video recordings. We constructed running records indicating when particular activities began and ended and noting a brief description of the activity. Activities included periods when the students engaged in large group discussions and small group inquiry activities (such as collecting observations, developing wonderings, identifying variables and completing experiments) and whole class sharing following these scientific inquiry activities. To identify episodes and types of interactions between teachers during co-teaching, the team of researchers examined the video recordings together while reading transcripts and located the position of these instances on the video (Jordan & Henderson, 1995). More detailed transcription and analysis of these episodes followed.

RESULTS

Types of coteacher interactions

Teachers interacted frequently throughout the inquiry unit in a number of ways. During the 117 minutes of video-recorded class-time in this micro analysis, we noted a total of 88 interactions between coteachers. We noted five types '**asides**' (27; spoken quietly and quickly); exchanges '**for students'** (15; louder and slower); '**interjections**' (14; e.g. to take the floor to convey an important point); '**check-ins' (**25; e.g. regarding timing) and '**resources**' (7; e.g. one teacher recording students' comments on the board for the other teacher's use as a resource). Almost all of these exchanges were short (30sec - 1minute) and although there is similarity in the categorization of types, the counts do not overlap. Based on our counts, we estimate that coteachers interactioned every one to two minutes (on average) throughout this inquiry unit. In the next section we report on the content of these exchanges.

Content of coteacher interactions

Exchanges between coteachers either focused on organization of activities following the *SI* framework (*Organizational talk*) or on student work (*Talk concerning student work*). These two kinds of talk are described below. However, first, since this talk was directly related to the inquiry activities supported by the *SI* framework, it is important to describe how the *SI* framework was being used in the classroom.

How the SI framework was being used in the classroom. The *SI* framework was illustrated on a set of posters that were attached to the wall at the front of the classroom, where the children were seated for large group discussions. The posters (freely available through Youth Science Canada n.d.) indicated a sequence of events and provided boxes for collection of students' ideas, in response to teachers' questions. This sequence of events included: making 'observations'; developing 'I wonder' questions about the event; developing 'variables' including 'things we can change' (independent variables) and 'things we can measure' (dependent variables); and phrasing a testable question of the form 'If I change xxxxxx what will happen to yyyyyyy'. The posters were used by the teachers as 'graphic organizers' that guided them through the inquiry activities. Students had booklets that were copies of the posters that they worked with during their small group activities. The structure of the class followed alternating whole group discussion or sharing times and small group activity times with the materials when the students collected observations, wonderings, ideas of variables and finally when they conducted their experiment. During whole class discussions at the different stages of the inquiry, teachers collected ideas from students, wrote these on sticky-notes and attached these to the posters in the appropriate spaces. Over three days, the teachers and students worked through the sequence of events that culminated with students creating and conducting simple experiments and sharing the stories of their experiments with the class.

Organizational talk. Organizational talk occurred during 'asides', 'for students' 'interjections', and 'check-ins'. During 'asides' coteachers talked about the upcoming activities, corrected each other if they had proceeded incorrectly and often pointed or tapped on the posters, or used large arm movements indicating to each other the steps they were following in their activities. For example, during one nine-second 'aside' Mr. Wise said quickly and quietly to Mr. Holmes, "Probably you should demo this" indicating (using a whole arm gesture) the section of the third poster that dealt with selecting one variable to change, the dependent variable to measure or observe and the variables that would need to be held constant. Mr. Holmes had just previously sent the children back to their work areas around the room. He responded to Mr. Wise and called to the children "Okay, can you come back for a sec, come back for a sec." Organizational talk between teachers, was sometimes performed 'for students' it was spoken in a louder voice and at a slower pace. For example, on one occasion, when the teachers were demonstrating an example of an experiment, Mr. Wise said slowly and in a loud voice "So, what did we learn Mr. Holmes?" To which Mr. Holmes responded "I learned that if it [the track] gets so steep …. It causes it [the car] to tumble" Organizational talk that involved 'interjections' occurred when one teacher interrupted and was given the floor to make an important point. An example occurred when Mr. Wise interrupted Mr. Holmes when children were giving their ideas of variables. Mr. Wise interrupted saying "okay, so we're jumping around a little bit, we've got a few things that people are giving us that are going to be 'what happens when we change something'. So someone said it might go faster and someone said it might go farther …"(writing these each on sticky notes and attaching to the appropriate space on the poster). Finally, there were teacher interactions that we denoted as 'check-ins" involving teachers saying for example "So what do you think Mr. Wise? maybe one more minute?" indicating the time that students needed to complete a task.

Talk concerning student work. Talk concerning student work occurred during 'resources' and 'interjections'. During 'resources', one coteacher collected student work and provide it as a 'resource' for the other. For example, during whole group discussions with the students, while Mr. Holmes led the class asking the students' questions such as "What did you observe?" Mr. Wise wrote students' responses on sticky notes and posted them in the appropriate position on the poster, thus creating a resource that Mr. Holmes could use in his discussion with the students. Periodically, Mr. Holmes paused, turned and looked at the posters and read aloud to the children their responses that Mr. Wise had written on the sticky notes. Coteacher exchanges that concerned student work were often 'interjections' occurring during whole class discussion where students were sharing what they had done in their small group activities and had written or drawn in their booklets. For example, on one occasion as Mr. Holmes read the students' collected observations on the sticky notes, Mr. Wise interjected to add a comment "a very interesting observation". As well, during students' expositions of their observations, wonderings and experiments in response to Mr. Holmes' questions, Mr. Wise often 'interjected' adding additional questions for clarification that extended the students' reports.

CONCLUSION

This study indicates that coteachers interacted frequently (on average every one to two minutes) throughout the SCSI supported by the *SI* framework. Interactions were classified into five types ('asides', 'for students', 'interjections', 'check-ins', and 'resources'). Coteachers' talk during interactions involved organizational talk and student work. The organizational talk with Mr. Wise helped to keep Mr. Holmes on track as he worked through this SCSI. The talk that involved student work supported Mr. Holmes supporting the children, for example with reporting their findings. This builds upon previous work (e.g. Roth et al, 2004, 2005) that looked at some types of interactions but not frequency. Establishing an idea of the frequency of interactions allows us to understand more fully the work that coteachers are doing to support and to learn. Unlike situations of parallel teaching that occur in some coteaching contexts, in this context teachers were interacting constantly. This study also provides practical details that could be of value to teachers learning to implement SCSI with the *SI* framework. This is the kind of support that students need before high school to help remediate some of the difficulties regarding their understanding of scientific processes (e.g. Arnold et al, 2014; Kuhn et al, 2017). Ultimately, this work can help children become scientifically literate adults, thus helping to build understanding around critical issues such as climate change.

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CURIOSITY-DRIVEN, INQUIRY-BASED SCIENCE PROJECTS BRIDGE FACE-TO-FACE AND ONLINE LEARNING FORMATS DURING COVID-19

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2. *B.C. School District No. 73*

ABSTRACT

The mass closure of schools as a result of the Covid-19 pandemic paralyzed many children's education. Teachers across the globe did their best to engage students and help support their learning through online educational formats. However, teachers and parents indicated that students' struggled with these approaches. This study aims to build on successes some science teachers had using curiosity as a starting point in inquiry-based science projects that bridged face-to-face and online learning formats. This year-long qualitative, participatory action research study brings together fourteen teachers (seven elementary and seven secondary) and four university faculty using an online community of inquiry framework. This work is in its early stages. Through two cycles of planning, implementation and reflection, the community of inquiry will ultimately develop a model for best practices and resources that respond to the educational challenges faced during the pandemic and help prepare teachers for future crises. These materials will be shared with other teachers as open education resources, that are freely accessible, digital, re-mixable and revisable. This work will also contribute to theory regarding best practices for curiosity-driven, inquiry-based science education in blended learning spaces.

Keywords: *curiosity, inquiry-based, science education, Covid-19 pandemic, online learning*

INTRODUCTION

The impact of the Covid-19 pandemic on education has been devastating; between January 2020 and June 2020 most nations (146 countries) had to close educational institutions, impacting over 60% of all students (more than one billion) worldwide (UNESCO, 2020). This kind of school closure not only impacts education but also leads to social and mental health issues for school-aged students (Waddell et al, 2020) and we support keeping school open, when this can be accomplished safely. However, we acknowledge that there are times, such as during the first months of the Covid-19 pandemic, when schools must be closed.

During those early months of the Covid-19 pandemic, efforts were made globally to maintain students' education online (e.g. Huang et al, 2020). However, in Canada (as elsewhere) teachers and parents of school-aged students had grave difficulties engaging students' interest in learning online. This situation brought to light the need to prepare ahead for the future by investigating pedagogical approaches that showed promise for engaging students' interest and bridging face-to-face and online formats during the Covid-19 school closures.

Our study aims to build upon successes that some teachers and university instructors were having with engaging students' online, in the area of science education, using the pedagogical approach of curiosity-driven, inquiry-based science education (described on p.2).

The purpose of this research is 1. To bring together science teachers, university faculty and researchers on the driving question, "How can we best support our students' learning in online and blended learning environments through curiosity-driven, inquiry-based science education?"; 2. To develop a model for best practices and resources that can be shared widely and freely as open education resources (described on p.3); 3. To study and support the group to fulfil their objectives over the course of the year; 4. To contribute to theory regarding best practices for curiosity-driven, inquiry-based science education in fluctuating learning spaces (face-to-face, online and a hybrid of the two).

LITERATURE REVIEW AND THEORETICAL APPROACH

Curiosity is "characterized by the joy of discovery and the motivation to seek answers" (Shah, et al, 2018, p.380). Curiosity is associated with the kind of wonder that can ignite interest and awaken students' imagination (Egan et al, 2014). Recent empirical studies have shown that high levels of curiosity are linked to increased academic achievement (Shah et al, 2018).

Curiosity can be used as a driver for inquiry-based science education (Lindstom, 2018) where teachers support students asking their own questions, planning investigations, analyzing data, reasoning, and presenting conclusions of their learning (Chin & Osbourne, 2010). Curiosity-driven, inquiry-based science education is aligned with the philosophical position of John Dewey (1938), who proposed that it is through their own experiences, that students generate the ideas that drive their learning. It is also aligned with sociocultural learning theory (Vygotsky, 1978).

Inquiry-based science education originated in the 1960s with authors such as Schwab, (1962). This pedagogy has more recently become a mainstay of science curricula in many countries around the world (Hong, et al, 2019). A wealth of research across decades indicates that when it is appropriately supported by teachers, inquiry-based science education increases student interest, motivation and achievement (Furtak et al, 2012; Lazonder & Harmsen, 2016; Kang & Keinonen, 2018; Aditomo & Klieme, 2020). It supports students developing critical and creative thinking and collaborative teamwork– competencies necessary for them to become critical learners and directors of their own learning (e.g. NGSS, 2013; BC Curriculum, 2015; Croce & Firestone, 2020). Inquiry-based science education is one of the recommended approaches for the inclusion of Indigenous' perspectives because it is experiential, recognizes the value of group processes and supports a variety of learning styles (FNESC, 2016). Inquiry-based science education is aligned with culturally responsive teaching (Brown, 2017) and differentiated instruction (Llewellyn, 2010), and it is the organizing principle in the BC science curriculum through the science curricular competencies.

The initiatives that we are building upon, occurred during the first months of the Covid-19 pandemic, when schools were closed. To support high school students' science learning, a group of teachers used curiosity-driven, inquiry-based science education. They provided students with materials and supported them to develop their projects using online means, including videoconferencing, as well as photos, graphics and through text-based supports provided synchronously and asynchronously.

Our aim with this study is to support this group of teachers working on their driving question "How can we best support our students' learning in blended learning environments through curiosity-driven inquiry-based science education?"

To bring these teachers together, we are using an educational community of inquiry (COI) model. According to Garrison & Akyol (2017) "An educational community of inquiry [COI] is a group of individuals who collaboratively engage in purposeful critical discourse and reflection to construct personal meaning and confirm mutual understanding. There is both independence and interaction (coregulation) in a community of inquiry [COI]." (p. 106).

Using a three-pronged approach that constitutes the overlapping presences, social, cognitive and teaching (Figure 1), the COI is designed to help create learning conditions to promote collaborative discovery and co-creation of knowledge (Bozkurt, 2019). Based on the work of John Dewey, COIs follow a constructivist perspective of learning that focuses on the notion that higher-order and critical learning and reflection occurs when participants are engaged in collaborative discourse and reconstruction of experience (Garrison & Akyol, 2017).

There are two important features of the COI structure for our study. One is that collaborative groups are vertical as well as horizontal (Trabona et al, 2019), meaning that we bring together representative teachers from across grade levels to meet with post-secondary faculty (vertical collaboration), as well as within levels (horizontal collaboration). This grouping is important so that teachers reach decisions that are not only valuable for them at their own grade level but also inform, and are informed by, the knowledge of teachers who teach at the levels below and above. The second is that the COI must be small enough and membership consistent enough to facilitate online discussions and allow building of social presence over the course of the year (Akcaoglu & Lee, 2016).

Understandings of curiosity-driven, inquiry-based science education may differ, across teachers, across grade levels and between school and university. To help participants make their understandings visible so that mutual understandings can be agreed upon, and to ensure consistency across the supports and resources that are produced, we began our work with a sample curiosity-driven, inquiry-based science education unit created specifically for online and blended learning by members of our team.

To make the outcomes of COIs accessible to all, we are using Open Education Resources (OERs). OERs are the building blocks for open participatory learning (Seely Brown & Adler, 2008) as they are digital, and designed to be easily accessible, shareable, reusable, re-mixable and revisable (DeRosa & Robinson, 2017). To the best of our knowledge, this will be the first time that OERs have been created specifically for supporting teachers in supporting their students doing curiosity-driven inquiry-based science education across face-to-face, online and blended educational spaces.

METHODS

This is a participatory action research study (Kemmis et al, 2013) that aims to support participants in COIs on an on-going basis, addressing their driving question ("How can we best support our students' learning in fluctuating environments through curiosity-driven, inquiry-based science education?"). This is a qualitative research study that uses a case study approach (Merriam, 1998) is to support teachers and instructors to take action and to design a model and curriculum, which will support curiositydriven, inquiry-based science education across face-to-face, online and blended learning formats to engage students' interest and support their learning and ultimately, made these resources accessible to all teachers.

Research Design

Our design for this year-long project, is to integrate research with two cycles of COI work, where a cycle includes planning, implementation and reflection. Research findings from the first cycle are provided to participants in time for their second cycle, so that at each cycle the model and resources can be developed and refined. Cycles occur via a blended format, including an initial meeting online where facilitators support teachers to plan their model and curriculum – followed by implementation, where teachers implement their curriculum with their students face-to-face in schools with online support from facilitators through a secure text-based platform (Mattermost) and a video platform (Big Blue Button). The cycle ends with a reflection meeting online where facilitators support teachers in sharing their findings from implementation. Meetings use videoconferencing and include sharing online on Mattermost, to develop and refine the model and resources. Meetings are recorded and online communication, and model and unit documents collected at the end of each cycle. Between cycles, researchers analyze data to bring back findings to the first planning meeting of the next cycle.

Timeline

The timing of events to occur throughout this year-long study are indicated below.

Oct 2020 – Jan 2021 – Cycle 1: Oct 23rd 2020: Planning meeting – explain the project, present the sample unit, facilitators support teachers to plan their model and curriculum for semester I using the sample unit as a starting point; *Nov 2020*: Implementation – teachers trial their model and units with students; *Dec 2020*: Reflection meeting –reflection and sharing on trial of model and units with students. Teachers make changes to the model and units that they have trialled, these, and videos of the meetings and online communication are collected by the research team; *Jan 2021*: Research team works on transcription and data analysis, refine the model and resources accordingly (as per teachers plans) to bring back to COIs for cycle 2.

Feb – April 2021– Cycle 2: Feb 2021: Planning meeting (teachers have new classes, new students) – COI teachers receive from the research team the results of data analysis from Cycle 1- the COIs make modifications and plans for the model and units for Cycle 2 for teachers' new classes for semester II; *March 2021*: Implementation – teachers trial their plans with students; *April 2021*: Reflection meeting – Reflection and sharing – COIs make further revisions to the model and units – these, and videos of the meetings and online communication are collected by the research team; *May 2021*: Research team works on transcription and data analysis, refines the model and resources accordingly (as per teachers plans) to bring back to COIs for final meeting. *June 2021*: Final half day meeting with COIs - the research team share the model and resources OERs with the COIs for final refining and decisions.

June/August 2021– Dissemination: The findings from this study will be of value to teachers in local school district, as well as students and parents, and all teachers, teacher educators, teacher candidates and researchers. Locally, OERs will be shared through teacher workshops and public meetings. They will be disseminated quickly and made publicly and freely available through open publication.

Participants

Following REB approval, 14 teachers (seven elementary and seven secondary) and four university faculty agreed to participate in the study. There are three COIs. Each COI includes representatives of each level of teaching (elementary, secondary and university faculty) and is facilitated by two members of our research team (one teacher and one faculty member). All teachers and faculty experienced the move to online teaching in March 2020. In September 2020, all teachers resumed face-to-face teaching except two who teach online. All faculty continued teaching online.

Data collection

We are collecting two kinds of data for each COI: recordings and notes from COI online meetings; and text-based discussions and communications on Mattermost.

Data analysis

Transcripts of recordings and text-based discussions and communications on Mattermost from our planning meetings are in the process of being analyzed for themes using a constant comparison analysis method (Leech & Onwuegbuzie, 2007) to address the driving question. We are in the process of creating a codebook (Merriam, 1998) using codes developed from our initial findings.

Trustworthiness

Triangulation will be used across the data sets and member checking (bringing conclusions back to our participants).

FINDINGS AND DISCUSSION

This study is in its initial stages. We are currently in the first cycle of the project. We have collected recordings and text-based discussions from planning meetings. Teachers are currently implementing their plans in their classrooms. Reflection meetings are taking place in December (16th &17th) 2020. In the final paper and at the conference, findings will be presented and discussed.

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ENHANCING SCIENCE INQUIRY SKILLS OF STEM STUDENTS THROUGH SOCIO SCIENTIFIC BASED INSTRUCTION

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ABSTRACT

In the K to 12 Science curriculum, one of the 21st century skills that needs to be developed among the learners is the inquiry skill. This mandate indicates that there is a need to upgrade science instruction and this can be achieved with the use of various innovative teaching strategies and techniques, one of which is the use of socio- scientific based instruction (SSBI) in science teaching. This study investigated how SSBI facilitate the development of inquiry skills among the students. It likewise determined students' science achievement along the selected science topics in Grade 9. The mixed method of action research was adopted to determine how SSBI facilitated in developing students' science inquiry skills. Convenience sampling was employed, involving the STEM students. Paired t-test was used to determine differences in the students' pretest and posttest performances. Results revealed significant differences between pretest and posttest. This result is suggestive that the use of SSBI facilitated the development of science inquiry skills among the students, specifically on providing explanations based on evidence, communicating, and justifying explanations. Interestingly, from the focus group discussion conducted, majority of the research participants affirmed that SSBI fostered interest in science learning, enhanced critical thinking and argumentative skills, fostered collaboration and environmental awareness, and helped them realize the importance of science to daily life. Results of the study underscores that using SSBI in science teaching facilitate the development of the students' inquiry skills in understanding science concepts.

Keywords: *STEM education, science inquiry skills, socio-scientific based instruction*

INTRODUCTION

Inquiry is the central feature of the K to 12 science curriculum, which enables the learners to become inquirers and critical problem solvers. Developing these skills would eventually promote 21st century skills among the learners. To realize this goal, science instruction should be learner centered and inquiry-based.

Science inquiry involves active construction of ideas and forming of connections, which allows students to take an active role in understanding their science learning. This also promotes students' engagement in the investigative nature of science and transforms learning from watching and listening to doing.

Questions serve as foundation of knowledge and discoveries in science learning. Allowing the students to ask questions would eventually stimulate critical thinking, which in turn, enhance their inquiry skill.

According to Elstgeest (n.d.), every young person is a born why and how questioner. They are inherently curious and seem to have a never-ending supply of questions (Edwards, 1997). However, as children proceed to higher grades they stop asking questions and no longer articulate a desire to discover.

Hence, the researcher would like to conduct a study in line with inquiry skill utilizing socioscientific based instruction. According to Evagorou, Jimenez-aleixandre, & Osborne, (2012), SSBI are socially controversial (or socially alive) topics or issues which have a scientific component but also incorporate other disciplines and interests (political, economic, ethical, etc.) and which involve the evaluation of moral and ethical aspects. Today's society continuously faces socio-scientific issues that pose political and moral dilemmas, such as GMO, nano-technologies or climate change. Science education should provide opportunities for students to experience science in contexts similar or analogous to those contexts that they will find outside of the school, with the goal of achieving scientific literacy for all citizens (Albe, 2007). In this sense, socioscientific issue based instruction in science classroom comprise of six sub themes that are upskilling, social awareness, development of thinking, meaningful learning, character and professional development, contribution to scientific literacy whereas disadvantages of this instruction process are challenges teachers and students, limitations of teaching and learning process in prospective science teachers' perspectives (Yapıcıoğlu, 2018). In addition, in an adequate teaching and learning scenario SSBI encourage the participation in discussion and debate, provide a framework for understanding scientific content and the nature of science, and help the development of HOTS (Higher Order Thinking Skills), such as critical thinking and argumentation (Evagorou et al.,2014). Further, Wang et al. (2018) found out that students' awareness of environmental issues, responsibility for sustainable development, self-efficacy for environmental issues, and environment-related activities had been significantly promoted. Additional qualitative findings indicated that the SSI discussion has gained the leverage of changing students' decision-making and standing position on environmental issues from emphasizing economic development to supporting environmental protection and sustainability. Pike (2007) highlighted that socio-scientific tasks ensure individuals to think about the consequences of science on societal life and improve their decision making and inquiry skills. SSBI enables practitioners to establish engaging contexts for science knowledge development, as well as to become more informed citizens (Amos, Ruth; Levinson, Ralph, 2019).

Research Questions

This research was conducted to determine the potential of SSBI in enhancing science inquiry skills of the Grade 9 STEM students of Tabaco NHS.

Specifically, it sought answers to the following questions:

1.What is the mean pretest and posttest performance of the students in the

a.control group

b. experimental group

2.Is there a significant pre-post mean gain in students' performance in both groups?

3.Is there a significant difference between the mean gain in students' performance of the two groups?

4.What inquiry skills, if any, were developed among the students using SSBI?

5. What are the students' voices about SSBI?

RESEARCH METHODS

The Quasi-experimental research, utilizing the pretest-posttest design was adopted in this study. Two intact classes of Grade 9 STEM curriculum of Tabaco NHS served as the research participant. Grade 9- Dalton class served as the experimental while the Grade 9- Lavoisier class served as the control. The SSBI was implemented to the experimental group while the control group was exposed to the conventional method of teaching.

Convenience sampling was applied since the researcher was handling these two intact classes. Each class was composed of 38 students. A pretest was administered before the study. This was followed by the implementation of the intervention to the experimental group. Posttest was then administered after the conduct of the study.

The pretest and posttest consisted of a 30-item questions of multiple choice type, with four options and five open-ended questions. A table of specifications was drafted with the corresponding cognitive dimensions. Before administering the test to the subjects, the test questions was validated and submitted to jurors for corrections and suggestions. A dry- run was conducted at Tabaco National High School to measure its content validity and an item analysis was made. Suggested items which were not clear and understood were deleted, modified, or reworded.

The topics covered were aligned with the Grade 9 learning competencies of the K to 12 Science curriculum:

1. Heredity: Inheritance and Variation
2. Causes of Species Extinction
3. Climate Change/ Global Warming
4. Use of Plastics
5. Water and Air Pollution
6. Health and Lifestyles (Respiratory and Circulatory System)

After the pretest and posttest, a focus group discussion was conducted among the learners. Tabulation and processing of data quantitatively followed to arrive at scientific analysis and interpretation of results using mean and t-test.

Implementation of the SSBI

Three stages were employed in SSB implementation.

Stage 1 - contextualisation of a situation/issue (a complex situation).

During this stage, the teacher introduces the 'scene', issue or area of concern and at the same time determines the students' prior science knowledge, depth of interest and its relevance for the students as a contextual area for science education learning.

Stage 2 - decontextualisation (breaking down the complex situation to learn the science).

Science ideas, relevant to the context, are decontextualised from the society. This part draws on science curricula and inquiry learning approaches, leading to student acquisition of related scientific concepts. Further, this component is driven by 'need to know' science, which provides a conceptual scientific bearing on the socio-scientific concern/issue.

It permits focusing on the scientific ideas, the solving of problems and the seeking and evaluating of scientific information. It enables science processes. It also builds on students' prior learning and with appropriate scaffolding by the teacher, develops intellectual self-actualisation and selfefficacy.

Stage 3 - recontextualisation (re-examining the complex situation).

Students consolidate their newly acquired scientific learning by being asked to transfer this to the context introduced in stage 1, thus enabling students to utilise relevant science in deriving socioscientific decisions connected with the society issue or concern recognised by students are being relevant to their lives.

RESULTS AND DISCUSSION

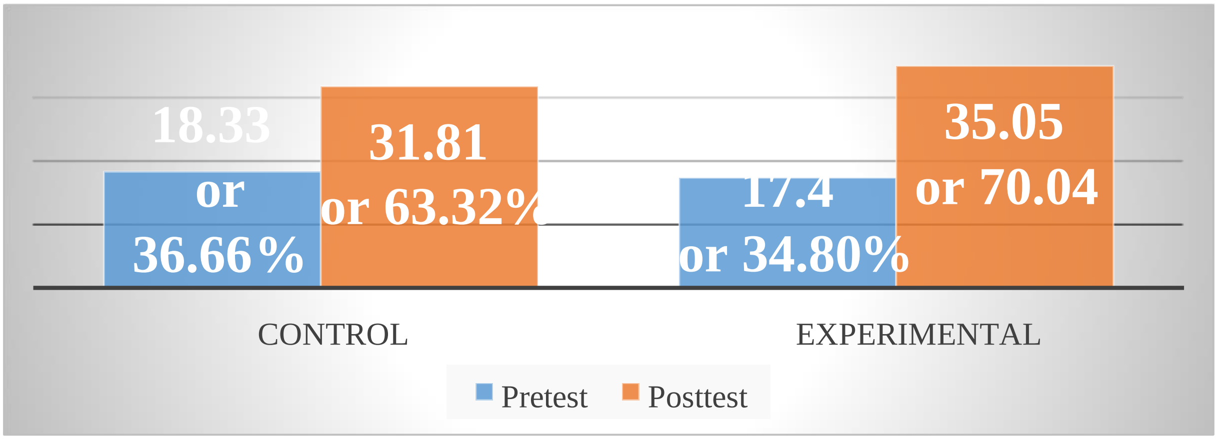

Figure 1. Pre-test and Post-test Performance of the Control and Experimental Group

Mastery Level (Descriptive Equivalent)

92%- 100%	-	Full mastery (FM)
83%- 91%	-	Near Full Mastery (NFM)
75%- 82%	-	Mastery (M)
51%- 74%	-	Near Mastery (NM)
25%- 50%	-	Low Mastery (LM)
24% below	-	No Mastery (NoM)

The table reveals that during the pretest, the control group obtained a mean of 18.33 or 36.66% performance level which is higher compared to the experimental group which had only a mean of 17.40 or 34.80% performance level. Both the pretest performance level of the two groups signifies that they are on the Low Mastery Level. The posttest results however show that the experimental group obtained the higher mean of 35.05 for a performance level of 70.04%. Moreover, the control group got only a mean of 31.81 for a 63.62% performance level. Nevertheless, both groups were on Near Mastery level.

Table 1. Pre- post Mean Gain of the Students' Performance in **Chemistry**

	Groups	Mean Gain	T- test	Interpretation	Decision
Pre-post	Experimental	17.65	4.22*	Significant	Reject
Pre-post	Control	13.48	1.43	Not significant	Don't reject

* Significant at .05 $\geq$ 1.97

Table 1 indicates the pre/post mean gain of students' performance in Chemistry. The resultant t-test of the two groups was 4.22 for the experimental and 1.43 for the control group. It can be claimed that there was a significant improvement from the pretest to the posttest in the group where the intervention was implemented.

Table 2. **Difference Between the Experimental and Control Group** in **their Chemistry Performance**

Test	**Groups**	**Mean**	**SD**	**Mean Diff.**	**T-ratio**	**Interpretation**
Pretest	Experimental Control	17.40 18.33	3.47 2.46	3.93	1.43	Not significant
Posttest	Experimental Control	35.05 31.81	3.24 3.84	3.24	3.90*	Significant

*Significant at .05 ≥1.97

The result of the pretest showed no significant difference on the performance of the experimental and control group. However the computed t-test during the posttest is 3.90 which is significant at .05 level. A significant difference existed between the two groups favoring the experimental group.

Inquiry Skills Developed Among the Learners/ Reflection

Strengthening the students' process skill of observation resulted in a gradual development of inquiry skills. These skills involved providing explanations based on evidence, communicating, and justifying explanations. It is worth mentioning that the students were fully engaged in the various activities and participated actively in both the small groups and the whole class, not the teacher. However, it was observed that the students still had difficulties with observation skills. Some basic science process skills were not yet fully developed like inferring and observing, taking into consideration that basic process skills have impact on students' ability to perform various inquiry skills. It does not follow that when students demonstrate inquiry skills, they are efficiently adept in the skills and it is not a guarantee that going through an inquiry-based activity develops and understanding about its process.

Student's Voices About SSBI

The following comments/feedbacks were retrieved from the learners employing SSBI.
Student A: I became aware of various issues especially those with scientific basis.
Student B: SSI lessons elicit my critical thinking skills. I love it!
Student C: SSI lessons are interesting & motivating.
Student D: It challenges me to perform the activities.
Student E: It enhances my communication skills and enhance my ability to defend.
Student F: My science process and inquiry skills were tickled.
Student G: My reasoning ability was improved. I learned how to listen to both sides.
Student H: My argumentation skill was basically improved!
Student I: Because of SSBI, I was able to realize the importance of science to daily life Student
Student J: It fostered me collaboration and I became aware of environmental issues.

CONCLUSIONS

Since the experimental group obtained a higher performance level compared to the control group during the posttest, the intervention enhanced the performance of the former group. Further, the intervention implemented in the experimental group was effective in enhancing inquiry skills of the students particularly on explanations based on evidence, communicating, and justifying explanations. The above findings yield numerous conclusions regarding the effectiveness of SSIbased instruction in impacting student learning. While these conclusions and accompanying implications and recommendations may prove useful in designing future studies and considering practices in SSIbased instruction, the limitations of this study prevent any meaningful or accurate generalizations to the broader population

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WHAT IS STEM? A COMPARATIVE CASE STUDY OF ELEMENTARY STUDENTS' STEM CONCEPTIONS BASED ON WHETHER THEIR SCHOOL HAS A STEM FOCUS

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ABSTRACT

National policy documents in the United States have called for an increase in the amount and quality of science, technology, engineering, and mathematics (STEM) education being offered to students, including the development of schools identified specifically as STEM schools. However, consensus around a definition of STEM in education has not been reached, and little research has explored how students understand STEM. To this end, this qualitative, exploratory study used semi-structured interviews to examine 5th grade (10- to 11-year-old) students' understandings of STEM and compared the STEM conceptions of students attending an elementary school with a STEM focus to those attending schools without this explicit STEM focus. Our findings suggest that elementary students have limited views of what STEM means and that students attending the STEM school conceptualized STEM differently than students attending schools without a STEM focus.

Keywords: *STEM education, STEM schools, student conceptions*

INTRODUCTION

National policy documents in the United States have called for a nationwide investment of time and money into developing quality science, technology, engineering, and mathematics (STEM) education programs to help improve student competencies in STEM and maintain the competitiveness of the United States in the global workforce (e.g., National Research Council [NRC], 2012). Specifically, there has been a call for an increase in the number of STEM schools serving diverse student populations (President's Council of Advisors on Science and Technology [PCAST], 2010). However, there are challenges to implementing STEM in schools, including the lack of a cohesive understanding of what STEM means (e.g., Bybee, 2013; Martin-Paez, Aguilera, Perales-Palacios, & Vilchez-Gonazalez, 2019). For example, Breiner, Harkness, Johnson, and Kohler (2012) define STEM broadly as the shift from traditional, lecture-based teaching pedagogies to more student-centric models, including inquiry and problem-based learning. This definition emphasizes STEM as a pedagogy and is less about the integration of science, technology, engineering and mathematics. Others, however, define STEM as the explicit integration of the STEM domains (e.g., Bybee, 2013; Kelley & Knowles, 2016). This ambiguity has resulted in various definitions of STEM being mobilized at both the practitioner and school levels. While it is not necessary that STEM be defined in the same way in all contexts (Bybee, 2013), it is important to understand how teachers and students conceptualize STEM to better help determine how mobilization of various definitions of STEM may influence these conceptions. In our previous research, we explored teachers' conceptions of STEM (Ring, Dare, Crotty, & Roehrig, 2017) and how teachers' conceptions of STEM are reflected in curriculum writing (Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018*)*. We found that teachers hold varied conceptions of STEM and that these conceptions are enacted in curriculum writing. Much of the student-centered STEM research has focused on students' interest and motivation in STEM (e.g., Chittum, Jones, Akalin, & Schram, 2017; Shahali, Halim, Rasul, Osman, & Zulkifeli, 2017), and very little research has explored ways students conceptualize STEM education. With that in mind, this study aimed to answer the research questions: *1) How do elementary students conceptualize STEM education?* and *2) How, if at all, do elementary students' STEM conceptions vary based on whether they attend a STEM-focused school or a school without an explicit STEM focus?*

THEORETICAL FRAMEWORK

The theoretical grounding for this study comes from the situated cognition framework (Brown, Collins, & Duguid, 1989). This framework, also known as situated learning, suggests that social, cultural, and contextual factors influence the learning that occurs in a specific space. Learning and cognition are fundamentally situated and cannot be separated from the way the learner experiences the learning environment (Brown et al., 1989). In this study, the students' conceptions of STEM are influenced by the experiences and interactions they had with STEM within their unique environments (e.g., their schools, peer groups, homes, etc.).

METHODOLOGY

Research Design and Context

This work employed a comparative case study design (Yin, 2014) and was contextualized within a small school district in the Midwestern United States. Elementary students' conceptions of STEM represented the case in this study, and comparisons were made between students attending Marquette, a STEM-designated elementary school, and the three other elementary schools without STEM designations within the same district (all school names are pseudonyms). The school district included approximately 5,000 students, 17% of whom were students of color. The framework guiding the district's vision for STEM was similar to that of Breiner et al. (2012), and STEM was defined as a pedagogy with a strong focus on inquiry and problem-based learning. Prior to becoming a STEM school, the teachers at Marquette had attended several professional development sessions guided by this framework. At the time of the study, the district was in the process of converting to an all-STEM district, with plans to convert the remaining three elementary schools to STEM schools in the coming years. This provided a rich environment for comparing elementary students' conceptions of STEM within the district.

Data Collection and Analysis

Semi-structured interviews were conducted with 5th grade (10- to 11-year-old) students attending the four elementary schools within the aforementioned school district. The interview included openended questions specifically related to STEM such as: What do you think of when you hear STEM?; How do you know when you are doing a STEM lesson?; How do science, technology, engineering and math fit together?; How do you feel about your ability to do well in STEM; and Why is STEM important? Additionally, the students were asked questions about science, technology, engineering, and math separately (e.g., How do you feel about science?). The semistructured nature of the interviews provided consistency between the interviews while allowing for follow-up questions related to students' comments and/or interests. The interviews were held in school-specific groups of 3-4 students and lasted approximately 25 minutes. All interviews were audio recorded and later transcribed.

Qualitative analysis was used to understand students' conceptions of STEM education. Transcripts were analyzed by the first two authors using inductive coding methods originating from grounded theory techniques (Glaser & Strauss, 1967). Using the software Dedoose®, one transcript was openly coded by the authors to identify initial codes and assure calibration in their coding (Wasser

& Bresler, 1996). After developing an initial codebook, the authors coded the remaining interview transcripts, adding codes as necessary. Discussion between the authors helped to refine the codes, and constant-comparative methods (Corbin & Strauss, 2015) were used to collapse the codes into themes. Cross-case analysis between students from Marquette (n=40 students) and the three nonSTEM-focused schools (n=85 students) was conducted to identify similarities and differences between students' conceptions across schools.

FINDINGS

Student Conceptions of STEM: All Schools

Analysis of student interviews revealed that there were similarities in the way students from all of the elementary schools conceptualized STEM, regardless of whether their school had an explicit STEM focus. Students tended to think of STEM as synonymous with the separate domains of science, technology, engineering, and mathematics. Students equated science with experiments and activities, saying things like, "[When I think about science,] I think about experiments...using liquids and gas and doing experiments." Technology was most often conceptualized as digital technology (e.g., phones, iPads, computers). Students thought of engineering as being equal to building, making comments such as, "I like engineering because you get to build stuff" or "I think [engineering is] cool because you can build a lot of things and you can make robots and machines that work for you." Mathematics was polarizing; students either liked it or did not like it. However, even students who did not like math tended to like the math games they played on their iPads.

Students from all of the elementary schools felt that STEM was important for their future in several ways. Students talked about STEM as a way to improve life in the future, saying things like "[STEM is] basically the future of us as humans because it actually makes our lives better. Instead of using all these non-renewable resources, we can find resources that'll never run out...to make our world better." They also felt that STEM would help them succeed in school or secure jobs, saying things like, "[STEM] is important because you'll need to learn this stuff if you want to have a job in the future."

Comparison of Conceptions: STEM School vs. Non-STEM-Focused Schools

Analysis of student interviews revealed differences in how students from Marquette and students from the non-STEM-focused schools talked about STEM. When first asked about STEM, students from the non-STEM-focused schools referred to STEM as a part of a plant, saying things such as, "I think of plants - that's the first thing that pops in my head," or "I think of a flower stem." Other students from the non-STEM-focused schools expressed uncertainty about what STEM was. Conversely, students from Marquette were able to talk about STEM beyond just the acronym. When asked what they thought of in relation to STEM, they referred to teamwork, hands-on activities, creativity, and fun. Students at Marquette also referred to grit in the face of STEM challenges, the idea that resilience and learning through failure is important. For example, one student explained, "Usually when we're doing something like that [difficult], our teacher tells us to never give up - that's how I know if we're doing STEM." Students from Marquette also understood that all of the domains of STEM were important, and, even though they first identified STEM as the four separate domains, they also made connections between them. One student explained:

> Well, they all connect to each other. We had trout in our classroom, and that connects with science because it's an animal. Then we used math when we tested the pH, the ammonia, the nitrate and the nitrite levels, using mean, median, and mode. For engineering, if there were to be oil in the trout water, we created how would we take that out. And the technology part...we used a trout cam so at home you could go on your computer and see what the trout were doing. So that's why I think it shouldn't be some random letters all mixed up because STEM, it works together in that way that all of it is connected...they all fit together.

Students from all schools described STEM as activities (e.g., projects, labs, assignments) that they associated with school. However, students from Marquette identified school activities that integrated all of the STEM domains (similar to the example above.) This is in contrast to students from the non-STEM-focused schools who tended to explain that "in school they teach things like science, technology, engineering and math," keeping the domains of STEM separate. Students from Marquette also suggested that they experienced STEM outside of the classroom, explaining that they had done STEM on field trips, in the outdoors, or at home. One student commented, "I do [STEM] in my grandpa's workshop. Sometimes, if there's something old or something, we'll take it...apart and look at it."

Most students had limited views of who does STEM, often referring to science, mathematics, or engineering teachers as those who do STEM. However, many students at Marquette felt STEM was a part of everything people do, from "working at your jobs" to "taking care of your money" to "understanding the world around you." This was in contrast to students from the non-STEMfocused schools who felt that STEM was primarily done by STEM professionals outside of school.

DISCUSSION AND LIMITATIONS

Similar to other research findings (e.g., Breiner et al., 2012), this study revealed that students have limited understandings of STEM and tend to view STEM as the separate domains of science, technology, engineering, and mathematics. However, students attending a STEM school were able to identify connections between the domains of STEM, while students attending schools without a STEM focus were less likely to recognize these connections. Additionally, students at the STEM school acknowledged the importance of STEM in their lives and were better able to identify examples of STEM in the real world. These important differences indicate that the STEM school was more successful in helping develop students' understandings of STEM in specific ways than non-STEM-focused schools, an anticipated and desired outcome (e.g., NRC, 2012; PCAST, 2010.) This study is limited to one school district, and it will be important for researchers to extend this research to better understand how students conceptualize STEM in other contexts and to identify the effects of attending STEM schools on students' understandings of STEM.

CONCLUSIONS AND SIGNIFICANCE OF THE STUDY

STEM education is an education reform effort that has the potential to impact students in positive and significant ways. This case study allowed several meaningful implications for STEM education to emerge. First, understanding students' conceptions of STEM is important for teachers implementing STEM in their classrooms. Understanding these conceptions (and misconceptions) will allow teachers to modify their instruction to highlight important aspects of STEM in an effort to better help students develop their understanding of STEM. Second, understanding students' conceptions of STEM will allow teacher educators, district administrators and professional development facilitators to better support teachers in their understanding and implementation of STEM. Finally, there is a need to better understand how the STEM frameworks that guide a school or district influence students' understanding of STEM. Future research will focus on this as well as how teachers' conceptions of STEM play a role in shaping students' conceptions of STEM.

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EFFECTS OF COMPUTER SIMULATION ON FEMALE STUDENTS' MOTIVATION AND ENGAGEMENT IN PHYSICS LEARNING IN TANZANIA

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ABSTRACT

In Tanzania, gender inequity, access parity, poor training in study skills and poor foundation in the sciences from primary school level influence the academic gender performance in learning. Differences in attitudes, participation, motivation and achievement have impacting on gender especially females in science subjects and physics in particular. As a result of this learning becomes unproductive and not meaningful as it encourages rote learning. Research suggest use of instructional strategies that promote cognitive conflict in learners experiencing inadequacy in their existing knowledge. New information could be acquired or added to the existing knowledge or information(Posner, Strike, Hewson, & Gertzog, 1982). Studies reveal computer simulations to be among more productive experience over traditional instructional strategies(Chen, Pan, Sung, & Chang, 2013; Tao & Gunstone, 1999; Tao & Gunstone, 2017; Trundle & Bell, 2010). There appear to be scarcity of empirical research in the Tanzanian context demonstrating the effect of computer simulations on motivating females in physics learning. *'To what extent does computer simulation motivate and enhance female students' engagement in physics learning?'.* Two hundred and sixty five(265) form two secondary school students (13 – 16 years) participated in the study. Mixed methods in data collection was used and preliminary findings are reported. Questionnaires, focus group discussion and semistructured interviews with both analytic techniques including descriptive statistics and thematic scoring and coding employed. Results from the study shows statistically significant($p<0.05$) scores in self-efficacy and self confidence in learning after computer simulation is used, indicating that females generate conceptual conflicts and as a result, promote conceptual change. These results provide insights that self-efficacy and self-confidence would promote engagement and innovation in female's physics learning. Further corroborated with responses from interview excerpts might be an indication that after computer simulation female students demonstrated understanding and mastering physics content that enhanced their motivation and willingness to engage in learning physics. Further research results would be valuable in extending upon this work.

Keywords: *conceptual change,* motivation, *engagement, computer simulation, selfefficacy, self confidence in learning*

INTRODUCTION

Over the last six decades, much of the research in science education and cognitive science worldwide has focused on students' prior knowledge and conceptions primarily in the natural sciences. During this period many studies concentrated on investigating the development of students' pre- instructional conceptions regarding science concepts. Because of these studies, science educators (e.g. Driver & Easley 1978) as cited by Vosniadou, (2012) became aware that students bring to science learning, frameworks that are robust and often difficult for teachers to change or eliminate. The results from these studies guided science educators to regard learning as the restructuring of existing knowledge and the constructing of new models to fit new understandings and experiences (Chaimala, 2009). As argued by Greeno et al. (1996) learning is understood to be a constructive process of conceptual change, that involves reorganization of concepts in the learner's canonical science knowledge and growth in cognitive abilities such as problem solving strategies and metacognitive processes.

Various strategies have been employed to ensure that science learners construct canonical scientific knowledge Hudson, (1998). Experience have found that learners' acceptance of new concepts has been challenged and sometimes influenced by social pressures. Evidence shows that social and cultural contexts play a significant role in changing learners' conceptions. These include but not limited to gender, ethnicity, religion and politics. Hatano and Inagaki (2003) and Hodson (1998) report lack of attention to the gender of learners.

As reported by Chambers and Andre (1997) prior to the 1990s, research had not examined the relationship between gender and conceptual change. Few studies that did include gender indicated that gender played a role in some aspects of knowledge restructuring Pearsall et al., (1997). Pearsall et. al. (1997) revealed different learning styles among males (i.e., meaningful or deep learning characteristics) and females (i.e., rote learning or surface learning characteristics) as a result of socialization that makes them differ in terms of success in complex hierarchical disciplines. Hence, the literature calls for further research on knowledge construction in the natural science (e.g., physics) to find out how conceptual change might meaningfully be mediated among gender groups.

LITERATURE REVIEW

Reports from some of African countries where gender segregation data are available, show that the number of females in science is low compared to the males. The few females who enroll in science subjects register low performance (Ajai & Imoko, 2015) . The literature on differences in gender and performance in science offer different views and findings (Ajai & Imoko, 2015; Ekine & Abay, 1999). Comparable evidence by Ogunleye (2001) from science education reforms of the 1980‘s reveals both pedagogical practice and the presentation of science in many classrooms reflected masculine social and cultural stereotypes. In addition, Ajai and Imoko (2015), Asimeng-boahene (2006), Masanja (2004) and Udousoro (2012) reveal other important factors on differences in gender and performance in science where male students are often favored compared to female students due to cultural factors. The practice results in curricula, pedagogical practices, and classroom organizations that hinder access and retention of females in science education (Udousoro, 2012).

In Tanzania, a number of educational policies and programs introduced efforts to bridge gender gap from primary school to the university level has been in place to address this challenge. Some of them have been to expand access, increase retention and completion rate, improve quality, as well as enhance institutional capacity and management (URT, 1995, Masanja, 2010; MoEVT, 2010 a,b). Even with these efforts, examination reports for the past eight years indicate very slow improvement in the performance of females in physics (e.g., CSEE, 2009 -2014). Confounding problem is the fact that the number of secondary school females taking physics is low compared to males, hence the current gender inequality in physics. Gender inequity and access parity, poor training in study skills and poor foundation in the sciences from the primary school level influence the academic performance of females (MoEVT, 2010a). As revealed by (Sesae, 2011) the experiences in turn influence attitudes, participation, motivation and achievement especially for females in science subjects and physics in particular. This is especially in a classroom situation where the females get confronted with instructions they do not relate to (see Chambers et al., 1997). As a result of this situation, learning becomes unproductive and not meaningful as it encourages rote learning. Employing instructional strategies that promote cognitive conflict would potentially result in females experiencing inadequacy in their existing knowledge; hence meaningful experiences through the process of conceptual change (Novak, 2002). Some studies by Bell and Smetana (2008), Tao & Gunstone (1999), Trundle & Bell (2010) reveal computer simulations to be a more productive experience over traditional instructional strategies in inducing cognitive dissonance by simulating the consequences of students' misconceptions.

Problem Statement

Although many studies indicate the benefits of computer simulation in promoting knowledge construction in physics learning, the review of literature reveals limited empirical evidence in the Tanzanian context specifically on the effect of computer simulations on gender' motivation in learning physics in secondary schools. Examining knowledge construction among students through their participation in physics learning may provide insights on how students' learning is likely to be enhanced through use of current instructional strategies. This research examined different motivation scales towards physics learning. Specifically, this research is guided by the following question: *To what extent do computer simulations motivate and enhance students' engagement in physics learning?*

THEORETICAL FRAMEWORK

This study draws from the perspective of conceptual change by (Posner et al., 1982) that builds on Vygostsky's (1978) theory of social constructivism that views learning as a social activity in which learners make meaning through both individual and social activities. The social constructivism is the result of its development from the earlier theory's limitation to consider the social dimension. According to Driver et. al. (1994) a social constructivist perspective recognizes that learning involves being introduced to a symbolic world. Thus, as socially constructed, Driver et al. add knowledge and understanding in this case including scientific understandings are constructed when learners engage socially in discussions and activities. Employing Driver et al.'s (1989) perspective and linking it with social constructivism, meaning making in scientific learning becomes a dialogic process involving learners - in conversation. Also as stated by Driver and Erickson (2008), learners construct knowledge using their prior knowledge and experiences.

Various constructivist theories have been applied in understanding and interpreting science learning or knowledge construction in science. Conceptual change theory (Posner et al., 1982) is a prominent framework for understanding the learning of science concepts. According to Appleton (1997) the main tenet of constructivist theories is that learners employ existing ideas to make sense of new experiences and information. Under this theoretical examination, conceptual change has been the most significant learning model to interpret students' alternative conceptions. This is because as Kang et. al. (2005) stress, knowing students' alternative conceptions is an essential starting point to develop strategies for introducing new scientific concepts. Embodied by the constructivist ideals, conceptual change model by Posner et. al. (1982), has been key to designing and implementing effective learner centered classroom instruction. The classical approach to conceptual change has over the decades guided research and instructional practices in science education (Vosniadou, 2012).

Within the classical approach, cognitive conflict has been key to achieving conceptual change (Vosniadou, 2012). Studies Baser (2006) reveal that students' alternative conceptions that are grounded in everyday experiences are resistant to change. Baser (2006) has cited physics as one of the areas where most of the students' prior knowledge remains unchanged despite receiving instruction aimed at eliminating their alternative conceptions.

Students' socio-cultural identities including gender are shown to affect the way they learn (Hodson, 1998). The socio-cultural practices in which learners' experience learning can be interpreted as different ways of "seeing things" into what Claxton (1990) terms "stances" which tend to guide individual students and their group activities. As deduced by Nashon, S. M., & Adler, (2012) adherence to the stances becomes the makeup that guides students' learning behaviour in such a way that confronting students with information contrary to their belief or theory may partially modify or resist to change. This presents a challenge not only for the conceptual change family but also science educators in terms of research and practice in teaching and learning science. A need to create a context of social interaction where the learner experiences inadequacy or instability of his/ her current belief or theory is required.

Therefore employing constructivist teaching strategies (e.g., Chen et al., 2013; Tao & Gunstone, 1999) coupled with computer simulations to induce cognitive dissonance (Kimmons, Liu, Kang, & Santana, 2012; Tao & Gunstone, 1997; 1999).

RESEARCH DESIGN

This is an interpretive case study (Merriam, 1998) mixed method design in which quantitative and qualitative results are reported for the study. The physics content on motion in a straight line was selected from the Tanzanian physics syllabus (MoEVT, 2010). Nine classes of form two students (N=265), male (n =154) and female (n=111) students from four private secondary schools were selected to participate in the study.

It was piloted to a sample of 50 students for the validity of the instruments. The questionnaire was then administered prior to the use of computer simulation and then after. The physics simulation used software that included among others use of computer graphics and video games. The software was adapted from Colorado University and integrated with physics content topic on motion in a straight line from the Tanzanian syllabus. Students used the results obtained during simulation for the distance, velocity and time to compare with the calculated results in the classroom using the three key equation of motion.

RESULTS AND DISCUSSION

The Cronbach's alpha (α) reliability measure of the entire questionnaire was 0.80 prior to intervention and 0.86 afterwards for whereas for each reported subscale it ranged from 0.66 to 0.76 for before scale and 0.67 to 0.77 for after scale (Table 1).

Table 1: Cronbach (α) for the before simulation (BS) and the after simulation (AS) (N=265) in the subscales

Range	Scale	
	SE	SeCL
BS 0.66 0.76	AS 0.67 0.77	

Note: BS: before simulation: after simulation(AS) for self efficacy(SE), self confidence in learning (SeCL)

A paired t-test showed a significant change in Self efficacy (SE) scores for females before simulation (M=3.51, SD=0.67) to after (M=3.87, SD=0.67), t (110) =5.01, p<0.05. The mean increase in self-efficacy scores for females is -0.36 with a 95% confidence interval (CI) ranging from -0.51 to -0.22. The eta-squared (η^2=0.19) indicated a large effect size.

The attribute of learning on self confidence in learning (SeCL) showed a remarkable increase in the mean score for females from (M=3.06, SD=0.51) to (M=3.77, SD=0.51) with the difference -0.71 with a 95% confidence interval ranging from -0.85 to -0.57, showing a significant at t(110) = -10.14, p<0.05 and represents still a large effect size, η^2=0.49.

The overall preliminary analysis in table 2 shows a highly significant increase in the mean scores in self-efficacy and self confidence in learning for females score from (*M*=3.28, *SD*=0.45) to (*M*=3.82, *SD*=0.46) the difference of -0.54 with a 95% confidence interval ranging from -0.65 to -0.43, significant at $t(110) = -9.73$, $p<0.05$ with a large effect size, $\eta^2=0.47$.

Table 2: Paired Samples test on effect of physics learning before and after computer simulation for females

Gender			M	SD	SE Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2tailed)
	SE	BS - AS	-0.36	0.76	0.07	-0.51	-0.22	-5.010	110	.000**
Female	SeCL	BS - AS	-0.71	0.74	0.07	-0.85	-0.57	-10.139	110	.000**
	Overall	BS - AS	-0.54	0.58	0.055	-0.65	-0.43	-9.73	110	.000**

**$p< 0.05$

Table 3 on Pearson results there exists a relationship between the motivation constructs to after than before computer simulation For example, a strong and significant correlation (r =0.41; p<0.01) between female students believe in their own ability to perform well in physics learning tasks with how exposing them to computer simulation activities provided an opportunity for them to get a richer experience that satisfied their learning. Similarly, female students believe in their own ability to perform well in physics learning tasks showed a weak relationship but significant correlation (r = 0.21; p<0.05) with the confidence developed by students after using computer simulation that enhanced skills and knowledge in performing physics tasks. In line with qualitative findings female students aired their voice how confidently going through computer simulation recall from what has been learnt practically and not anymore understanding from the surface.

Table 3: Pearson correlation analysis of the motivation scales before and after computer simulation among female students

Pearson Correlation (significance two-tailed)	SaCL^{b,a}	SeCL ^{b,a}
SE^{b,a}	0.13	0.13
	0.41**	0.21*

Notes: Self Efficacy (SE), satisfaction with current learning (SaCL), and self confidence in learning (SeCL) before$^{(b)}$ and after$^{(a)}$ simulation. *$p< 0.05$, **$p<0.01$.*

The preliminary findings provide insights that differences in motivation belief in physics learning exist among males and female students after simulation. The paired t-test and the Pearson correlation that were used to determine the relationship between the motivation constructs shows a significant difference(p<0.05) in scores before and after computer simulation is employed among females (see table 4&5). There is a significant change in mean score from a pre- to post simulation for a, associated with increase in females' perception after participating in simulation activity as shown on table 4. Tuan, Chin, Tsai, & Cheng (2005), revealed that an increase in student's self-efficacy after simulation is on students believe they have, on capability of accomplishing learning task. Furthermore, empirical evidence from Pintrich, Marx, & Boyle, (1993) indicate that self-efficacy as a motivational belief influence students' cognitive engagement and in turn influence conceptual change. What is observed is that computer simulation encouraged interaction among groups which they had not experienced before. Also, the external factors such availability of resources in this case computer simulation, climate of the classroom where students interacted with one another as well as with computer. It enhanced their understanding and mastering of physics concepts which in turn helped them begin develop the skills for achieving required knowledge. The sentiment from student on recalling what has been learnt practically made her understanding no longer on the surface suggests that computer simulation as an instructional strategy set a premise that female students were perceiving things differently from their original point of view(Nashon, S. M., & Adler, 2012). To recall and understand is a clear indication that they were able to make connection between the new understanding of concepts from what was already existing and was relevant(Pearsall et al., 1997). What can be extrapolated from the above is that, the context of social interaction where these females experienced inadequacy or instability of their current belief has a contribution to these results.

CONCLUSION

The preliminary results from the secondary school in Tanzanian context predicts motivation belief as a source of conceptual change for female students, but this may need further attention. Results are indicative that computer simulation as an instructional strategy provide opportunity for female to develop motivation in science learning and has the potential to engage students especially females to contribute to conceptual understanding of their physical world.

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RESILIOCENTRIC ENGINEERING FOR E-STEM EDUCATION AND HOW TO LEAD STUDENTS TO ENGAGE IN THE ACTIVITIES

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ABSTRACT

Increased awareness about the effects of climate change along with myriad impacts from environmental degradation of the ecosphere have raised serious concerns about our collective future on planet Earth. Research in STEM education focused on the environment (E-STEM) offers an important pathway toward envisioning and enacting a viable and sustainable future for the next generation. This paper proposes a perspective that closely examines the technology component of E-STEM education through a Nature of Technology lens. After defining the role of technology in STEM education and discussing different views of technology within varying environmental ideologies, we claim that engineering activities in E-STEM education should equip learners to contribute to the development and use of technologies that are environmentally friendly and ultimately suitable for achieving Sustainable Development Goals (SDGs).

Keywords: *nature of technology, environmental ideologies, resilience, SDGs, systems approach*

INTRODUCTION

The primary focus of this paper is the role of technology as the "T" component in environmental STEM (E-STEM) education. In particular, the role of the technology component in E-STEM education has not been widely discussed in the research literature, especially with regards to the implementation of classroom activities, even though advocacy and support for STEM education are well established (NRC, 2006; NSB, 2007), and integration among STEM areas of learning have been examined (Honey, Pearson, & Schweingruber, 2014). In this paper, we claim that environmental ideologies should be given careful consideration when designing student learning activities focused on engineering. Further, we offer a two-pronged approach to serve as a scaffold to support the ongoing work of educators committed to E-STEM education.

Notably, the U.S. vision for science education captured in the *Next Generation Science Standards* (*NGSS*) envelops science, technology, society, and environment (NGSS Achieve, 2013). According to Appendix J of the NGSS, many possible applications of disciplinary core ideas can be demonstrated through the complex interdependence among science, engineering, and technology in relationship to natural world. In addition, the appendix highlights the importance of the teacher's role to invite students to learn about the interactions among STEM components. In *A Framework for K-12 Science Education* (NRC, 2012; *Framework*) and the *NGSS* (2013), however, technology is defined as products which are the result of engineering. Then too, the core essence of technology usually has been interpreted as computer-use or just something made (Clough, 2013; *NGSS* Appendix I, p.1) with an echo of calling for coding education to foster future engineers.

Perspectives on the nature of technology described in previous national reform documents (AAAS, 1989; NRC, 1996) appear to have been replaced.

On the other hand, Bybee (2013) has suggested that global challenges and changing perceptions of the natural environment are important differences that distinguish current STEM education reform efforts from prior ones. He also suggested opening the development of STEM approaches to seek and support visions for an environmentally sustainable world. In addition, Hutton and Dixon (2016), with reference to ideas from UNESCO & ILO (2002), proposed the importance of technical and vocational education that regards STEM education as a tool for promoting environmentally-sound sustainable development. Taking these notions into account, how can we develop STEM education approaches that support environmental learning through careful attention to the technology component of STEM?

To develop the general and descriptive theories for E-STEM development, this paper discusses the role of technology in STEM education, how to broaden the nature of technology to encompass perspectives on the environment, and how we can integrate those ideas into STEM education for students by translating the way SDGs are distributed into student-centered approaches. Thus, this paper is a position paper which claims that we should consider the nature of technology when we develop E-STEM lesson plans by guiding students' thinking about effects of human technology on nature through considering environmental ideologies.

NATURE OF TECHNOLOGY AND ENVIRONMENTAL IDEOLOGIES

Shume (2017) produced a conceptual framework for ecological world views that examined ontological, epistemological, and axiological differences to form four dimensions: egocentrism, technocentrism, ecocentrism, and resiliocentrism. She mapped socio-ecological thought based on environmental ideologies about wolf hunting onto her framework (Figure 1). This example can also serve to explain how technologies (human activities) impact the relationships between nature and human beings.

In Shume's framework, egocentrism utilizes technology to protect human property by destroying or devaluing wolves (nature). Technocentrism manages wolves (nature) as an instrument for economic development of natural resources. Ecocentrism protects wolves (nature) sometimes to the point of disabling corporate technologies that threaten them. Last, resiliocentrism regards human-nature relationships as inextricably intertwined thus obligating humans to manage ourselves with an intent to decrease risks associated with system disturbances. Resiliocentrism recognizes nature's key roles in both natural and social systems.

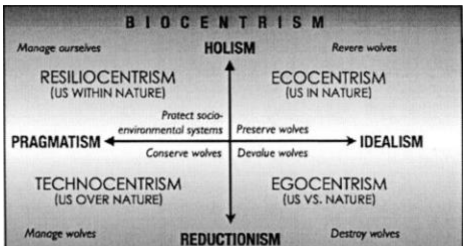

Figure1. Environmental Ideologies Mapped with the Wolf-hunting Case

Replaced Purpose of T with Engineering

When we look at the history of establishing defining concepts for engineering in U.S. national standards, we see that the concepts of engineering have been studied by the National Research Council (NRC, 2010), following ITEEA's work of defining technological literacy (ITEEA, 2000/2002/2007). Notably, both included the idea of engineering design as the main concept students learn.

Can we take this as the replacement of the purpose of technology with an engineering one? If yes, they are replaced because of the definition of technology and engineering have been clearly stated (NRC, 2012, p.202). In these definitions, technology became a modification of natural world. Thus, can technology be interpreted as just a result of engineering? No, the definition also shows the extent where engineering can be applied. This extent lets us know how we modify the natural world through iterative cycles, and vary objects, processes, and systems. Thus, those definitions seem to show that E, T, and even S are interwind and have connected characteristics by nature. In the NGSS, Scientific Inquiry has been replaced as Scientific Practices which envelop separate learning objectives such as contents, processes, and competencies within the combined term. This understanding is not in conflict to past perspectives which defined science as an entity that included whole STEM disciplines (AAAS, 1989).

MANAGING ENGINNERING CAN LEAD THE LEARNING OF TECHNOLOGY

Framework for Giving A Context to SDGs and The Bottom-Up Approach

To support a student-centered approach, starting the curriculum from students' definition of the problem is an important first step and suitable for project-based learning. However, environmental education often starts from an environmental problem which is unfamiliar to the students. Possibly, to decide the goal or objectives for environmental education for diverse purposes, it was too abstract and broad such as awareness, knowledge, attitude, skills, evaluation ability, and participation (UNESCO, 1975). Then too, those goals cannot be connected to the students' real learning in their classes. We can observe a common problem in integrative STEM class preparation: that although we need to define exactly what we teach for class preparation and standards alignment, student-centered learning begins from students' interests and not solely from preparation of that discipline.

Emerging efforts for SDGs are seeking to solve this problem by using a bottom-up approach with the broad goal of sustainable development (Kanie, 2017). Just as all students are different from each other and they set diverse problem for their projects, all countries engaged in SDGs effort have diverse circumstances and specific problems for the sustainability. Thus, SDGs are provided to the world but each country must decide how to achieve these goals. In this sense, the SDGs do not limit the context, but rather allow for multiple entry points through the contextual diversity in each country and every student.

Translating Framework For E-STEM Approaches

Table 1 shows the ideas described above within an educational psychological framework. We can determine themes, context, construct, base of the construct, and the students' performances from STEM practices. Before we implement an E-STEM lesson, we can only decide the theme for student learning. Even context can be different in different classes. Both context and base of the construct can be revealed from the process of qualitative coding. Coding, unfortunately, cannot produce directly generalizable constructs, because this framework based on an assumption of contextual differences and the need to define the extent of generalization and application though additional research. This step is also needed to connect practical research projects to theoretical ones while establishing partnerships, although we can postulate the constructs before collecting data from students.

Table 1. Framework for Supporting Student Diversity in STEM Goal Development

Construct	Object of interest the study is trying to reveal	Broad Generalizable ↑
Theme (s)	SDGs or related broad themes of Environmental Ideologies	
Context	Different classes have different contexts but similarities also can be coded up from students' performances	
Base of the Construct	Coded up from the students' performances	
Students' Performances	Start of the bottom up approach from any source of performance related to an E-STEM lesson	Specific Divergent

Thinking Under Environmental Ideologies

How can we foster the ideas of environmental ideologies as the theme of E-STEM implementation? As we discussed above, recognizing environmental ideologies as a component of the nature of technology offers a compelling path forward. We can propose ideas on an axiological axis and apply them as the philosophical background within which students engage in engineering activities while recognizing anthropocentric engineering and ecocentric engineering.

Anthropocentric engineering focuses on the development and use of technologies to solve environmental problems in ways that privilege human needs and wants over those of nonhuman entities. Conversely, ecocentric engineering seeks to solve environmental problems in ways that regard humans as an integral part of an interdependent web of relationships in nature. As Shume's ecological world view framework (2017) and Corbett's (2006) spectrum of environmental ideologies show, a range of anthropocentric and ecocentric orientations exist. Nonetheless, anthropocentric and ecocentric engineering can be broadly contrasted based on ideological assumptions underpinning how engineering problems are framed and how resulting technologies are developed and applied.

Holling (1973) stated that resilience and dynamic stability are important properties of natural ecosystems. When we consider the notion of resiliocentric engineering, idea of resilience itself can become a key of E-STEM education as the Theme on Table 1. Resilience can also be interpreted as engineering resilience and distinguished from ecological resilience.

According to Hollnagel et al. (2006), "the essence of resilience is therefore the intrinsic ability of an organization (system) to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap and/or in the presence of a continuous stress". Although this definition is different than Holling's 1973 version, it shares the fundamental notion of the functioning in the system adjusting itself to sustain required operation under expected or unexpected conditions (Folke, 2010). The shift in definitions broadens the scope of resilience. Resilience is more than being able to recover from threats and stresses,rather it involves being able to perform as needed under a variety of conditions. Thus, as stated in Shume's framework in Figure 1, resilience suggests managing ourselves, and the idea of resilience offers an alternative approach to the efficiency-driven, techno-centric world (Mitchell, Griffith, Ryan, Walkerden, Walker, Brown, & Robinson, 2014).

Resilience, as we refer to it here, however, may not be the opposite side of techno-centrism nor failure or breakdown. Rather, "things that go wrong happen in (more or less) the same way as things that go right" (Hollnagel et al. 2006). This notion also aligns with the idea of sustainable development and suggests how we can provide the theme for students during implementation of ESTEM learning activities**.**

TOWARD A STUDENT-OWNED PROBLEM DEFINITION IN E-STEM IMPLEMENTATION

Synthesizing Human Needs and Ecological Needs

In a theoretical manner, we can anticipate the difficulties students encounter when learning the importance of ecocentrism with emphasis on the idea of resilience. As we stated above, allowing students to choose their own problem to investigate is key for student-centered approaches in E-STEM teaching and learning. However, how can we lead students to think about engineering problem solving in a resiliocentric manner?

One way we can apply the big picture of ecological engineering as the theme for students is to focus on their definition of engineering problems. Mitsch and Jorgensen (2003) suggests 1) it is based on the self-designing capacity of ecosystems; 2) it can be the field (or acid) test of ecological theories; 3) it relies on system approaches; 4) it conserves non-renewable energy sources; and 5) it supports ecosystem and biological conservation. Translating those concepts into classroom activities focusing on the idea of resilience, students 1) engage in the activities to understand possible capacity of an ecosystem; 2) test the theory of ecology on the field (or acid) test; 3) relies on or find out the mean of system approach; and 4) develop an solution to conserve non-renewable energy source and 5) to support ecosystem and biological conservation.

Resilience Comprises Changing Over Time

To support those activities and resulting learning outcomes, a systems approach can serve to scaffold establishing the theme within a student-centered engineering problem defined with a lens of resiliocentric engineering. Particularly, concepts related to changes in systems over time include more specific concepts that will lead to an understanding of resilience.

A systems approach can be characterized by five key concepts: parts and objects, interaction and relationships, subsystems, input and output, and changes over time (Landers, Naylon, & Drewes, 2002). Landers et al. list the supporting concepts for understanding a system's change over time as listed in Table 2.

Table 2. Supporting Concepts for Change Over Time

Accumulation, Climate, Cycles, Diversity, Evolution, Extinction, Geomorphism, Ideas and concepts, Innovation and invention, Knowledge, Migration, Mutation, Population, Probability, Rate, Redundancy, Scale, Species, Threshold

Extracted from Landers et al. (2002), p.11

As concepts are learned in STEM education, these ideas can also serve as important cross-cutting concepts alongside other in *NGSS*. Thus, these concepts do not only support students' understanding of system change, but also functioning to connect S+T+E+M as an integral component of learning within an entire unit of study.

As explained above, we offer two lines of inquiry to engage students in resiliocentric engineering problems, radical system change, as entry points into E-STEM course work. First, considering the line of inquiry stemming from conceptions of technology, engineering resilience may support anthropocentric orientations to human life styles and prevent radical change in society. In this sense, society itself also can be seen as a type of technology. After students recognize technological impacts on nature, they can explore ecological resilience and sustainability. Thus, there is a deep need to provide multiple opportunities for students to recognize the role technology plays within natural systems. As a second line of inquiry, therefore, we can foster student learning about concepts supporting a sophisticated understanding of system change. By targeting the learning of those concepts where technology supports resilience, we may lead students to understand resiliocentric engineering for ecological resilience.

CONCLUSION

In this paper, we argued that environmental ideologies and their application should be an important part of E-STEM education. To lead students to define resiliocentric engineering problems, the framework for defining context and the base of construct from the students' performance (Table 1) and the supporting concepts for understanding system change over time (Table 2) can serve as a supportive framework for designing for E-STEM learning experiences. Alone, these ideas will not suffice because of the need to resolve teachers' difficulties of delivering technology. Thus, we need additional development of related supportive frameworks and further research for this purpose.

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RE-STORYING THE M IN STEM: HOW MATHEMATICS EDUCATION MIGHT/CAN SHAPE STEM AND STEM EDUCATION

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ABSTRACT

This paper explores alternative stories for exploring and re-imagining the role or place of mathematics in STEM education. Using narrative and dialogic inquiry as authors and researchers we share three stories as examples of changing the story of STEM education. Our first story draws upon the context of the science, mathematics, and technology involved in fish farming to prompt us to listen to and ask mathematical questions that challenge the need for such farming in the first place. Our second story considers a re-storying of mathematics in STEM from a tool for science to STEM as a place for learning and teaching mathematics. Finally, our third story, explores indigenous earth-centric values and spirituality as another storyline for STEM education. Together these stories offer the field additional ways of both re-imagining mathematics in STEM and re-imagining STEM education itself. As such our paper speaks to a profound changing of the story of STEM education to make space for STEM education to become something different.

Keywords: *mathematics in STEM, indigenous perspectives, STEM education*

INTRODUCTION

STEM based curricula and educational programs galore—maker spaces, inventioneering labs, video game design, digital arts, aerospace, coding, robotic camps, and in the US, National STEM/STEAM Day. Never ending, today's demand worldwide for STEM skills in the workplace and projected growth for new STEM careers sends a clear message about what education *should* be doing to focus on 21st century skills, increase participation of marginalized groups, prepare for today's and future technologically driven jobs to equip students with a competitive edge for them to contribute to the ever-increasing digital economy. As a result, the strong presence and consequent privileging of STEM makes it difficult to notice, much less hear other stories which are connected to STEM education, or consider how they can inform and advance the field.

In this paper we share our research, discussing alternative stories we see as directly related to STEM education, and exploring key questions prompted by them such as: 1) How does the act of listening to other stories or story-lines create space in which to expand our thinking about what STEM education could be? 2) In what ways can mathematics education contribute new possibilities for STEM education?

Through the contexts of robotics, architecture, and a fish hatchery we share stories and story-lines that diverge from current ones in the field, present insights, and pose implications which we see as vital to enabling more diverse and generative forms of STEM education.

RELATED LITERATURE

Collectively, we situate our research within critical, ecological, and indigenous frameworks. While each framework is distinct from the others, together they offer theoretical perspectives that not only enable our understanding of narratives and practices which dominate STEM education today, but make necessary, the inclusion of other stories and practices for the innovation of research and pedagogy.

More often than not, much of what we conceive as traditional or common-sensical engagement in education, educational reform included, serves only to further entrench issues that are in need of being challenged. As a result, we continue to oppress schools and society. From a critical perspective then, educational change requires not only altering the very ways in which we think and act, but doing so demands questioning, confronting, and disrupting our most deep-seated conventions in favour of alternative possibilities which may well be unconventional and controversial.

There is growing interest and commitment among educators to examine the impact that traditional and common-sensical issues within STEM education have on schools and society at large. Current arguments focus on apolitical approaches to STEM curricula that frame the development of human capital as promoting engineering design and 21st century skills (Bowers, 2016; Wolfmeyer, Lupinacci, & Chesky, 2017;); eurocentric (i.e., sexist, racist and neoliberal) economic policy where STEM education will ensure corporate profit, infinite growth of STEM fields, and sufficient human resources; and how STEM as discourse creates further separation between the STEM disciplines and the humanities, and generates deeper divisions and dichotomies.

Many of these acts deemed educationally and culturally oppressive have also been argued as directly connected to the increasing devastation of the earth and its natural systems (Bowers, 2016). For example, privileging the digital economy can be seen as silencing alternative systems of education and society in which non-money-based practices foster more sustainable and ecologically just relations with the earth. Neither culture nor education nor environment nor issues associated with them can be conceived as separate from one another. Rather, each is fundamental to and dependent upon one another as dynamic and relational ecologies.

From an ecological perspective then, the need for STEM education to be more and different than simply increasing human capital and corporate profits focuses on addressing cultural and environmental concerns that at the same time, resist cultural colonization (e.g., Bowers, 2016; Glanfield, Thom, & Ghostkeeper, 2019; Wolfmeyer et al, 2017). Such efforts are directed toward revitalizing the commons within cultures; that is, promoting intergenerational knowledge and skills that come from mentoring relationships, which are then recursively refined over time through adapting and living in relationship with the land. Examples include agriculture and food preparation as well as developing and making use of technologies that ensure the viability of natural systems.

METHODS

We draw upon narrative and dialogic inquiry as our methods (Clandinin, 2013; Freire, 1970/2000;). Although we are situated across geographical distances we engaged in critical discussion around the relationships of M in STEM through face-to-face discussions when possible, but most often through online video platforms where we could record our conversations for future analysis. Our discussions began with an M in STEM Think-In symposium at a Canadian university and have continued for the past two years. Our critical conversations drew us to engage with and analyze our stories of relationships with mathematics, with STEM, with place and a more-than-human world. We offered our stories to each other, and in so doing began as Clandinin (2013) writes, re-storying and deepening our understanding of how mathematics education is shaped by STEM and STEM education, and how mathematics education could, in turn, shape STEM.

RESULTS

Our results are offered as three stories from various perspectives. Each story explores possibilities for imagining or experiencing another storying of mathematics in STEM education.

Story 1: Using Mathematics to Explore 'What Happened Here?'

Larsen and Johnson (2017) write that the agency of place is "a summons to encounter, dialogue, and relationship among humans and nonhumans who share the landscape" (p. 2). By sharing narratives of mathematics in place, we can open up story-lines to think about what the M in STEM and STEM education might be in the context of relationships with land and issues of justice. We consider the experiences of a Grade 6 teacher at an educational fish hatchery, part of one of our research projects. Using narrative inquiry and walking methodologies we gathered stories of this teacher's experiences and draw upon these experiences to consider opportunities for offering further storylines for STEM education.

Building a fish farm or fish hatchery requires engagement with STEM related fields. Models of salmon lifecycles and study of environmental conditions were needed to acclimate salmon to artificial conditions. Mathematics required includes waterway measurements (depth, current, relationship to rainfall and temperature over time); statistics of fish populations in waterways measured over weeks, months, and years; ratios of fish leaving and returning from waterways; ratio of roe to milt for spawning salmon; survival rates for roe and fry; water temperatures and light conditions for roe hatching; healthy release weight for fry; and comparison of data for species (pink, chum, and coho). Application of these mathematical data, calculations, and models allows for the design of hatcheries that could meet the local goals for environmental restoration, harvest, and species recovery. This includes choice of waterway sites and the design of apparatus for catching and releasing salmon. Methods, tools, and techniques for fertilizing, and raising salmon roe to fry also rely on application of environmentally linked mathematics. Building hatcheries also requires considering concerns such as genetic interactions of hatchery fish with wild fish, comparative ratios of survival rates, and genetic mapping of those who survive. In learning and teaching fish hatchery methods and design, a context for M in STEM education is offered as a place to apply and justify the need for STEM.

Walking along the Mamquam River in BC, it is obvious that the water level is low with very few spawning chum this November. This fall saw record levels of low rainfall. Low fish stock means that the Squamish Nation who have harvested salmon in this area since time immemorial "could not carry out fishing activities for food fish" (Squamish Nation, 2017) in some of the recent years. Fisheries and Oceans Canada currently operates 23 fish hatchery facilities and spawning channels that "release hundreds of millions of juvenile salmon every year to supplement wild stocks and sustain British Columbia fisheries" (Department of Fisheries and Oceans, 2018). Yet wild fish stocks continue to struggle. And growing scrutiny of fish hatcheries suggest hatcheries present significant risks to wild salmon including growing evidence that the DNA of wild and hatchery fish is different (Hume, 2017). This could call for further STEM research and further education of hatchery operations.

Consider another response. Consider exploring with students not only the science, mathematics, and technology needed for building effective hatcheries but exploring why such hatcheries are needed in the first place. We ask, following Greenwood (2013): What happened in this place that requires building fish hatcheries? What is currently happening here? And what are appropriate actions for the future? Mathematics can be used to examine how settler colonization, land disposition for dams, resource management, and overfishing led to decisions to build fish hatcheries. Mathematics can be used to examine questions that explore to what purpose, for whose benefit, and privileging whose perspective do fish hatcheries serve? With these questions students could engage in mathematics that is more than a tool of science and technology but also a tool for questioning ethical use of mathematics in STEM. In this way, mathematics could offer opportunities to shape STEM education.

Story 2: Learning Mathematics with Robotics in a Remote Northern Alberta FN Community
Indigenous people are underrepresented in STEM education and careers St. Jacques et al., (2016) and not immune to the political agenda of economic development and human capital. Battiste (2005) argues that Eurocentric viewpoints consider that indigenous people are frozen in time and do not progress like Europeans. Such eurocentric thought entrenches and bounds binaries (e.g., European and Indigenous) (Wolfmeyer et al., 2017). Rather than considering STEM as a means for developing human capital, or as another measure of difference, perhaps STEM could be an opportunity for teaching differently, specifically for teaching mathematics differently.

Programming robots to move can provide powerful opportunities for learning mathematics that are compatible with Battiste's notions of (2005) Indigenous knowledge. She states that "Indigenous knowledge is an adaptable, dynamic system based on skills, abilities, and problem-solving techniques that change over time depending on environmental conditions" (p.6). Similarly, programming robots to move requires problem solving techniques and skills that are adaptable and dynamic depending on the environmental conditions.

This story takes place at First Nation in rural Northern Alberta with children in Grades 4 and 5 learning mathematics while programming their robots to move. One of the tasks the children tried was programming their robot to follow a regular polygon (triangle, square, pentagon or hexagon). Among many concepts, this task required using decimal numbers to program the robot to move a specific distance of wheel rotations. The class had just learned decimal numbers the previous week, but not one child could summon those learnings for programming. However, when prompted with an image of a number line and conversations of what numbers are between 2 and 3, the children quickly applied decimal numbers for programming. The immediate feedback of whether or not the robot moved to the correct location enabled accurate distance approximations. When the robot did not move as desired, the children were not discouraged. Rather they were quick to try again. They often conferred with their partners and other groups to generate new ideas for solving the problem. The robotics tasks provided almost infinite opportunities for students to test and refine their mathematical skills. By the end of the week, all the children had strong spatial sense of decimal numbers related to how far the robot travelled.

Decimal numbers as part of rational numbers are tremendously important for understanding further mathematics. The robots provided teaching learning opportunities of number that were contextual, realizable, experiential, engaging, and meaningful. The experience was also positive and enabling. Compatible with Battiste's (2005) notions of Indigenous knowledge, the robotics learning environment enabled the children to iteratively deepen their programming and spatial sense of number to problem solve various challenges. Their knowledge was adaptable and dynamic in response to the requirements of the task. In this instance, STEM was useful for helping children deepen their mathematical skills and number sense. Rather than being a tool of science and technology, science and technology were a tool for teaching and learning mathematics.

Story 3: Telling Stories: Mythopoetic Narratives and STEM Education

How might the act of listening to stories featuring architectures of indigenous cultures create generative spaces in which to think differently about STEM education? In studying architectures of the Inka-Andean, Douglas Cardinal, and Elmer Ghostkeeper (Glanfield et al., 2019), we noticed coherent and distinguishing differences amongst them. Identifying the differences as distinct cultural views and particular building and design activities, we conceived the coherent and fluid relationships between these as STEM; specifically, as living land-guaging algo-rhythms which recursively define STEM, or in other words, building and design activities that contribute to the wellbeing of cultural life *and* the natural environment.

In light of these insights and moving into the context of story and STEM education, we are curious how this work in re-imagining STEM can inform the education of it. We focus on one of the three featured architectures from our previous research—the design and building activities of Métis knowledge keeper Elmer Ghostkeeper (Surkan, 2018; Ghostkeeper, 2019). Listening more closely to the story of the visioning and situating of Ghostkeeper's house, we examine what is telling about the stories; that is, the mythopoetic narratives—metaphorically based linguistic processes (Bowers, 2014) embedded in them. These include: "The Great Spirit, Our Creator, created land as living beings that are viewed as gifts;" and "People are viewed as part of the land; their relationships with the land create a renewal of spirituality through exchanges" (Ghostkeeper, 2007, p. 82). These contrast with western mythopoetic narratives present in conventional forms of STEM education today such as 'human invention as scientific and technological innovation,' 'humans are separate from the land'; which give rise to cultural and environmental challenges. We see Ghostkeeper's earth-centric values and spirituality as radical features for changing the story of STEM education by offering an-other story—mythopoetic narratives that effectively make space for STEM education to become something different than what currently appears as culture free and spiritless.

CONCLUSION

In this paper we share our stories to open-up spaces for listening to alternative spaces in which to think differently about STEM education. This work connects with and flows from our ongoing inquiry into re-imagining STEM and what this offers mathematics education and STEM education. Furthermore, indigenous frameworks in which knowledge systems are embedded in, emerge from, and are conceived through, for example, spiritual practices, music, art, animals, plants, and the land illuminate the centrality of place, culture, and a more-than-human world. It is these specific manners which Indigenous peoples come to know, experience, and create a world. Approaches to STEM education, such as ones that include both western and indigenous cultures (Onwu & Mosimege, 2004) or said another way, bring different "ways of knowing, doing and being into conversations with each other" (Lunney Borden & Wiseman, 2016, p. 140) call for place-based curricula and pedagogies. In doing so, STEM education promotes the learning of concepts and solving of problems at hand; with and in community as they emerge and are understood in these contexts.

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CONNECTING TEACHERS' BELIEFS ABOUT PHYSICS AND CONCERNS REGARDING A NEW CURRICULUM DOCUMENT

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ABSTRACT

Curriculum documents indicate what is to be learned by the end of a school year; as Canadian provincial governments mandate new curriculum documents, it is assumed teachers will teach these courses as indicated. Despite teachers' familiarity with change, teachers commonly reflect on, question, and, sometimes, resist new curriculum documents. Yet, what causes these reactions? Based on the view that beliefs about knowing in physics (a.k.a. epistemic beliefs) act as a filter with which teachers' read curriculum documents, this study investigated whether these reactions to new curriculum documents could be connected to epistemic beliefs. This study contributes to the thin literature investigating teachers' epistemic beliefs about physics. Sixteen teachers across a Western Canadian province were interviewed regarding their (1) beliefs about physics and (2) concerns about a new, grade 12 physics curriculum document. Interviews were transcribed and then coded using thematic analysis. Results from coding were analyzed for potential connections between beliefs about physics and teacher concerns. Findings show connections between teachers' beliefs about the source and content of physics could be connected to their concerns about this curriculum document. This study presents a case for (1) further study into teachers' epistemic compatibility with mandated teaching resources and (2) differentiated professional development opportunities based on teachers' concerns and beliefs about physics.

Keywords: *physics teachers, epistemic beliefs, teacher concerns*

GOALS AND OBJECTIVES

Despite teachers' familiarity with change, teacher concerns often manifest because of resistance to, and questioning of, educational change (Hall & Hord, 2015). Yet, what causes this resistance? I contend one factor could be a differing view of what it means to know physics than the view represented in an incoming, government-mandated curriculum document, since beliefs about what constitutes knowledge in that subject area, among other factors, guide teachers' interpretation of curriculum documents (Tobin & McRobbie, 1997). This view of what constitutes knowing in physics is often described as epistemic beliefs.

Epistemic beliefs regarding science have been studied in their relation to other phenomena such as metacognition (Yavuz, 2014), performance and motivation (Buhel & Alexander, 2005), understanding of physics equations (Domert et al., 2007), and, commonly, teacher beliefs about practice, teaching, and learning (Sin, 2014). However, teachers' beliefs about knowing the subject they teach have yet to be studied in relation to curriculum implementation. To address this gap, this study sought to explore connections between teachers' beliefs about physics and their concerns regarding a new, grade 12 physics curriculum document.

THEORETICAL FRAMEWORK

This study sought to connect two areas of research: epistemic beliefs and concerns. Each of these constructs has its own field of research, supported with different theoretical frameworks. Hence, to unite these two areas of research, two theoretical frameworks were used.

One's beliefs about knowledge in physics can be described by four loosely-independent areas: beliefs about the content, structure, certainty, and source of knowledge (Muis & Geirus, 2014). Beliefs about physics knowledge be situated along four continua, each based on one of the identified independent areas: physics knowledge as pieces of isolated information or as a single, coherent system; as absolute and unchanging or tentative and refutable is attributed to beliefs about the certainty of physics knowledge; as discovered from an external reality or a human constructed endeavour; as mathematics-focused at one end or as conceptual at the other (Hammer, 1994; Muis & Geirus, 2014; Yavuz, 2014). I use the terms *mathematical physics* and *conceptual physics* as commonly used in physics education research but recognize mathematics is much more than equations; another way of describing these terms is physics content as algebraic and equation-focused (mathematics) and intuitive and qualitative (conceptual). Combining these four areas of belief provides a theoretical framework describing a teacher's view of what constitutes knowledge in physics.

The Concerns Based Adoption Model (CBAM) (Hall & Hord, 2015) provided a widelyaccepted framework to investigate and analyze teacher concerns. CBAM considers concerns to be emotional responses and worries resulting from personal reflection on changing educational contexts (Hall & Hord, 2015). Within CBAM, the Stages of Concern (SoC) model was used to categorize and describe teacher concerns using broad labels of concerns regarding self (stages 1 – 2), concerns regarding tasks and classroom operations (stage 3), concerns regarding consequences (stage 4), and concerns regarding collaboration and further development (stages 5 – 6).

METHODOLOGY

Sixteen teachers from across a Western Canadian province participated in semi-structured interviews. All teachers in this province teaching grade 12 physics were eligible for this study; in an effort to avoid alienating teachers not officially prepared in physics education, participants' background in physics was not formally discussed. Teachers discussed their epistemic beliefs about physics at the beginning of the interview and transitioned into discussing concerns regarding the new, grade 12 curriculum document for the latter portion of the interview. Throughout data collection, each time a new theme emerged from interviews it was incorporated as probing questions during subsequent interviews; participants of previous interviews were also contacted to collect their views on new themes.

Interview data was coded using thematic analysis, first using the epistemic beliefs framework and then for teacher concerns. In using thematic analysis, the researcher identifies, analyzes, and reports patterns (or themes) viewed within data using six phases: (1) familiarize yourself with the data, (2) generate codes (if necessary) and code the data, (3) search for themes, (4) review themes, (5) define and name the themes, and (6) select exemplars representative of the theme and report (Braun & Clarke, 2006).

Following coding, participants were placed along a continuum of epistemic belief for each of the four areas of physics given their strength of agreement with one of two dichotomies. An example of this placement can be seen at the bottom row of Table 1. Teachers' beliefs about the certainty and structure of physics knowledge were consistent among participants. However, participants ranged across the continua of beliefs about the source and content of physics, hence, the continua of beliefs about the source and content of physics were compared against the concerns held by each participant to look for patterns of potential connection (see Table 1 for this visualization). Teachers' beliefs about the source and content of physics were also viewed in relation to their SoC profiles (see Table 2).

Table 1

Visualizing teachers' beliefs about the source of physics and their concerns

Resistance among other teachers	I	*G*	K				*F*	
How are other teachers doing it?		*A*	B N	L	D	M	*F*	
Students unprepared for content		*G* *A*	K N	O H	D			
Content is too theoretical/light			P N *E* B	*J*		M		
New/Non science teacher induction		*G*	N	O H *C*		M	*F*	
Course variation		*G* *A*	N K	O H *C* *L*			*F*	
Too much content to cover		*G* *A*		O H *C*			*F*	
Lack of instructions, resources, time		*G*	P *E* N B	O *J*			*F*	
Success on departmental			N B	O				
Discomfort with content			*E* K B N	H *J* O *L*	D			
Physics knowledge is socially constructed	I	*G* *A*	P *E* K B N	H *J* *C* O *L*	D	M	*F*	**Physics knowledge is rooted in reality**

**Participants believing physics was rooted in mathematics are noted in italics*

Table 2

Comparison of Teachers' Beliefs about the Content of Physics Knowledge and Strongest Level of Concern about the new Physics 30 Curriculum Document

	Stage 1: Informational	Stage 2: Personal	Stage 3: Management	Stage 4: Consequence	Stage 5: Collaboration	Stage 6: Refocusing
Believed physics was rooted in mathematics			Alan, Franz, Jens, Pharris, Chaz, Egon	Gru	Leilani	
Believed physics was qualitative in nature		Brad	Nadia	Harley, Olivia, Kye	Marcos, Denise, Ian	

RESULTS AND DISCUSSION

Concerns about Teacher Effectiveness with the New Curriculum

Physics teachers' efficacy regarding their instruction has been attributed to a lack of preparation in physics (Sunal et al., 2019), but findings from this study suggest more need be considered. Teachers at all levels of experience expressed concerns about their comfort in teaching this document. However, those teachers who saw physics as socially constructed were not concerned with their abilities to teach the content in this new document. As Ian (pseudonym) put it, this was because the new physics curriculum document told the story of physics as he saw it. This new curriculum document aligned more closely to the epistemic belief that physics was socially constructed, according to teachers in this study. Hence, efficacy about teaching a subject may also be connected to their beliefs about knowing in that subject.

Epistemic compatibility has been recently explored with secondary science students (Pekrun et al., 2017; Rosman & Mayer, 2018), finding students whose beliefs did not align with those expressed within read documents showed negative reactions, including anxiety and questioning. As curriculum documents have inherent biases, driven by the goals of a science curriculum, and teachers' view curriculum documents through their epistemic filters (Wallace & Priestly, 2017), it would stand to reason teachers could also have reactions based on compatibility (or incompatibility) of their beliefs with those perceived within a curriculum document. Findings from this study provide evidence confirming this proposed contention. Teachers who saw physics as socially constructed were less concerned with their capabilities in teaching this new physics curriculum document since they felt their beliefs about the structure of physics were well represented. This study revealed a warranted vein of epistemic compatibility research with teachers in addition to the research being done with students. Teachers, just as students, react based on the compatibility of their beliefs with a document.

In addition, those strongly believing that either physics knowledge was conceptual or physics was mathematics-based worried about the amount of content in this curriculum document whereas those with less commitment to either extreme tended not to share this concern. However, the concerns of each group differed. Teachers interpreting this document as focused on teaching physics as conceptual and qualitative were not worried about the physics in the document; these teachers were frustrated with the amount of review students needed to understand the necessary mathematics. On the other hand, mathematics-based teachers felt they could not cover all the content in this curriculum because they interpreted the indicators and outcomes to include more mathematics explicitly written. This finding suggests teachers may require more assistance in the interpretation of this curriculum document, specifically the breadth and depth of the mathematics to be taught.

Concerns about a Lack of Support and Resources

Teachers' beliefs about the content of physics could be connected to several concerns regarding the support of teachers and lack of resources. Teachers believing physics knowledge was conceptual were concerned about their ability to prepare students for standardized exams. Concerns about a lack of resources and direction differed for teachers believing physics is mathematics-based and those believing physics is conceptual and qualitative. Finally, teachers believing that physics is mathematics-based tended to focus on lower levels (focused more on the self) of concern than teachers believing physics was conceptual.

Only teachers believing physics knowledge is conceptual and qualitative expressed worries about their effectiveness in ensuring students' success in standardized physics tests. Research has described the issue of disconnect between curriculum and standardized assessments (i.e. Gabby et al., 2017). Staderman et al. (2019) attribute this disconnect to a general increase in science curricula emphasizing the nature of science; it is difficult to assess the nature of science on standardized exams, hence, the assessment focuses on different content than is focused on in the curriculum document. However, teachers worried about this exam preparation shared concerns about the exam's focus on 'equations' and mathematics-based content. Teachers are provided with practice exams to help guide their students' preparation and many teachers use practice exams as a resource to interpret the breadth and depth to which they should teach many outcomes. Yet, if a teacher saw physics as conceptual and read the curriculum with this epistemic filter, encountering a mathematics-focused exam (as described by these teachers) may incur worries about their capabilities. Hence, it is important that curricula and standardized assessments be aligned but it may also be necessary to orient teachers' to the epistemic assumptions informing both curriculum documents and standardized assessments.

It was more common for teachers believing physics content was rooted in mathematics to express concerns about a lack of resources and direction on how to implement the content in this new curriculum document, but this concern was present among teachers across the continuum of beliefs about the content of physics. Teachers believing physics was qualitative in nature wanted more direction on what would be asked on the provincially regulated exam and classroom-ready strategies for implementing this new curriculum document. Teachers believing physics knowledge was mathematics-based wanted resources to teach the more 'abstract' topics (as they called them) introduced in this document. Mathematics-based teachers also wanted more direction on how much class time to spend on each topic to help them decide how 'deep' to teach concepts. In this study, teachers' beliefs about the content of physics appeared connected to the resources they desired to assist their implementation of this new curriculum document. Findings corroborate those studies suggesting the development of resources for teachers based on their specific needs (Borgerding et al., 2013; Gabby et al., 2017). It is advised that those implementing a new curriculum document ensure resources differentiated resources based on teachers' beliefs about physics knowledge are made available. Specifically, conceptually-oriented teachers requested classroom ready strategies and guidance on the provincial physics exam and mathematics-focused teachers wanted explanation on abstract topics and indications of expected time on each outcome.

Finally, teachers believing physics knowledge was mathematics-based primarily had their highest level of concern in stage 3 (management) whereas conceptually-focused teachers held highest levels of concern in stages 4 (consequence) and 5 (collaboration). Studies have shown teachers with low content knowledge (Borgerding et al., 2013; Gabby et al., 2017), heavy workloads (Kwok, 2014), and fewer professional development opportunities (Oguoma et al., 2019) typically focus on lower stages of concern (personal and management). This research furthers these findings by indicating that teachers' beliefs, at least those about the role of mathematics in physics knowledge, may also impact their levels of concern, indicating a need for those in charge of new initiatives to use teachers concerns and beliefs to guide professional development offerings during the implementation process. This would suggest teachers also be made aware of their primary stage of concern, beliefs about the subject they are teaching, and how these two areas connect to development opportunities.

CONCLUSIONS AND SIGNIFICANCE OF THE STUDY

Teachers in this study were not homogeneous in their beliefs about physics, particularly the source and content of physics, and differences in beliefs were connected to some concerns raised during this study. Teachers who saw physics as socially constructed were less concerned with their abilities to teach this new curriculum document; it told physics the way they saw it. Teachers with strong beliefs that either physics content was conceptual or mathematicsfocused were more likely to have concerns about too much content in this curriculum document than their more centrally-located (on the continuum of beliefs about physics content) counterparts. Teachers believing physics was mathematics-based were not concerned about preparing their students for a provincially-controlled exam while teachers who believed that physics was conceptual and qualitative were concerned about this. Teachers along the continuum of beliefs about physics content worried about a lack of resources; the type of support wanted varied based on whether teachers believed physics was mathematics- or conceptually-focused. Finally, teachers believing physics was mathematics-based were more likely to focus concerns on the management of the curriculum implementation where those believing physics content was conceptual and qualitative tended to focus concerns on consequences of this curriculum and collaboration. This evidence indicates physics teachers' epistemic beliefs and their concerns about a new curriculum document can be connected.

Finally, this research presents a need to consider epistemic belief compatibility with teachers. Recently, educational researchers of epistemic beliefs have begun exploring connections between students' interaction with epistemic activities and resulting epistemic emotions (see Pekrun et al., 2017; Rosman & Mayer, 2018). Yet, research investigating teachers' epistemic compatibility with documents is virtually non-existent. As teachers interpret curriculum documents based on their beliefs (Wallace & Priestly, 2017) and given the connections between epistemic beliefs and concerns, this study highlights the importance of future research investigating teachers' reactions based on epistemic compatibility with documents/resources.

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WASISƏ̲K KISIHTOHTIT [CHILDREN MADE IT]: CODING WORKSHOPS AS A SITE FOR PROFESSIONAL DEVELOPMENT FOR TEACHER CANDIDATES AND PRACTICING TEACHERS

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ABSTRACT

In Canada, there are many differences in regards to computer science education in public schools. Not only are schools diverse in location [rural/urban] but socioeconomic status as well-where after-school programs, Saturday science clubs, and summer programs help define and widen the 'education divide'. According to the Assembly of First Nations, 70% of Indigenous children are educated in off-reserve schools (Kovacs, 2009). It is essential that teachers construct appropriate learning opportunities within and outside schools. This qualitative study examines best practices, in a local context, for teaching coding and digital literacies with students from a variety of schools, communities, and families. By promoting participation across generations, these coding workshops engage students, families, and teachers in becoming creators and full participants in today's digital society.

Keywords: *coding, STEM, non-traditional populations, teachers, extracurricular*

INTRODUCTION

Logical reasoning is a necessary component of computer coding as well as being a foundational skill that encompasses '21st Century learning'. As suggested by the K-12 Computer Science Framework (2016), "implementing computer science education requires engaging curriculum, evolving course pathways, technical infrastructure, and the involvement of the community and informal education organizations" (p.32). "Many new initiatives are appearing where start-ups and non-profit organizations offer innovative and engaging training approaches to coding" (Balanskat & Engelhardt, 2014, p.4). However, few Canadian provinces fully integrates coding into its elementary-level curricula, forcing students to find these skills elsewhere. Moreover, many students lack effective access to these programs.

Indeed, in Canada, there are many differences across the country in regards to computer science education in public schools--since Education is predominantly a provincial responsibility. Not only are schools diverse in location [rural/urban] but in socioeconomic status as well. Some schools are located in areas with middle-class incomes where parents and local businesses provide monies, expertise, and time in order to enrich children's education. Additionally, these same schools provide or house afterschool programs, Saturday science clubs, and summer programs that help define and widen the 'education divide' (St. Denis, 2010; Wilson-Gillespie, 2004; Wood, 2002; 2003). Many of these afterschool programs are not offered in rural areas where students do not have the opportunity to travel, or the cost is just too great for many students of low socioeconomic status [SES]. Additionally, on-reserve and off-reserve Indigenous and rural students often attend what Margolis, Goode, and Ryoo (2015) call low-resourced-schools.

Objectives

This study will examine best practices, in a local context, for teaching coding and digital literacies-- in keeping with research methods addressing vulnerable populations and potentially, Indigenous students (Archibald, et al, 2010; TCP2, 2014; TRC, 2015; Wilson, 2008). The following questions will guide this study, to what extent can:

1. coding and design workshops be engaging to children, parents, B.Ed. students, and practicing teachers?

2. families and teachers design and learn together with creative technologies and maker space/production approach [E.g. Pre-coding activities, MaKey-MaKey, Code.org, Scratch Jr.]?

3. children's creativity be supported when family creates with them?

4. children and families develop other digital technologies/literacies/uses that are considered supportive of their cultural community and histories, or Indigenous knowledge, oral histories, and traditional languages?

These workshops were especially made available to students in grade 3-5 and their families with limited access to elementary-level technology resources and social support around technology. Consultation with the Intermediary, Elder, school, and community suggested ways to identify and invite participants. Moreover, the location for the coding/maker workshops often were not schools, since they may not be viewed as a positive learning space (TRC, 2015). By promoting participation across generations, these workshops engage students, families and teachers in becoming creators and full participants in today's digital society.

RESEARCH DESIGN

Conceptual Framework

The sociocultural approach examines how identity, as a self-chosen description of a person, takes place within human action. Additionally, this approach reminds us that "personal narratives and life stories are: socially situated actions, identity performances and fusions of form and content" (Mishler, 1999). Narrative data are recognized "as modes of 'secondary production', drawing on and redoing culturally available plots to construct their [the participants'] own distinctive stories" (Mishler, 1999, p.25). Lave and Wenger recognize the importance of social relations within a community of practice because students do not learn only from their instructors. As well, "it seems typical of apprenticeship that apprentices learn mostly in relation with other apprentices" (Lave & Wenger, 1991, p. 93). More recently Wenger (1998) elaborates that "more experienced peers are not merely a source of information; … they also represent the history of the practice as a way of life. They are living testimonies to what is possible, expected, desirable" (p.156). This concurs with the research that affirms the importance of role models in developing 'imaginable' identities, especially in regards to girls/women and minorities (Bandura, 1997; Harding, 1997; Johnson & Okoro, 2016; Wood, 2006). Theories of learning and identity with regards to STEM education are intricately inter-twined. The process of becoming an active learner is studied in light of learning as social participation. Wenger contends that "participation here refers not just to local events of engagement in certain activities with certain people, but to a more encompassing process of being active participants in the practices of social communities and constructing identities in relation to these communities" (1998, p.4).

Methodologically, the predominant design adopted is a naturalistic qualitative inquiry. Grounded theory strategies will include: a) simultaneous data collection and analysis, b) pursuit of emergent themes through early data analysis, c) discovery of basic social processes within the data, d) inductive construction of abstract categories that explain and synthesize these processes, e) sampling to refine the categories through comparative processes, and f) integration of categories into a theoretical framework that specifies causes, conditions, and consequences of the studied processes (Charmaz 2000; 2008; Wood, 2006). This constructivist approach to ground theory places priority on the phenomena and sees both data and analysis as created from the shared experience of researcher and participants and the researcher's relationships with the participants (Wood, 2006).

Methods

The method used includes open-ended interviews with elementary–aged participants, B.Ed. workshop leaders, and practicing teachers. The co-constructed narratives of the workshop participants were the primary source of data. In the event of a participant needing a few guiding questions, a list was provided for the interviewer. In addition, the process of learning, and becoming creators during the workshop and the products created were documented. Interviewed participants were given a small gift as a token of appreciation (Seidman, 1998; Wilson, 2008). Data was managed and memos written with qualitative software [Nvivo]. This process continued until saturation, when no new information was found. The data was triangulated including our detailed observations from the workshop, the products created, and the participants' interview data (Charmaz, 2000; Creswell, 2013).

This 3-year ongoing study was approved by the university Research Ethics Board and consists of three components: 1) the workshops, where students and family become coders/creators in an engaging way; 2) the perspectives of learning computer coding were gathered from the children, B.Ed. students, and practicing teachers; and 3) participants were given the opportunity to explore how digital literacies can be a vehicle of expression for cultural histories/identities or Indigenous knowledge and traditions. Students and families design and learn together with 'Creative Technologies' and 'Maker Space/Production Approach' [E.g. Pre-coding activities, "MaKey-MaKey", STEM activities, and Scratch Jr. which teaches elementary-age coding]. Workshops were conducted during the summer, after-school, Saturdays, and Professional Development days. All interested students, grades 3-5, in the community were included. Thus, two purposes were achieved: to discover best practices for teaching pre-coding to elementary-aged students, and to address local level problems with the anticipation of finding immediate solutions (Mertler, 2017).

Indigenous World-View

These research methods were in keeping with Indigenous research methods and the TCPS2 guidelines for vulnerable populations (Charmaz, 2000; TCP2, 2016; Wilson, 2008). Moreover, learning opportunities that "includes Indigenous Knowledge also strengthens cultural identity and self-esteem and demonstrates to students that what they are learning at school is part of their lives" (Kovacs, 2009, p.10). By learning from both Western and Indigenous ways, students are not required to change their cultural identity or leave their identities at the door as they have had to do in the past (Kovacs, 2009). Indigenous knowledge as a part of the provincial curriculum and learning includes integrating Indigenous content, perspectives, and ways of knowing into lessons to provide opportunities for all children to learn about lands, tradition, history, worldviews, and different value and belief systems (Bernard et al., 2015; Gear, 2012; Kovacs, 2009). Kovacs (2009) further posits that the "engagement of community, parent, and youth through relationships within an early learning context includes networking among immediate family, extended family and community members as an integrated part of a child's life. A strength-based approach provides an inventory of the strengths the entire family brings to support the child's learning environment" (p.13).

This research took place in a variety of settings in the community such as: Indigenous recreation programs and community centers, public libraries, and Indigenous schools. An Intermediary was hired, who is a member of a local First Nations community, to assist with obtaining counsel, conducting the workshops, and interviews—along with communicating results at conferences. This is essential as an "Intermediary" is necessary to gain community support, parental participation, and gain general entry with the Indigenous community (Wilson, 2008).

RESULTS AND DISCUSSION

Teachers, pre-service and practicing, found that the process of reflection and making meaning out of the learning experiences was beneficial. Where together, with one or two students—the precoding activities were discussed and connected with elementary mathematics/STEM curricula learned in classrooms. These extracurricular spaces allowed the mathematics and pre-coding concepts to be linked, to gel into something more-where new creative ideas emerged. While some elementary-aged participants lacked language to label or name concepts, their descriptions and stories allowed an image of the process to appear. While complete saturation has not yet occurred, and data collection and analysis is still on-going—some key categories emerged from the teachers including: gender differences, math anxiety, valuing creativity, engaging activities, access to extracurricular programs, differences teaching in schools versus community, high quality learning, and linking workshops to classroom learning. Most of the teachers believe that good coding/STEM lessons can be similarly replicated in the classroom. While the scope of this presentation is concerned with the teachers' perspectives--triangulated data from observations, products created, and interviews produced the following categories with the elementary-aged participants: freedom and control, creativity, fun/engagement, math anxiety, home, and school. These categories will be further explicated and guide suggestions for best practices.

Educational Importance

This research is creative and novel in that there are currently few fully developed curricula, that is--teaching and learning objectives, suggested units and lessons, or assessments—fully implemented or validly tested for the elementary grades in public schools in Canada. While after-school programs put together fun activities, they are not logically designed programs that move from simple to complex, or are guided by international standards and linked to other STEM curricular outcomes that elementary students should be learning in schools today. Computer coding is one important aspect of 21st Century learning. As such, it should be complementary to, and integrated with, other important STEM learning outcomes to promote understanding and application (K12CS, 2016). In this way, students will ultimately be fluent in the language of design allowing for new types of digital literacies to emerge. The STEM international standards that informed our activities are interdependent—recognizing that engineering design has connections to technology with applications of science and mathematics in the natural world. These standards influence corresponding mathematical concepts reflected in North American elementary-aged curricula such as operations and algebraic thinking, reasoning abstractly and quantitatively, modeling with mathematics, and using appropriate tools strategically (ISTE, 2016; K12CS, 2016; NCTM, 2002; NGSS, 2013). Moreover, technology standards for educators direct teachers to facilitate learning with the use of technology and student learning strategies in digital platforms, virtual environments, hands-on makerspaces, or in the field—using a creative, design process and computational thinking to communicate ideas and make connections (ISTE, 2016; McCollough & Ramirez, 2012). These standards and best practices guide all activities in our program.

CONCLUSION

In sum, this research tried to develop a positive coding/STEM relationship with students in grades 3-5, especially those underrepresented in the STEM fields--their families and communities. This is not easily measured and it takes time. The repeat students bring their parents more frequently. It is a process. Additionally, we provided professional development to the new and practicing teachers who act as the workshop leaders. Workshop leaders develop confidence and initiative in teaching coding and STEM as well as working with the students and families. This was very much a reciprocal learning experience. Taking these best practices to practicing teachers--using the workshop approach with the B.Ed. students-- is a collaborative way to share this knowledge in a useful format.

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EFFECTS OF EVIDENCE-BASED STEM MODEL ON STUDENTS' PERFORMANCE

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ABSTRACT

During the development of the Science, Technology, Engineering, and Mathematics (STEM) education, one of the most important questions is the assessment of the students' performance in class. Evidence-based learning theory provides an innovative view for this question, which emphasizes to measure and enrich the individual's experience with evidence. In this study, the evidence-based STEM model was raised by integrating evidence-based learning theory into the STEM class, and the evidence-based evaluation framework was also constructed based on classroom observation and related researches. And the SASBD platform was developed by our team, which was used to assist the evidence-based STEM education practice. An instructional experiment using the new model was conducted. The results showed that students made a significant progress in this lesson and all of them were satisfied with the evidence-based model. However, there are still some limitations and work to do in future, such as additional experiments, the enrichments of in-class evidence and so on.

Keywords: *STEM education, evidence-based learning, evaluation framework, evidence, guidance*

INTRODUCTION

In order to improve the citizen's scientific literacy and help children to make full preparation for their future lives, the Science, Technology, Engineering, and Mathematics (STEM) education is drawing more and more attention all over the world, which has been included in many countries' national policies. As a lot of STEMforced programs have been implemented, however, many diverse problems are emerging, and one of the most critical problems is the assessment. (Hall, A., & Miro, D., 2016) The current measurement systems and tools in STEM education are associated with significant limitations (Anderson, 2011; Black & William, 1998, 2009; Gallagher, 2000; Yeh, 2006), such as just to focus on students' learning outcomes, unable to represent the high-level skills. Therefore, many scholars advocate for changes to the goals, forms of the assessment (Anderson, 2011; Black & William, 1998, 2009; Gallagher, 2000; Yeh, 2006).[1] Besides, some research findings have demonstrated the need of innovative, experiential-based approaches to STEM education to develop students' STEM interests and competencies (Hall, A. et al., 2016).

THEORY BACKGROUND

The Challenge in STEM Education

STEM education can assist students to construct and transfer new knowledge into the real-world setting with an integrative approach (Stylianos Sergis et al., 2019; Apedoe et al., 2008; Fortus et al., 2005). As a result, it permeates into the global landscape of educational reform (Gabriela Alonso Yanez et al., 2019). However, there are lots of problems in STEM education, such as students had poor performance in STEM disciplines or and teachers felt limited about measurement tools and evaluation methodologies (Emily Saxton et al., 2014). In order to support effective implementation, STEM education has been facing a new challenge to investigate empirical evidence (Froyd & Ohland, 2005; Kwon & Lee, 2008; Narum, 2008). Besides, it is an arduous task for teachers to assess and provide students with individual guidance with lots of information tools, which are used to collect data in STEM class (Sergis, S. et al., 2019). Thus, it is imperative to focus on collecting and applying the evidence to promote STEM education.

Evidence-based learning theory

The evidence-based learning has been recognized as an innovative method to improve the quality of care and patient outcomes through significant and reliable evidence (Laibhen-Parkes et al., 2015), since the evidence-based education is derived from the University of Oxford Master's programme in Evidence-Based Health Care. This learning approach is based on the problem-solving, self-directed model of adult education (Knowles,1990). The central feature contains a two-way process: increase individual' experience with evidence and measure the individual's experience based on evidence (Davies, 1999). With the evidence continuous cycles of improvement can be built into practice (Thalheimer, W., 2007).

Thus, evidence in STEM education can represent the students' learning process which help teachers to assess and provide individual guidance. Besides, students' experience will be enriched by inquiring tasks with evidence.

EVIDENCE-BASED STEM MODEL

Evidence-based STEM model integrates evidence-based learning theory into STEM class. As is seen in figure1, there are usually six steps in a STEM lesson: engaging, planning, exploring, designing, making, sharing and evaluating. There may be more than one learning activity during each step. When students engage in an activity, the evidence is generated. The process reports is based on evidence, which could help teachers understand about the students' learning process better and take some guidance to improve students' learning. When the class is over, the general reports will be produced immediately based on all the evidence.

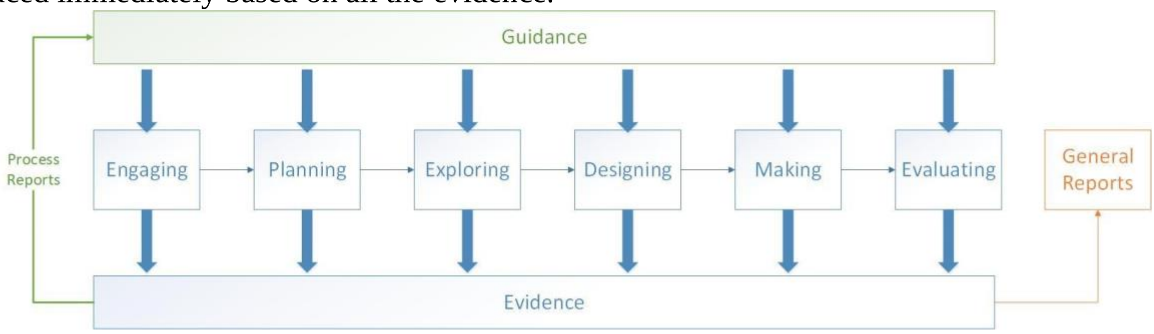

Figure 1. Evidence-based STEM Model

THE EVIDENCE-BASED EVALUATION FRAMEWORK

According to the nature of the STEM education concluded by Rodger W. Bybee: (1) the importance of science education; (2) the increasing emphasis of technology in our daily lives; (3) the recognition of engineering included in problem solving and innovation; (4) development of 21st Century skills. (5) the integrated curricular approaches to studying grand challenges of our era (Bybee, R. W., 2010).

The evidence-based evaluation framework contains four indicators: core competence, Knowledge level, learning attitude and engineering literacy.

- Core Competence

It represents the development of the students' future-oriented skills to prepare for the 21st century, and integrate the American 21st century skills and Chinese students' core competence frameworks.

- Knowledge Level

It is to check whether students have understand the specific knowledge within the STEM disciplines, such as physics, chemistry, biology, math and so on, so this indicator bases on the national curriculum standards. There are four levels for each knowledge with different interval value: excellent, good, medium and poor.

- Learning Attitude

It focuses narrowly on the students' classroom behaviors in class and reflect the degree of their participation. According to nearly one year' observation about the STEM Class, we concluded 18 kinds of specific behaviors, which were classified two categories: Positive and Negative. Each category has 9 kinds of behavior labels.

- Engineering Literacy

It is to show the students' performance in the engineering processes, with six steps——defining questions, collecting materials, designing sketches, making models, modifying and improving and demonstrating and sharing.

RESEARCH QUESTION

This study explored how to assess students' learning with evidence and explored a new learning model in STEM class. It based on a learning platform named "STEM Assessment System based on Big Data", which was developed by our team. It can record evidence in class and produce reports. Specifically, there were three key research questions in this study:

RQ1: How to design a STEM model to solve the question of the outcome-based assessment?

RQ2: How to verify the effects of the evidence-based STEM model?

RQ3: How do students like the evidence-based STEM model?

METHODS

The learning environment of evidence-base STEM Model—the SASBD platform

In order to achieve automatic data collection, a learning platform named "STEM Assessment System based on Big Data (SASBD)" was developed by our team according to the evidence-based STEM model.

The Basic Function of the SASBD Platform

The SASBD platform bases on the evidence-based evaluation framework. The current version of this platform can only be used on the PADs, so it just supports one-to-one instruction in class. With the platform, online and offline evidence can be collected in automatic way or manual way, then all the evidence will be analyzed, and eventually reports are produced. Its main functions are as follows:

- Support Learning and Teaching Activities

Before class, the teacher can create a new lesson on the platform, add learning activities, and distribute this lesson to the corresponding class. When the class begins, the students log on the platform, engage in the learning activities, collaborate with their peers and finish tasks.

□ Collecting the Data in STEM Class

When students are engaging in the online and offline activities, all types of evidence are generated. For example, the results of answering a question, the process of designing a circuit diagram and making a music card, the artefacts and so on. (Figure 2)

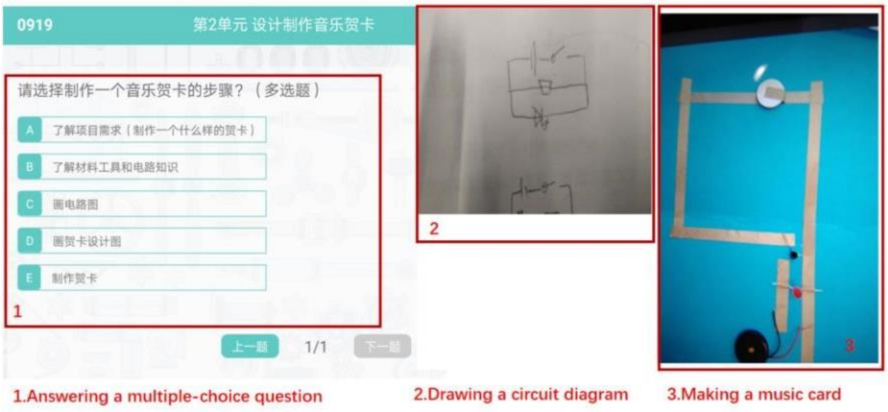

Figure 2. Different Types of Evidence

□ Providing Class and Individual Reports

After class, both class and individual report are immediately produced. The class report will show the overall performance, and the individual report can represent the details about one's achievement in this lesson.

Participants and Settings

The participants in the experiment were 16 ninth grade students from a public middle school in Beijing, aged between 14 and 15. Before this lesson, they all had completed the learning of the circuit and mastered the basic knowledge of the series and parallel circuit and reached an intermediate level in the achievements of STEM related subjects. In this lesson, they were randomly divided into 7 groups, with 2 or 3 peoples in a group. As they had experienced studying on SASBD platform with PADs several times, they were familiar to this platform.

Experimental Procedure

The experiment was conducted for a STEM course, which aimed to guide students to understand how a music card works and to make it. It was expected that the students would be able to understand the basic circuit knowledge and successfully transfer it to real life.

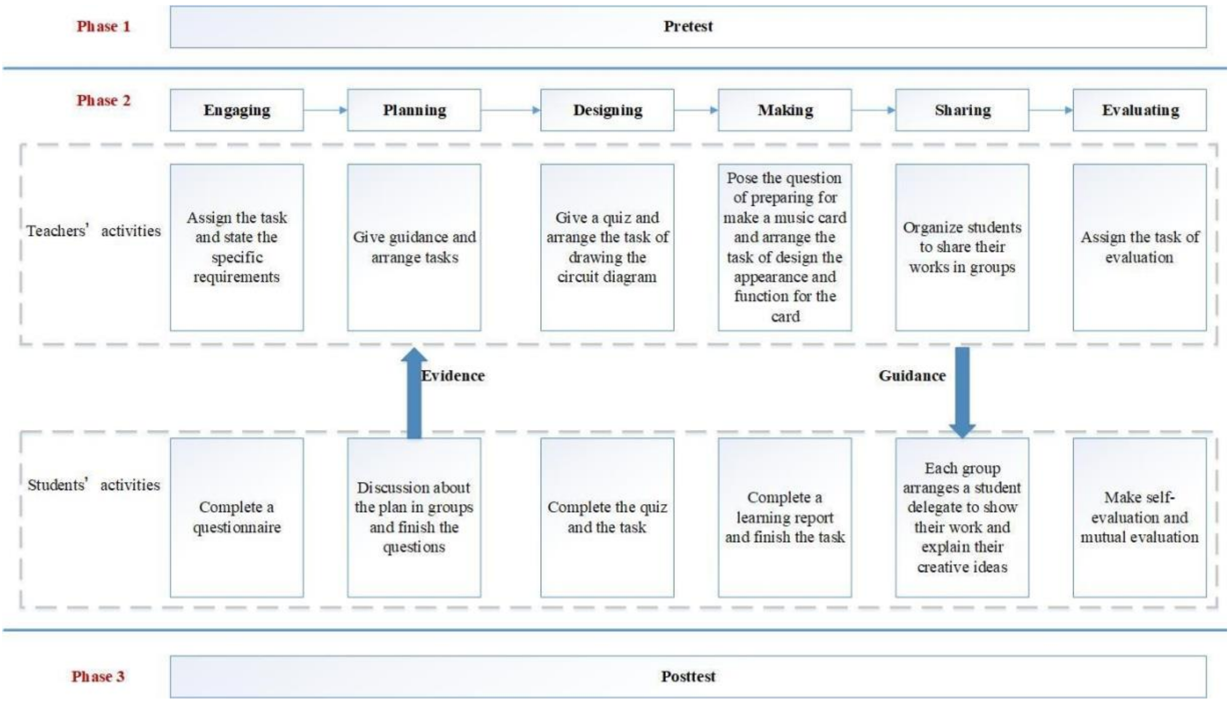

Figure 3. The Procedure of the Experiment

The figure 3 shows the procedure of the experiment, which consists of three phases conducted over a period of 150 minutes. In phase1, the students completed a 30-mins pretest.

In phase 2, six steps of the evidence-based STEM model was conducted. The learning activities lasted 90 minutes. The teacher carried out the lesson with the SASBD platform. Both the teacher and the students used PADs. The online and offline evidence in each step was collected by SASBD platform. The teacher gave guidance according to the process reports.

In phase 3, the students completed a 30-mins posttest. The two tests were paper-based tests and covered three aspects of the content: the series and parallel circuit, diode and designing a circuit diagram.

Data Collection and Analysis

There are two kinds of data: offline and online data. The offline data was the students' scores in the pretest and posttest, which was analyzed by SPSS. Besides. The online data could be collected through the SASBD platform. As all the evidence had been analyzed automatically on this platform, the teacher and students would get the reports after class. The data about the students' satisfaction about the evidence-based STEM model was collected and analyzed.

RESULTS

How to Verify the Effect of the Evidence-based STEM Model?

First, a paired sample t-test was performed on the pre-test and post-test scores (Table 1). The P (2-tailed) <0.01, which indicated that there was a significant difference between the pre-test and post-test scores. As the mean of the post-test scores was much higher than the pre-test scores, it indicated the students had made an obvious progress in understanding the basic circuit knowledge through the learning.

Table 1. The outcome of the paired sample t-test

Category	Number of students	Mean	Standard Deviation	t	P(2-tailed)
Pretest	16	47.50	36.61	3.889	0.001^{**}
Posttest	16	76.88	26.76		

*p<0.05, **p<0.01.

How do students like the evidence-based STEM Model?

After class, every student answered a question — "Compared with usual learning method, I prefer to this kind of learning model in today's lesson", and there were five choices—"Strongly agree, agree, be uncertain, disagree, strongly disagree ". The table 6 showed that nearly all of the students were very satisfied with this model (Table 2).

Table 2. The results of the students' satisfaction about the SASBD platform

Option	Number of the students who chose the option	Percentage
Strongly agree	13	81.25%
Agree	3	18.75%
Be uncertain	0	0
Disagree	0	0
Strongly disagree	0	0

DISCUSSION

This study has explored a new instruction model in STEM education. The evidence-based STEM model is to enrich students' learning experience and measure the learning process and outcomes with evidence which can assist teachers to understand the students' learning and give some guidance if necessary, in order to improve the learning, teaching and assessing of the STEM education.

To support the evidence-based STEM model, the SASBD platform was developed by our team with the evidence-based evaluation framework. In order to check whether the new model was effective, an experiment was implemented with the SASBD platform. And the results of the data analysis showed that the students had made a great progression and also were satisfied with this new model. The correct answer rate was dramatically improved in the posttest compared with that in the pretest. This suggested that the evidencebased STEM model could effectively promote the students to understand the knowledge and successfully transfer it to solve real-life problems. One potential explanation is that the evidence-based learning motivates students to learn actively, as it focuses on evidence and feedback (Florian Eitel et al., 1999). As a result, in order to collect the evidence from the learning process, teachers need to provide the students with many opportunities for active learning in order to collect all kinds of evidence. With real-time feedback based on the process evidence, teachers give guidance and students who have difficulty in learning will get individual support, which will push them forward more.

LIMITATIONS AND FUTURE WORK

Although it was proved that this new instructional model played a positive role in STEM education, there are still some limitation and lots of work to do in future. Firstly, additional experiments are needed to provide much more convincing evidence to prove the advantage of this new instructional model. In order to increase the credibility of the experiment, it is necessary to add a control class just without guidance or increase the number of the students engaged in the experiment. Besides, the reliability and validity of the evaluation framework of the SASBD platform need to be proved with much more data, so we should collect more data with the SASBD platform.

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RESEARCH ON THE INFLUENCE OF LEARNING BASED ON GAME DESIGN ON THE DEEP LEARNING OF MIDDLE SCHOOL STUDENTS

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ABSTRACT

The knowledge of deep learning experts, the cultivation of high-order thinking and the input of emotions are the goals pursued by current education. Game-based learning refers to the use of appropriate tools to build games to support student learning. This approach provides learners with powerful contextual and real-world questions that effectively stimulate students' interest in learning and motivation to learn. Develop high-level thinking and creativity in the process of design, development and debugging to achieve deep learning. The study collected the test scores of the students, the final works and the programming notes. Through qualitative and quantitative analysis, the results are as follows: The game designbased learning is enough to promote students' deep understanding and application of programming knowledge; in terms of thinking, the experimental group performance There are more complex task interactions and problem solving; in terms of emotions, the experimental group has invested more time energy and expressed more interest. At the same time, the study found that collaboration can make up for the lack of learning methods to a certain extent and improve students' thinking level. This method provides an idea for improving the current programming teaching.

Keywords: *game-based learning, deep learning, open-source hardware programming*

INTRODUCTION

Deep learning is a new requirement of teaching in the new era and an important indicator of the quality of learning. In the Horizon Report, deep learning is one of the key trends driving the application of school education technology (Wang & Zhang, 2016)i. Deep learning refers to actively and critically learning new ideas and knowledge, using diverse learning strategies to deeply process knowledge information, establishing new and old knowledge information, building personal knowledge systems and effectively migrating them to real situations. Solving complex problems (Bu & Feng,2016). Deep learning emphasizes students' meaningful construction of knowledge, the cultivation of high-order thinking and the input of emotions, which are the goals pursued by current education.

With the rapid development of computers and networks, programming skills have gradually become the basic skills of the 21st century. More and more schools are teaching programming, cultivating students' mastery of programming knowledge and the ability to use programming thinking to solve practical problems. However, as programming teaching tends to be younger, there is a general difficulty in understanding programming concepts in the actual programming process (Di Lieto, M.C., et al., 2017), students' learning stays in skill imitation, difficulty in knowledge transfer, lack of creativity and learning motivation, and inability to achieve deep learning (Yan & Zhong, 2018).

Therefore, how to find a suitable learning method for students and improve the deep learning of students' programming knowledge is a problem that needs to be solved in the current programming teaching of primary and secondary schools.

In order to promote the realization of deep learning in programming, the existing research mainly intervenes in programming teaching from two aspects: teaching strategy and teaching mode. The teaching strategy mainly explores three aspects: programming tool selection, tool allocation strategy and collaborative form. However, this kind of research pays more attention to the influence of strategy on programming performance, and does not deeply explore its role in understanding the specific programming concept. Fundamentally improve the imitation of this form of teaching. The exploration of teaching mode provides ideas for improving this problem as a whole. For example, Zhong Bochang cooperates with first-line teachers to extract four kinds of new programming teachings: invention and creation, scientific inquiry, interesting interaction and experimental simulation. Mode. These four types of teaching have all improved the shortcomings of imitation and lack of creativity in the original teaching mode to a certain extent, and also provided a good idea for the source of teaching cases. However, this part of the research stays at the theoretical stage, and there is a lack of empirical research to quantify the data to present its impact on students' learning outcomes.

Learning based on game design refers to a learning method in which the learner actively designs and develops the game in the real problem situation, and uses the feedback to improve the function to realize meaningful knowledge construction. The method provides students with an effective learning situation through “game design”, which includes real tasks and complex backgrounds, which can promote students to learn independently and achieve meaningful knowledge construction (Robertson, J. 2012).

LITERATURE REVIEW

Definition and characteristics of deep learning

The concept of deep learning was first proposed by Marton and Saljo. When they studied the strategies adopted by students in reading academic papers, they found that learning can be divided into shallow learning and deep learning (Marton F, Saljo R.1976). Scholars have different understandings of deep learning and summarize relevant literature. Deep learning is mainly reflected in three aspects of cognition, thinking and emotion. (1) Cognitive aspect, deep learning means that the cognitive structure of learners changes and achieves high Hierarchical cognitive goals (Duan & Yu,2013). (2) In terms of thinking, students improve their metacognitive level and other high-order thinking skills through reflection, conceptual interaction and other behaviors during the learning process (De Corte, E. 2003). (3) In terms of emotions, deep learning indicates that students have high behavior and high emotional input. Although scholars hold different opinions on definitions, the researchers' views are more consistent on the results of deep learning, that is, deep learning shows that students apply what they have learned to new scenarios and solve practical problems (Robertson, J., & Howells, C. 2008).

Learning definition and application based on game design

Learning based on game design, that is, the student is the designer of the game, the process of game design is the process of learning. In the Chinese literature, no scholars explicitly put forward the concept of "learning based on game design", but in the foreign literature, the author found many similar expressions, such as computer game making, game-base construction learning, computer assisted game making, learning through game-making, etc., although there are differences in the name, in terms of connotation, the game design is the content of teaching, allowing students to actively learn and construct knowledge in the process of designing the game. Develop high-level thinking skills.

Game design is a comprehensive task that provides students with an effective learning context that encourages students to use a variety of skills to create complex artifacts such as game rule design, character creation, visual design, and Computer Programming (Robertson, J. 2012) .
Compared with the single identity of the "player" that the learner only has in the game, the learner will have different identities such as user, designer, copy plan and programmer in the game design process. It promotes the initiative and creativity of students, and there are constant trial and error and modification iterations in the game production process. This process cultivates students' problem-solving ability and deep understanding of knowledge (Vos, N., van Der Meijden, H., & Denessen, E. 2011).

Many researchers have conducted empirical research to verify the effectiveness of learning based on game design. Some researchers apply game design to programming and mathematics to improve students' learning performance. For example, Wilson uses Scratch for programming teaching, and evaluates the game designed by students from the perspective of procedural knowledge, programming structure and practicality. It is finally found that students use interactive, loop and conditional statements in the game. The programming concept is well mastered (Wilson, A. , Hainey, T. , & Connolly, TM . 2013). Denner asked students to create games with programming software after class, and found that programming activities can promote students' understanding of programming concepts (Denner, J., Werner, L., & Ortiz, E.,2011). Jiang Fengguang and others used Scratch to write math games to promote students' mastery of mathematical equations (Chiang, F. K. , & Qin, L. .,2018). In addition to promoting the mastery of specific subject knowledge, more researchers have explored the impact of this approach on student abilities, such as problem-solving skills, critical thinking, and creativity. Gary built the game design pattern (GMP, full name Game Making Pedagogy) to solve the learning problems students encounter when using interactive media. The model sets up seven stages to guide students to design, develop and debug their own games. Can promote students' problem-solving skills, learning motivation, and creativity in interactive media (Cheng, G. ,2009). Robertson explored the impact of students using Neverwinter Nights 2 software to make their own successful learning in the UK's excellence program. The study found that students' motivation to learn, knowledge transfer, and determination to complete tasks were achieved through the production of computer games. Upgrade . Thomas explored the impact of this approach on 21st century skills, and found that students have improved problem-solving skills and creativity in the production of game projects (Thomas, MK , Ge, X. , & Greene, BA ,2011).

In summary, in the programming teaching of primary and secondary schools, there are problems such as difficulty in understanding the concept of students' knowledge, lack of motivation, and low creativity, which cannot achieve the goal of deep learning. The game design-based learning effectively improves students' learning motivation, knowledge construction level and problem solving ability by providing real problem situations, rich tasks and multiple roles, which promotes students' deep learning. Therefore, this study will apply the game design-based learning to the programming teaching of open source hardware, and explore its impact on deep learning of programming. The specific research questions are as follows: **Can game-based learning promote deep learning in middle school programming?**

At the same time, according to the evaluation dimension of deep learning, the problem is divided into the following sub-problems:

(1) Can learning based on game design improve the cognitive level of learner programming knowledge?

(2) Can learning based on game design promote the development of students' high-level thinking?

(3) Can learning based on game design improve the emotional level of students' learning programming?

THEORETICAL FRAMEWORK

Learning framework based on game design

The task-driven approach believes that the learners, learners, and learning activities are the core elements of the teaching process. The richer the learning activities, the richer the teacher's behavior will be, the better the corresponding student behaviors and learning effects will be. The relationship between them can be Expressed as: Q=F(AT, AS, T) (Du & Fan,2006). When setting up tasks, the driving problem should have practical directivity. The problem of designing mosaic

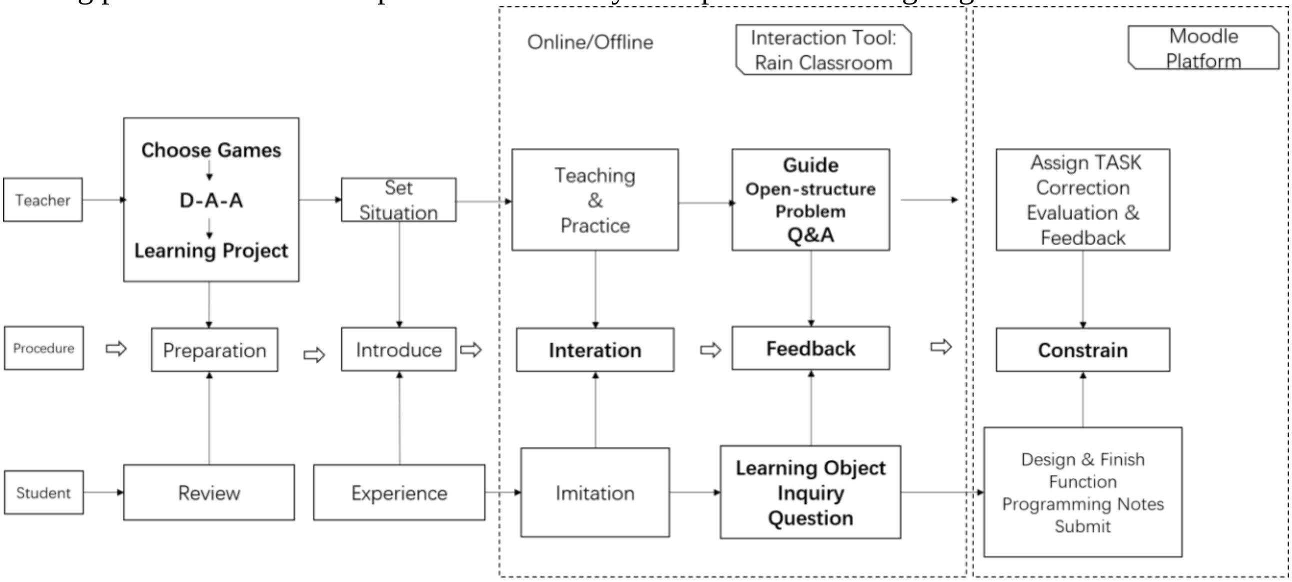

Figure 1 Experimental group "learning based on game design" teaching framework

knowledge must have certain problem space and the characteristics of complexity and multi-path, and cultivate students to use knowledge to solve practical problems (Lindh, J., & Holgersson, T.,2007). The completion of deep learning requires three stages: knowledge acquisition, skill development, and application of knowledge to solve problems. The transition between each stage does not occur naturally, and it depends on certain strategies (Kucuk, S., & Sisman, B.,2017). Based on this, this study adopts the framework and process of task-driven method, and uses game design as a strategy to support the promotion of each teaching link, in order to promote the deep learning of student programming. The framework built is shown below:

In the pre-class preparation stage, the teacher refers to the reverse engineering DAA activity model and transforms the actual game into a teaching case through the three steps of "deconstruction-analysis-reorganization". The task setting of the experimental group follows three stages of deep learning, namely, the acquisition of knowledge, the improvement of skills, and finally the use of knowledge to solve problems. Specifically, in the task setting, the first stage "interactive task" corresponds to the knowledge acquisition, that is, the basic use method of the master component, and the second phase "feedback task" corresponds to the skill improvement, and the phase is a shallow to deep transition link, so the task Set to semi-open, pointing to problem solving, while also retaining a certain problem space.

MATERIAL & METHOD

Context

The study subjects were 50 high school students from the affiliated middle school of Peking University, including 25 in the experimental group and the control group. All the participants were enrolled in the open source hardware course through the school elective system. The students mainly came from the first year of high school. Most of the students had taken the python course and had a certain programming foundation. However, most students did not have access to opensource hardware. Therefore, the operational skills are relatively lacking. At the same time, the development level of high school students' thinking is relatively perfect, with high abstraction and theory.

Due to the randomness of the course selection, this study analyzed the initial level of the subjects. The source grades, elective courses, and instructors of the subjects were all different, and they were not comparable. Therefore, the whole study was selected. Uniform evaluation criteria: GPA, as a pre-test data. There was no significant difference in the grade points between the experimental group and the control group, which met the requirements of quasi-experimental research and could be followed by experimental intervention.

Procedure

The study began in July 2018 and ended in July, with a total of 36 weeks of 9 weeks, including two lessons per week, each with a duration of two hours. In the first 16 weeks, the experimental group and the control group completed the basic knowledge of software and hardware. From 17 to 28 hours, the experimental group used game design-based learning, and the control group used skill-based learning. In this process, students' programming was collected. Notes; After all the courses have been completed, the students' knowledge mastery will be tested by paper and pencil, and the students' final works will be collected. Finally, the collected materials and data are analyzed to draw conclusions.

Design method for evaluation of deep learning

This study uses a game design-based learning approach to design the curriculum, and in the teaching to verify its promotion of student programming deep learning. The evaluation of deep learning is carried out in three dimensions: cognition, thinking and emotion. The study collects the test scores of the students, the final works of the students and the programming notes. The corresponding measurement dimensions and methods are shown below:

Table 1 Deep learning evaluation dimensions and tools

Data Collection	Assessment Dimension	Research Tool
Knowledge test score (subjective, objective)	Cognitive	Test
Product （program、text、picture、video etc.）	Cognitive、 Thinking 、Emotion	Assessment Scale
Programming Notes	Cognitive、 Thinking 、Emotion	Qualitative coding

DATA ANALYSIS & DISCUSSION

Game-based learning is less effective in applying and analyzing cognitive goals

Since the experimental and control samples in this study were all 25 samples and belonged to small samples, the Kolmogorow-Smirnov Test and the Levene Test were used to test the normality and the homogeneity of the variance, respectively. The sample was found to satisfy a normal distribution with no difference in variance. An independent sample t-test was performed on the data of the experimental group and the control group, and the data were as follows:

Table 2 Experimental group and control group test score independent sample t test

Item	Category	Num	Avg	SD	SE	t	Sig.
Total	Experimental	22	76.09	14.395	3.069	0.917	0.365
	Control	21	72.00	14.873	3.246		
Deep-learning Score	Experimental	22	43.59	10.276	2.191	0.446	0.658
	Control	21	42.14	11.001	2.401		
Surface learning	Experimental	22	25.50	5.125	1.093	1.587	0.120
	Control	21	22.86	5.790	1.264		

As can be seen from Table 11, the scores of the total score, deep knowledge and shallow knowledge of the experimental group were higher than those of the control group, but they did not reach significant differences. Therefore, there was no difference in the scores of the knowledge test between the experimental group and the control group.

Learning based on game design has a positive impact on students' deep knowledge application and emotional input

The students' work was scored from the three dimensions of cognition, thinking and emotion, and the scores of the experimental group and the control group were tested differently. Since the sample size is small, all the data are tested for homogeneity and normality of the variance. In the end, only the two scores of the total score and the depth of knowledge application are satisfied. An independent sample t test can be used, and other items are used. Mann-Whitney U test of parameters.

It can be seen from the table that the works of the experimental group are superior to the control group at the overall level ($P=0.031<0.05$), and the experimental group is also more obvious in the depth of knowledge application ($P=0.035<0.05$). It shows that the experimental group has a deeper understanding of knowledge when making works. At the same time, in terms of emotion, the experimental group showed more time input ($P=0.01<0.05$) and resource call ($P=0.01<0.05$) than the control group, indicating that the use of game design-based learning promoted students' emotional aspects. Level of commitment.

Table 3 Experimental results of different dimensions of the experimental group in the experimental group

Dimention	Test	Group	Avg	SD	t	Sig.
Cognition	Score	Experimental	32.09	7.661	2.322*	.031
		Control	24.64	7.393		
	Experience	Experimental	3.18	.874		.300
		Control	2.82	.603		
	Width of application	Experimental	3.27	.905		.116
		Control	2.64	.809		
	Depth of application	Experimental	3.55	1.073	2.268*	.035
		Control	2.45	1.214		
Emotion	Explore	Experimental	3.45	.934		.797
		Control	3.18	1.328		
	Resource	Experimental	3.91	.701		.010*
		Control	2.55	1.293		
Dimention	Test	Group	Avg	SD	t	Sig.
	Time engagement	Experimental	3.73	1.218		.010*
		Control	2.18	1.328		

$^{*}p<0.05$

Learning based on game design can promote students' deep application of knowledge, improvement of program logic structure and emotional input

In terms of knowledge mastery, the control group stayed in the simple combing and review of knowledge, while the experimental group was able to call more previous knowledge to solve the problems encountered. In terms of thinking, the experimental group had higher complexity and more functions than the control group. The control group mainly realized the basic functions. Some students carried out the function development at the detail level on the original basis. The students in the experimental group tend to propose new requirements and implement them on the basis of the original. At the same time, in terms of debugging procedures, the experimental group showed more exploration and deeper learning than the control group. The control group generally only objectively lists the difficulties encountered in programming, and the experimental group basically formed the behavior pattern of asking questions → analyzing the causes → solving the problems. After asking questions, students in the experimental group tend to find out the cause of the bug and debug it. In terms of emotions, the students in the experimental group recorded their sense of accomplishment, interest in the task, time and energy invested in the programming notes, and some students expressed their fears, while only one classmate in the control group expressed the task. Interested.

CONCLUSION & FUTURE

In order to promote students' deep learning in programming, this study combines the elements of deep learning with game design, proposes a learning style based on game design, and adopts a paradigm of quasi-experimental research to explore the way in cognitive, emotional and thinking.

The impact of dimensions on students' deep learning, through data collection and analysis, is concluded as follows:

Learning based on game design can promote students' deep application of knowledge

In this study, an independent sample t-test was conducted on the test scores of the students. It was found that the experimental group was higher than the control group in terms of total score, deep learning score and shallow learning score, but they did not reach significant difference. Because of the limitations of the paper-and-pen test on the analysis and creation of the two dimensions of the target evaluation, it shows that there is no difference between the experimental group and the control group in the dimensions of memory, understanding, application and analysis. The analysis of the student's work found that the students in the experimental group had more indepth application of knowledge in the production of the work. The functional design of the experimental group was more complicated. When using the same knowledge point, the students in the experimental group focused more on the analysis and evaluation. Application, not simple operation. By analyzing the students' classroom coding, it is found that the experimental group can link the newly learned knowledge with the existing knowledge, and realize the in-depth understanding of knowledge through the interaction of concepts (Kucuk, S., & Sisman, B. ,2017).

Learning based on game design can promote the development of students' higher-order thinking

This study analyzes the student's programming notes and draws conclusions. The experimental group showed more problem solving and improvement of the program logic structure, and higherorder thinking was improved. This study conducted a differential test on the scores of the thinking of students' works, and found that there was no difference in thinking between the experimental group and the control group. The conclusions of the two data analyses are inconsistent. The reason may be that the student works are completed by the peers. The way of peer collaboration makes up for the lack of learning methods and promotes the development of students.

Learning based on game design has a positive impact on students' emotional level

This study analyzes the emotional scores of student works and draws conclusions. The experimental group used more resources and invested more time in making the works, and had more emotional input. The emotional input code of the student's programming notes was analyzed, and it was concluded that the experimental group expressed more emotions and invested more energy. This may be because the students in the experimental group have more immersion and more emotional experiences when exploring and interacting. The study found that on the whole, girls are more willing to express emotions than boys, and the proportion of statistical writing found that 90% of the notes were written for girls. Other studies have similar findings, that boys do not like to follow the teacher's instructions, while girls are more concerned with the task of writing (Thomas, MK , Ge, X. , & Greene, BA ,2011) In the study of pupils' behavior patterns, Kucuk found that female students expressed more feelings than boys, and that girls had more negative emotions than boys (Cheng, 2009). In terms of learning interest, students in the experimental group showed higher interest in teaching cases. It may be because of the fun nature of the game itself that gives students the interest and motivation to learn further.

The setting of game difficulty will affect students' cognitive level and emotional input.

Learning based on game design is a double-edged sword. This study found that in the ninth lesson, students' programming notes have more positive feedback and functional design, but in the notes of Lessons 10 and 11. There is a more extreme situation. Some students express the fun of the game and the sense of accomplishment obtained through the design of the game. However, some students express that the task is too difficult and the individual ability cannot be completed. The main reason is the difficulty of game design. The game functions in the last two sections are more complicated and difficult. Therefore, in future research, it is necessary to coordinate the balance between the difficulty of the game and the new knowledge.

With the promotion of programming education in primary and secondary schools, how to better promote the deep construction of students' knowledge and the development of higher-order thinking is a common concern of researchers and front-line teachers. Compared with the existing research, this study draws on the strategies of other disciplines to promote deep learning, and integrates it with deep learning, and proposes a game-based learning method suitable for open source hardware programming, which improves the current imitation of programming teaching. The problem of light application has promoted the deep learning of student programming. At the same time, in the game design-based learning, the difficulty setting of the game is the key factor for the effect of the method, and future research can focus on the balance between the difficulty of the game and the new knowledge. Finally, in many studies, collaboration is also an important way to promote deep learning, and it is also an effective measure to reduce the difficulty of programming. Although this study involves collaboration, it does not collect relevant data, nor does it have programming collaboration and deep learning. The relationship is explored, and future research can choose such concerns and conduct research.

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EXAMINING THE MANIFESTATION OF SCIENTIFIC EMPATHY AMONG KOREAN ELEMENTARY SCHOOL STUDENTS

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ABSTRACT

The purpose of this exploratory study was to examine how scientific empathy manifests among a select group of Korean fifth-grade elementary school students during a problem-solving process. The students (n=12) were divided into three groups according to their empathic abilities and assigned a common scientific problem to solve. An analysis of their linguistic interactions was conducted. The analysis confirmed that almost all factors of scientific empathy (name them) were expressed in the students' inquiry process to varying degrees. The overall manifestation of scientific empathy in their inquiry process was found to be affected by the level of general empathy. However, the emergence rate of scientific empathy factors did not appear proportional to the level of general empathy ability. Although the lower general empathy group had less frequent utterance on total scientific empathy, this group's utterance ratio of each scientific empathy factor, it nonetheless was relatively higher than that of other groups, except for the emotional empathetic concern factor. In addition, in the case of groups where the higher utterance rate of total scientific empathy manifested, the utterance of scientific practice increased over time. The study concludes that scientific empathy has different characteristics from general empathy and its factors have a positive effect on scientific practice.

Keywords: *scientific empathy, empathic ability, scientific practice, linguistic interaction, problem-solving*

INTRODUCTION

Scientists seek to solve questions about phenomena through inquiries (Braben, 1994). These inquiries, as a problem-solving process of scientists, have emphasized a rational aspect in science education so far. (Hafner & Stewart, 1995). Recently years, however, the importance of solving problems through its “non-rationalize” or emotional aspects of the endeavor have begun to be considered. Especially, the concept of inquiry emphasizes sociocultural characteristics and practice (Nersessian, 2002). In response, some argue that learning takes place not only in individual cognitive processes but also in social interactions, and that the results should be measured not only in terms of personal ability but also in how well individuals engage in social activities (Lave & Wenger, 1991). In this respect, the use of empathy in the process of problem-solving, which encourages the active participation of students in inquiry and enhances group solidarity, should take an important role in science education.

Generally, empathy is defined as cognitive and emotional responses to others in a perceived meaning or emotion in various situations as if they were one’s own, which emphasizes cognitive and emotional characteristics in interpersonal relationships. The shared goals among all members for effective cooperative interactions for collaborative problem-solving are one of the most useful methods to support and promote understanding and trust between people of various backgrounds and talents (Martin, 2010; Park, 2010). So, these social aspects of empathy, even in very heterogeneous groups, have the potential to aid problem solving process (Chopik, O'Brien & Konrath, 2017).

Empathy is an element that gives insight not only from the social aspect, through relationships with others, but also from the individual perception in pedagogy. Teich (1992) highlighted that if students feel empathetic towards a topic, this feeling helps them to produce unique solutions to problem-tasks through diversity of sensory engagement. In particular, Zeyer and his colleague (2019) mentioned the importance of empathy in science classes. In this line, Kohut (1975) argued that scientific methods used in science are far from actual observations, and that if empathy is applied to science as an observation tool, the depth and breadth of the research would be expanded. After all, the consideration of empathy in modern science education could be a catalyst, and an important element of social discourse to stimulate students who are the main agents of recognition of science concepts. Considering that contemporary scientific practices are phenomena which manifest through scientists' reciprocally engaged meaningful practices of experimentation and theorizing (Rouse, 2002), empathy will often play an important role in students' scientific practice in terms of interaction with others and personal cognition that occur during their *'Doing Science*'. However, the study of empathy has been extremely rare in science education. Even science classes require empathy that reflects their academic characteristics (Chun, Yang & Kang, 2018; Yang & Kang, 2019), so the study of empathy in the scientific inquiry process should reflect the fundamental praxis of scientists (Osbeck, Nersessian, Malone, & Newstetter, 2011). However, previous studies on the link between the nature of scientists and empathy were only presented as part of scientist's epistemic affect (Jaber & Hammer, 2016) and, in a similar context, an analysis of scientific empathy among scientists (Yang & Kang, 2019). Among them, Yang and her colleague noted that a total of 11 scientific empathies are extracted from empathy expressed by scientists. Based on the *Interpersonal Reactivity Index* (IRI; Davis, 1980), scientific empathy they analysis are such as 'Empathy from the perspective of the research object', 'Feeling like part of object', 'Influenced by fellow researchers' motivation', and 'Sensitivity to problems'. It is educationally significant that scientific empathy appeared in the above scientists' problem-solving process and has been confirmed through the students' case. In particular, it is necessary to select students who are similar characteristics of the scientists' group to find out how the scientific empathy factors appear in their problem-solving process and how they differ from the general empathy ability. Also, there is a need to confirm whether the scientific empathy identified during a scientist's inquiry process plays a role as a factor in the engagement and sustenance of students' scientific practices from their *'Doing Science'*.

Based on the previous research on the empathy of the scientists, this exploratory study seeks to confirm whether such scientific empathy appears to manifest in the situation of students' science classroom-based problem-solving activities and persists the dynamics of learner's engagement through scientific pursuit by linguistic discourse. In this study, research questions were as follows:

1) How is the emergence of scientific empathy factors influenced by general empathy in the students' science classroom-based problem-solving activities?
2) How is the scientific empathy related to scientific practice as students' problem-solving progresses?

METHOD

Participants

This study considered 16 fifth grade elementary school's students in a medium-sized city in Korea. The research participants were recruited in response to Greg Feist's (2006a, p. 115) view of traits of scientists as interest, talent, and achievement in science. Only those data of science club students who had high scientific interest and science achievement over the score of 90/100 were used for analysis if they and their parents had consented to the study which yielded a total of n=12 individual students for the final analysis. In addition, they were tested for levels of general empathy with the *Interpersonal Reactivity Index* (Davis, 1980), and as a result of this, students were classified as "Higher" in the top 30% and "Lower" in the bottom 30% relatively (Table 1).

Table 1 Differences in empathy among the groups (n=16)

Level	Higher	Medium	Lower
Group A	1	2	1
Group B	4	-	-
Group C	-	-	4
Excluded group of Research	-	4	-
Total	5	6	5

Context of the project

The project was similar to the problem-solving of scientists in the "*2012 Basic of STEAM Program for Gifted*" (KEDI, 2012) and applied to students as participants. In this project, which took place from June to July 2016, the researchers focused on 'idea generation' and 'prototype' stage, where students can experience the inquiry process in authentic ways like practicing scientists. A total of four, one-hour activities were held each week for a month, with the topic "*Let's become a balancing artist*". The project contents were for students to learn basic knowledge of balancing and to design and complete the most balanced structures for each small group.

Analytical methods

The data collected comprised field notes of instructors and observers, and audio records about group activities. For articulate reflection of students' feeling and thinking, individual student interviews were conducted, and collective small group interviews completed once the analysis of the students' utterances in each activity was finalised. Applying the constant comparative method (Glaser, 1965), the implied meaning of the data collected was multilaterally analyzed. All recorded contents were transcribed and then analysed by scientific empathy (Yang & Kang, 2019) and scientific practice (NRC, 2012, 42p) frameworks.

RESULTS

Factors of Scientific Empathy in Students with similar scientific learning abilities

In the case of Group A that heterogeneously composed the level of general empathy, even though their linguistic interaction occurred most actively, the emergence of their scientific empathy was represented by 55.5% of all utterances. However, in the group with high general empathy (Group B), a large part of the overall utterance was identified to be scientific empathy (68.4%), and the group with low general empathy (Group C) showed less emergence of the scientific empathy of overall utterances (28.6%). And, when this group was classified by the level of general empathy, it was confirmed that the higher general empathy level appeared as the greater emergence of scientific empathy in their whole linguistic interaction. Table 2 shows the utterance results of the scientific empathy factors when the 12 students were divided into groups according to their general empathy ability and then engaged in the common problem-solving project.

Table 2 Scientific empathy linguistic interaction between groups

Scientific empathy		Heterogeneous Group A	Homogeneous Group B	Homogeneous Group C	Total
Perspective Taking (PT)	Empathy through other disciplines	38(12.6%)	32(13.2%)	20*(21.1%)*	90(14.1%)
	Empathy from the perfective of the research object	31(10.3%)	9(3.7%)	8*(8.4%)*	48(7.5%)
	Accommodating other's opinion	86(28.5%)	49(20.2%)	13(13.7%)	***148(23.2%)***
Scientific empathy		Heterogeneous Group A	Homogeneous Group B	Homogeneous Group C	Total
Fantasy (FN)	Imagination through experiment based on observation	0(0%)	0(0%)	0(0%)	***0(0%)***
	Thought experiment	34(11.3%)	28(11.6%)	18***(18.9%)***	80(12.5%)
	Feeling like part of object	2(0.7%)	7(2.9%)	5***(5.3%)***	14(2.2%)
Empathic Concern (EC)	Influenced by fellow researchers' motivation	29(9.6%)	***48(19.8%)***	3(3.2%)	80(12.5%)
	Touching from the subject	24(7.9%)	***22(9.1%)***	2(2.1%)	48(7.5%)
	Excitement studying more	29(9.6%)	***26(10.7%)***	3(3.2%)	58(9.1%)
Personal Defense (PD)	Heartache for others' failure in their research	16(5.3%)	9(3.7%)	6*(6.3%)*	31(4.8%)
	Sensitivity to problem	13(4.3%)	12(5.0%)	17***(17.9%)***	42(6.6%)
Sum of Scientific interaction		302(55.5%)	***242(68.4%)***	95(28.6%)	636(51.7%)
Total linguistic interaction		***544***	354	332	1230

First of all, the data have been interpreted with an emphasis on the overall of manifested factors. In general, students demonstrated 10 factors out of 11scientific empathy factors. The most frequently uttered factor was 'Accommodating other's opinion' represent more than 20% of utterance across group types. In the Watson and Crick's cases (Watson, 1968) Yang and her colleagues analysed, they suggested that this factor appeared a lot in the process of identifying the DNA structure by listening to the opinions of other experts in the field. The emergence of scientific empathy factors under the level of general empathy showed a big difference in EC, an emotional empathy factor with others. The higher empathy group (Group B) showed higher scientific empathy factors associated with EC compared to other groups, while lower empathy group (Group C) showed relatively higher utterances in scientific empathy factors of personal cognitive attributes than other groups, except for EC attributes. In particular, even in groups with low empathy ability, there is a factor that shows relatively many utterances in terms of scientific empathy, so it can be indirectly confirmed that scientific empathy is different from general empathy.

Linguistic Interaction of Scientific Empathy and Scientific Practice by Groups

To identify the relationship between general empathy and scientific practice, comparing Scientific Practice discourse by group, the total number of Group A cases was 149 (22.4%). Group B was 150 (35.0%) and Group C was 110 (27.7%). The higher general empathy group had many utterances on scientific practice, but even though in the less general empathy group, the utterance of scientific practice did not appear to be the lowest. Since the relationship between general empathy and scientific empathy cannot be seen as a positive correlation, we compared scientific empathy with the scientific practice over time. These comparison of linguistic interactions among three groups over time is presented in Figure 1.

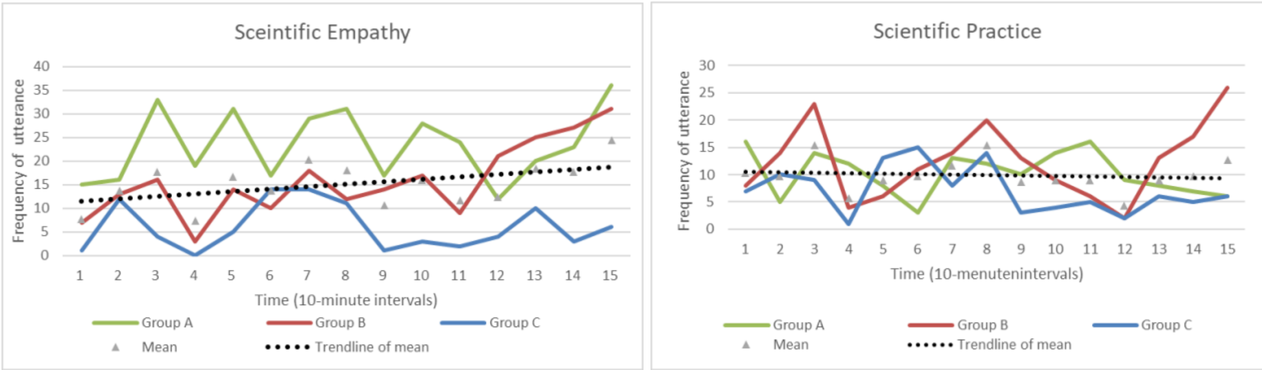

Figure 1. Comparison of verbal interactions frequency among three groups by time

Through the mean trendline of the three groups, the scientific empathy factor is increasing as the problem-solving process progresses, but the scientific practice is consistent.

The heterogeneous general empathy group (Group A) has been found to increase scientific empathy over time but decrease scientific practice. However, homogeneous general empathy groups (Groups B and C) increased both scientific empathy and scientific practice as the problem-solving process progressed. Of course, in the case of Group B which appeared a lot of EC-related scientific empathy factors, scientific empathy and scientific practice utterances increased above the average at one point in time. By the way, group C which expressed many individual cognitive attributes of scientific empathy was ascertained to increase at below the average trend.

DISCUSSION

Ideal scientific inquiry comes from a fusion of cognitive, epistemological and social aspects (Hafner & Stewart, 1995). In this respect, empathy plays an important role in science education (Zeyer & Dillon, 2019). In this exploratory study, the dynamic of the scientific empathy factor manifested was identified as the difference from the general empathy and the influence of the emergence and stability of students' scientific pursuits.

First, groups with high levels of scientific achievement and interest in science showed more than half of the utterances of scientific empathy in the process of solving problems. Although not all factors of scientific empathy were evenly emergent according to the level of general empathy, certain factors of scientific empathy were stimulated by the level of general empathy. The group with high general empathy showed high frequency of scientific empathy related to EC, and the group with low general empathy showed high in various widths of scientific empathy emergence on personal aspects of PT, FN, PD. This suggests that scientists with high general empathy will have many scientific empathy factors of emotional attributes through relationships with others, and those with low general empathy will have many scientific empathy factors with individual cognitive attributes. In other words, a group with a high level of scientific achievement and interest may manifest certain parts of the scientific empathy factor even if the general empathy ability to generate interactions with others is low. As a result, it was confirmed that scientific empathy appeared in the problem-solving process as a different role from general empathy. This study is meaningful because the results of previous studies on the specificity of scientific empathy (Chun et al., 2018; Yang &

Kang, 2019) were confirmed through the substantial interaction of students. Second, it confirmed the influence of scientific empathy on sustaining the scientific pursuit of students. Through the analysis of intra-group linguistic interactions with scientific empathy and scientific practice, it was indirectly ascertained that scientific empathy affected scientific practice and was steadily improved over time in students' scientific problem-solving processes. In the group of high scientific empathy with others' emotional attributes (Group B), the interactions related to scientific practice were expressed more often from the latter part of the problem-solving process. On the other hands, in the group of high scientific empathy in personal cognition (Group C), the number of utterances on scientific practice increased steadily in the problem-solving process later even though the number of utterances were few. Based on the above findings, it could be confirmed that scientific empathy is inherent in empathy in terms of personal cognitive in addition to empathy with others' emotion, which is usually found in general empathy. And these two aspects continue to engage students in science by interacting positively with scientific practice. Although this study is significant to confirm the relationship between the specificity of scientific empathy and the persistence of science participation, there are limitations to it. First, scientific empathy and scientific practice showed the opposite pattern in the heterogeneous empathy group as the problem-solving process continued. Second, 'Imagination through experiment based on observation' among the scientific empathy factors was not identified in students' linguistic interactions. At last, the lower general empathy group appeared the under average utterance of scientific empathy and scientific practice. So, further research is needed to explain these limitations. To understand the emergence and stability manifested in students' scientific pursuits, it is essential to study their scientific empathy within those pursuits.

This exploratory study is meaningful in that scientific empathy itself has idiosyncrasies that are different from conventional empathy, and it can also predict that scientific empathy as the characteristics of scientists can interact positively with students' engagement. However, there will be limitations in generalizing the phenomenon, which was verified in a single project. In future research, it is necessary to modify and supplement the questionable parts of scientific empathy applied to science education with a much larger sample.

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OWNING STEM: PRE-SERVICE TEACHER'S PROFESSIONAL DEVELOPMENT THROUGH A COLLABORATIVE RESEARCH PROJECT

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ABSTRACT

Integral Science, Technology, Engineering and Mathematics (STEM) is a growing area in teacher education. Yet, there is still a dearth of resources to support early childhood educators' enactment of STEM education sensitive to the unique context of Canadian classrooms. Set in the context of linguistically and ethnically diverse urban Canadian classrooms, in this paper, we discuss a pre-service teacher's learning to envision her future STEM teaching, through her engagement with a collaborative research project between her university and a local school board. With the ethnographic data including video, interview, and observation notes, the pre-service teacher engaged in analysis focusing on the characteristics of integral STEM teaching in early childhood education (Grade 1 and 2). Her learning centralizes the notion of owning or appropriating STEM that allowed the development of diverse and enhanced images toward STEM among young learners. Also, she came to understand interdisciplinary and interconnected ways to maximize and personalize the (limited) resources for early STEM education available in an urban school. We discuss the significance of research engagement that involves video-based analysis of students' learning and an experienced teacher's enactment of STEM education, as a form of professional development for pre-service teachers.

Keywords: *STEM teacher education, pre-service teacher education, early STEM education*

GOALS AND OBJECTIVES

Integral Science, Technology, Engineering and Mathematics Education (STEM) education is an emerging content area for pre-service teacher education. STEM teacher education garnered growing attention in recent scholarship (Adams & Gupta, 2017; Davis, Chandra & Bellocchi, in press; Kim et al., 2015). In many parts of the world, STEM education is not yet an official curriculum and often subsumed under mathematics education or science education. Until recently, STEM education was not part of pre-service teacher education and a limited number of pre-service teacher education programs offer a mandatory STEM education course in Canada (Preciado Babb et al, 2016). Considering the distinctive history and epistemology within Canadian STEM education (Shanahan, Burke, & Francis, 2016), situating the uniqueness of Canadian early STEM education, including its linguistic and ethnic diversity, warrants further examination.

In this context, the goal of our paper is to gauge how a pre-service teacher came to understand and envision STEM education in the context of Canadian early childhood education, through her engagement with a collaborative research project. The project was achieved through the partnership among various stakeholders: teacher education program at the university, a local school board, and an urban school. We worked toward the common goal to improve access to rich STEM learning opportunities for all students, including newly arrived immigrant and refugee students living in economically under-resourced neighborhoods. Yuen (Author 1) is a pre-service teacher, who has backgrounds and interests in STEM disciplines, who is also an early childhood education specialist.

She is also a bilingual person and has the lived experiences relatable to many students in the school. Takeuchi (Author 2) has been teaching STEM education in pre-service teacher education at the university. We together engaged in school-based ethnographic study on STEM education by collaborating with a local urban school that is populated with a high percentage of "English language learners (ELLs)" or emergent bilinguals.

Our paper focuses on a pre-service teacher's learning afforded by the research experience and her dialogues with an experienced classroom teacher and a university-based teacher educator/researcher. In our literature review on STEM education, we noticed a relative dearth in early childhood education (Kindergarten to Grade 2) (except for, for example, Kazakoff, Sullivan, & Bers, 2013), compared to secondary and post-secondary education. Early encounters with STEM education are reported to be significant: Having high-quality early STEM experiences can support children's growth across areas as diverse as executive function and literacy development (McClure et al., 2017). In this context, our paper aims to demonstrate how engagement in a collaborative research project can be an impactful way to enhance STEM pre-service teacher education in Canadian early childhood education.

THEORETICAL FRAMEWORK

Central to our analysis and the pre-service teacher's narrative was: What does well-designed STEM education look like? To approach this question, we drew from Wertsch's (1998) distinction between *appropriation* and *mastery*. One of the central tenets of sociocultural theory is that human learning is mediated by technical and psychological tools (Vygotsky, 1978). Building on sociocultural theory, Wertsch attended to the tension between cultural tools and learners as active agents. Mastery is the process of knowing how to use cultural tools, whereas appropriation refers to "making a cultural tool one's own" (Wertsch, 1998, p.145). This distinction serves as a lens to discern teachers' *using* STEM tools from *owning* or making the STEM tools one's own. In the context of this study, we used this theoretical lens to distinguish teachers' mastery of STEM tools (e.g., knowing how to use Sphero and introduce block coding to students) from teachers' appropriation of STEM tools (e.g., adding personalized nuances to the use of Sphero as a tool to engage learners in community-based inquiry).

METHODOLOGY

We framed this paper from a narrative inquiry methodology to centralize the meanings a preservice teacher ascribed onto her experiences in the process of classroom-based research (Riessman, 1993). Taking a narrative inquiry methodology, we aim to understand the pre-service teacher's professional development *from within*, instead of gauging the phenomenon from outside. The study took place in two phases: 1) video-based ethnographic research on early STEM education in an urban elementary school (where the pre-service teacher was involved) and 2) collective analysis (between authors) on the pre-service teacher's narrative. This paper focused on the second phase to understand what a pre-service teacher learned through her involvement in the first phase, as she envisages her future STEM teaching. In the following section, we centralize her narrative as an integral part of our findings.

The study was conducted in a Canadian urban elementary school located within the inner city. The school principal described the school as a multilingual environment and comprised of more than 90% "ELL" or emergent bilingual students. Furthermore, the school is characterized as a transient setting generally acting as the first community where families settle after immigration and leave once they have settled down in the city. In terms of demographics, the school has a student population of approximately 340 students with representation of more than 40 different languages from around the world. During an interview process, students had identified the usage of various first languages other than English including: Arabic, French, Hindi, Kurdish, Malayalam, Mandarin, Portuguese, Russian, Tagalog, and Tamil.

Our study took place in an experimental elementary STEM classroom led by the learning leader (Ms. Jean, a pseudonym) of the school. The data was collected over two months between three different Grade 1 and 2 split classrooms with a total of 43 consented participants. We collected 25 hours of video data through 12 observation days. Each class received 90 minutes of STEM instruction per week and students focused on a continuous team-based STEM project that was interdisciplinary in nature. The data was collected through ethnographic methods including fieldnotes created through participant observations, researcher reflection/journaling, video and photographs of the observed classes, students' works during the observed classes and face-to-face interviews with Ms. Jean and students. Both fieldnotes and video/photographs helped to describe the details of social organization of the classroom, including classroom space, types of classroom practices, group formation, artifacts used/created in the class, teacher-student interactions, and student-student interactions. Our analysis started with content logging of video data and writing analytic memos.

While the first phase of our study was guided by an ethnographic methodology, the findings presented in this paper were guided by a narrative inquiry methodology to examine pre-service teacher's learning. Her narrative was constructed with the following guiding question in her mind: What is the framework of teaching practices that can lead to diverse images toward STEM among students? In order to analyze students' images of STEM, we analyzed a word cloud generated through a discussion that the teacher and students had on what STEM means. The word cloud shows the frequency of the words used by students to describe STEM: the bigger the text is, the more frequent the word was. The narrative introduced in the following section was constructed based on the pre-service teacher's classroom observations, interviews with an experienced teacher and students, and analysis of video data.

RESULTS AND DISCUSSIONS

In this section, we will highlight the narrative of a pre-service teacher (Yuen) on the central aspect of her learning: appropriating or owning STEM in the early childhood education context. As described in detail in this section, appropriating or owning STEM referred to teacher's capability of using one STEM tool for multiple pedagogical purposes and in an interdisciplinary manner. The following narrative describes one of the concrete examples of appropriating STEM in teaching and depicts the pre-service teacher's understanding of "appropriating STEM" as a pedagogical framework.

Narrative of the Pre-service Teacher on Her Learning

In this classroom, I (Yuen) had observed Ms. Jean use one of the robotics kits (Sphero) in various and intertwined ways: learning block coding, learning geometric shapes, discovering characteristics of buoyancy and density, building chariots, painting art pieces and engaging in a sharing circle using the Sphero. The Sphero was used as a connector of various disciplines (mathematics, science, art, and computational thinking).

The following example shows the process in which Ms. Jean used the Sphero in her STEM classroom. Ms. Jean started with mathematical goals at the core but then shifted the focus to create art pieces. In this sense, the Sphero as a single tool came to be used as a tool for students to engage in interdisciplinary learning. The learning task provided to the students was to create five geometric shapes using the Sphero. Ms. Jean provided the class on the board with the five geometric shapes that students needed to code with their Sphero. Ms. Jean emphasized that all the shapes can look differently; for example, students were told that diamonds were in fact squares because they too have four equal sides. During this process, students were required to think about the turning angles, speed and duration to which their Sphero are required to travel to produce geometric shapes. After several weeks of students working on coding their geometric shapes, Ms. Jean gave a new learning task of using the Sphero to create a painting that students can take home as a gift for their family members. Students used the geometric shapes that they created in the earlier weeks and had their Sphero be dipped in paint and to draw out on a large piece of poster paper (see Figure 1). As the Sphero had to stay within the Sphero arena (see Figure 1) to keep paint off the floor, students needed make alterations to their initial code the students created. During this process, Ms. Jean created a safe space for students to test and improve their existing code to build geometric shapes that can be painted. Students had shortly discovered that they had to alter the speed and time in order for their Sphero to successfully fit within the parameters of the arena. For example, students found that if their speed was too low, it would become stuck in the bumps of the cardboard-built Sphero arena. However, if the speed was too high, it would travel too quickly and exceed the space that was provided. Although the focus shifted to an art-based project, mathematics learning and coding developed earlier were embedded within this project.

Reflecting on this unit, I came to notice that, even with only one tool (Sphero), the students were able to engage in interdisciplinary STEM learning. Students were able to be immersed in rich disciplinary inquiries in an inter-connected manner. For example, in order to draw an art piece using the Sphero, students examined characteristics of geometric shapes and adjusted their code so they could paint what they desired to. Students were able to spend time immersed in the course content rather than learning how to use the tools. Through this well-designed unit, all students including the newly-arrived students expressed their ideas in various ways beyond language. For example, students used gestures to express geometric shapes they wanted to draw or they moved the Sphero to communicate with others. I learned that the teacher's passion and enthusiasm about her STEM can be passed onto the students to become more engaged and stimulates for further exploration.

From the Students' Enhanced Images Toward STEM

At the end of the year, Ms. Jean and each of her STEM classes created a word cloud asking for terms that students would use to describe STEM (Figure 2). We found that the words with the highest frequency being used to define STEM consisted of emotional, cognitive, and design elements. Some examples of these words included "fun, thinking, observe, building, making, testing." Some lower frequency words (i.e., smaller words in the word cloud) used to describe STEM included "artist and drawing" which were terms not as commonly associated with STEM. As Ms. Jean provided diverse teaching practises within her STEM classroom which resulted in the students' various understandings of STEM. Through the Sphero unit alone, the tasks were interdisciplinary in nature and were interconnected various disciplines in meaningful ways. With the diverse repertoire of teaching STEM exhibited by Ms. Jean, students were able to create a diverse image of what STEM means to them. This learning experience provided me as a pre-service teacher with a framework of teaching — appropriating and owning STEM — as I engage in my practicum experience and in my future teaching career.

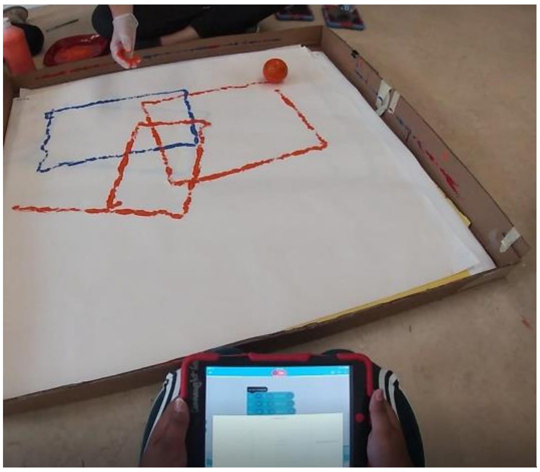

Figure 1. **Students' painting using a Sphero.**

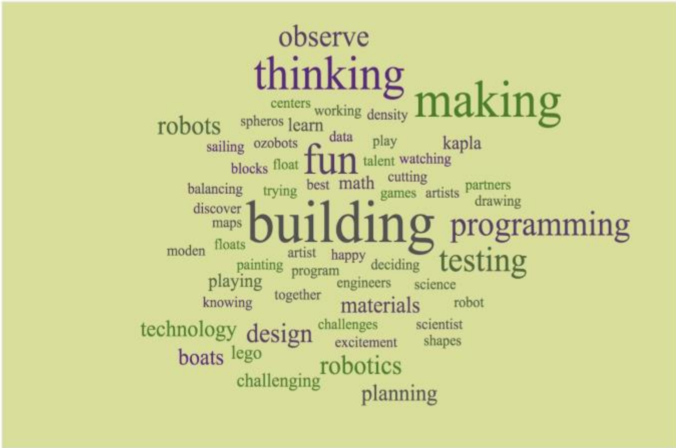

Figure 2. **Students' images of STEM.**

CONCLUSION AND SIGNIFICANCE

In this paper, we highlighted what a pre-service teacher learned about STEM education to envision her future teaching of STEM, through her involvement in a collaborative research project. In this context, the pre-service teacher's narrative introduced in our findings suggests how preservice teacher's conceptualization of STEM education came to expand by observing and analyzing the videos of classroom practices, listening to students, and conversing with a teacher, through her involvement in collaborative research. While the use of video analysis in pre-service teacher education has been discussed (e.g., Santagata & Guarino, 2011), our paper adds to the existing body of pre-service teacher education by demonstrating the power of research engagement within the context of early STEM education, centralizing a pre-service teacher's voice. Given that resources for early STEM teacher education is still limited, this paper suggests one impactful way to fill such a gap.

Based on the pre-service teacher's narrative, we shined light on the notion of *owning or appropriating STEM* to demonstrate the central aspect of learning that the pre-service teacher brought forward. In the classroom where the teacher *owned* STEM to teach, the teacher found interdisciplinary and interconnected ways to maximize and personalize the (limited) resources available in their environment. From this perspective, effective STEM education does not have to rely on quantities and diversity of materials available at schools. Instead, the teacher can develop a wide range of pedagogical facilitation to maximize one resource to advance early STEM education in a meaningful way. In such a classroom, as demonstrated in the findings introduced above, students —including newly arrived immigrant and refugee children—can develop diverse images toward STEM and foster key languages and practices (e.g., modeling, testing, designing, challenging, as seen in the word cloud in Figure 2) for their engagement with STEM disciplines. As we discussed in the Introduction, teacher education in the area of early STEM is still emerging, especially in Canadian contexts. Historically, who are included and who are excluded from the disciplines of STEM has been influenced by gender identities, language, race, and socioeconomic status (e.g., Adams & Gupta, 2017; McGee & Bentley, 2017). Situating our inquiry in a linguistically and ethnically diverse school, which is becoming more and more common in Canadian urban schools, we showed a possibility of advancing STEM teaching with students in need, from the early years.

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HOW DOES THE DEGREE OF GUIDENCE SUPPORT STUDENTS' COMPUTATIONAL THINKING IN EDUCATIONAL ROBOTICS?

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ABSTRACT

Computer programming education is widespread around the world. It has a direct connection with computational thinking, which has received considerable attention recently. Computational thinking is viewed as a critical and necessary skill in the 21st century that everyone should learn. Besides, six years ago, Wing had argued for adding this new competency to every child's analytical ability as a vital ingredient of science, technology, engineering, and mathematics (STEM) learning. The primary objective of the study is to analyze the effects and possibilities of enhancing the CT with robot education activities and the influence of teacher guidance degree. This study investigated the development of 44 students in 2th to 4th grade through a robot education course with WeDo 2.0. It adopts quasiexperimental research, and a strong guidance group and a minimal guidance group were set up to test the changes in the development of students' computational thinking under different levels of teacher guidance during the implementation of robot education activities. The results show that the robot education activities can effectively improve students' computational thinking, there is no significant difference in computational thinking between different teacher guidance, and students' computational thinking ability has no significant difference in gender.

Keywords: *robot education activities, teacher guidance, computational thinking*

INTRODUCTION

Computational thinking originated from the procedural thinking proposed by Simon Papert as early as 1980. In recent years, computer programming education attaches much attention in elementary education (Wilson, Hainey, & Connolly, 2013). In terms of the developing of computer programming skills, Lye and Koh (2014) believed that programming education is an effective way to cultivate students' computational thinking. Researchers argued that Computational Thinking (CT) is a fundamental skill for not only computer scientists but almost everyone (Zhong, Wang, Chen, & Li, 2016). Wing (2006) believed that CT was the process of applying problem-solving, system design, and human behavior understanding of basic concepts about computer science. It included a series of thinking activities that cover computer science and can be as important as reading, writing, and arithmetic to students. Researchers claimed that CT was an essential skill as reading, writing, and other basic language arts skills, pointing out that "programming is a language for expressing ideas (National Research Council, 2010). Besides, some other researchers also stated that the CT has five elements of abstraction, generalization, decomposition, algorithm, and debugging (Angeli et al., 2016). Although there was still no precise definition of computational thinking, the three-dimension framework of CT constructed by Brennan and Resnick (2012), including computational concepts, computational practices, and computational perspectives, has been recognized by many researchers. However, Shute (2017) summarizes more than 70 authoritative literature on computational thinking and divides it into six dimensions: decomposition, abstraction, algorithm, debugging, iteration, generalization, and set operative definition after each dimension.

Cultivation of CT

Through literature review, it is found that the computational thinking has been cultivated from different disciplines, such as Puttick & Tucker-Raymond (2018) and others have taught students about the role of climate change by using the Scratch design game in the visual programming environment to promote the systematic thinking and participation of students, combined with science education. Sáez-López, Román-González, & Vázquez-Cano (2017) use technical resources such as Scratch and Raspberry Pi to create a series of art projects through student-centered teaching methods to assess the integration of computational thinking in art education. Through various practices, researchers regard computational thinking more as a way of thinking, integrating it into mathematics, physics, art, and other disciplines, and integrating the cultivation of computational thinking. Besides, robot education is one of the main activities in developing computational thinking (Chen et al., 2017). Educational robots are powerful and flexible teaching and learning tools that use specific programming tools to engage students in robotic construction and control activities (Kim et al., 2015).

In addition, in the research related to computational thinking, many studies are comparing the gender and age of the subjects. Atmatzidou & Demetriadis (2016) uses appropriate CT models to explore students' CT skills in two different age groups and genders. Develop and determine that students eventually achieve the same level of CT skills development that is not related to their gender. The study found that girls, in many cases, require more training time than boys to achieve the same skill level. In the study by Shim et al. (2017), it is found that students have no significant differences in gender and age in computational thinking under robot programming activities.

The effect of teacher guidance

In the process of education and teaching, teachers have always played an indispensable role, and the debate about the influence of teachers in teaching has existed for at least the past half-century. Teacher guidance refers to the teaching interventions that teachers can support in the development of students' abilities during the teaching process, specifically the corresponding questions or tips that can guide students to improve their abilities (Gama, 2004). The researchers divided the guidance of teachers in the teaching process into three types: no guidance, minimal guidance, and strong guidance. The minimal guidance means that the teacher only gives guidance to the students in the process of teaching with verbal questions, hints, feedback, etc. Strong guidance means that the teacher not only gives verbal guidance feedback but also gives written questions and hints for certain ability training. Let students answer in writing to develop students' abilities (Atmatzidou et al., 2018).

In previous studies, some researchers believe that people learn best in an unguided or minimal guided environment. They usually think that learners must discover or construct basic information on their own, rather than providing the necessary information (Papert, 1980). In the process of minimal guidance, learners must discover or construct some or all of the necessary information for themselves, instead of providing them with all the essential information and being required to use it for practice and students can flexibly adapt to the problem in the problem-based learning process (Schmidt, Loyens, Gog, & Paas, 2007). However, a definite task can lead to an increase in the workload of the course, which may affect students and educators (Anewalt, 2002). And in robot education activities, Atmatzidou, Demetriadis, & Nika (2018) explored the impact of teacher guidance degree on students' metacognitive ability and problem-solving abilities. According to all the above studies, it is interesting to investigate the effects and possibilities of enhancing the CT with robot education activities and the influence of teacher guidance degree.

AIMS

The primary objective of the study is to analyze the effects and possibilities of enhancing the CT with robot education activities and the influence of teacher guidance degree. The specific goals are:

(1) Can robot education activities for computational thinking improve the computational thinking ability of primary school students?

(2) Does the degree of teacher guidance in robot education activities have a significant impact on the computational thinking ability of primary school students?

(3) Is there a significant difference in gender in the computational thinking ability of primary and secondary school students in robot education activities?

METHODS

This study adopts quasi-experimental research, and a strong guidance group and a minimal guidance group were set up to test the changes in the development of students' computational thinking under different levels of teacher guidance during the implementation of robot education activities. The pre- and post-test design and carried out for four rounds. 44 participants took part in each round, and the data was collected before and after class.

Participants

The participants of this study were 44 elementary school students (26 boys and 18girls) from Grade 2 to Grade 4,24 participants were in a strong guidance group, and 20 participants were in a minimal guidance group. After the implementation of the entire round of activities, the final effective data collected was 37. The data sources are from gender. Among them, there are 20 strong guide groups, 11 boys and 9 girls, with an average age of 8.2 years. The minimal guide group is 17 people, 14 boys, and 3 girls, with an average age of 8 years.

Fig.1 Students are completing the guiding task

Fig.2 Students are demonstrating their work

Instructional design

The instructional design was adopted from the teaching guide provided by WeDo2.0 with a problem-based learning approach. It consisted of four themes, including "Rocket launchers" Mars probes" Mars intelligence groups" and open one-hour challenge activities. The participants took one theme course in each round.

Instruments

The instruments include tools of strong guidance, minimal guidance, and the questionnaire of CT. The minimal tools are just verbal questions such as "What are the problems you are trying to solve? What is your solution? Can you describe it? Why are you doing this?" to guide the students' learning process. Strong guidance is the training of the corresponding ability. In the process of activity, the students can answer or write down the corresponding learning and thinking process through problems or prompts, to achieve the purpose of strong guidance. This study is based on six dimensions of computational thinking defined by research: decomposition, abstraction, algorithm, debugging, iteration, and generalization. Under each corresponding dimension, disassemble according to the problems that may arise in the robot education activities, write down the guiding issues. And tips for developing students' CT in a more targeted manner. As shown in Table 1. The questionnaire developed by Shim, Kwon, & Lee (2017), the reliability coefficient is 0.84, the Expert validity KMO value is 4.67.

Table 1 A strong guiding problem for the development of computational thinking

Dimensions	Questionnaire
Decomposition	Read the questions in the activity carefully and make sure you understand what these questions are asking? Discuss with other members of the group and write down any places you may not understand. Think about and write down which parts of the question can be broken down into?
Abstraction	Think about the goals you need to solve and record the relevant data. What is the relationship of law between this goal and the problem data? Draw this pattern.
Algorithms	Think about which modules and settings do you want to use? Use arrows to draw a series of instructions and steps you need. Think about which instructions can run at the same time and remove as many extra steps as possible.
Debugging	Does the robot really solve the required problem? If not, what could be the reason? Which piece of code have you identified this problem? Write down what changes you need to make to fix the problem.
Iteration	Is your solution to the ideal solution for you? Compare the code shown, what is the difference between it and your code? Think about how you can optimize your code or solution? Write down and run your optimization plan.

Generalization	What have you learned from this activity? Can I apply it to the event afterward? Thinking and writing down the key to helping you solve this problem? Think about how this kind of problem-solving can help you solve problems in your life or other situations? List one or two.

RESULTS

Paired sample T test of computational thinking

Results of pair-samples t-test of programming attitude indicated that the score of post-tests was significantly higher than score of the pretest from the minimal guidance group (t (17) =2.210, *p*=0.042), strong guidance group (t (20) =6.385, *p*=0.001).

Table 2 participants' programming attitude

			t	*df*	*p*	*Cohen's d*	
Minimal Guidance	17	CT	2.210	16	0.042*	0.536	
		Decomposition	6.769	16	<.001***	1.642	0.267
		Abstraction	1.102	16	0.287		
		Algorithms	0.543	16	0.595	0.132	
		Debugging	3.043	16	0.008**	0.738	
		Iteration	-3.801	16	0.002**	-0.922	
		Generalization	-0.765	16	0.455	-0.186	

* *p* < .05. ***p* < .01. ****p* < .001.

Table 3 participants' programming attitude

			t	*df*	*p*	*Cohen's d*	
Strong Guidance	20	CT	6.385	19	< .001***	1.428	¯1.396
		Decomposition	6.242	19	< .001***		0.487
		Abstraction	2.179	19	0.042*		
		Algorithms	3.308	19	0.004**	0.740	
		Debugging	3.943	19	< .001***	0.882	
		Iteration	-1.143	19	0.267	-0.255	
		Generalization	2.027	19	0.057	0.453	

* *p* < .05. ***p* < .01. ****p* < .001.

Covariance analysis of computational thinking

In this study, the covariance analysis was performed on the students' computational thinking ability and the total scores. The data results are shown in Table 4. We can see that the total score of the pre-tested thinking ability is significant (F=9.478, *p*=0.000), and the main effect of the group is not significant (F=1.2, p=0.281). The interaction between the pre-test score and the independent variable is not significant. (F=0.781, p=0.383), this result showed that there were differences in the scores between the different groups, which was mainly caused by the pretest scores (F=9.657, p=0.004), and the individual differences in the subjects were larger. However, the grouping variables of strong guidance and minimal guidance have no significant influence on students' computational thinking.

Table 4 Understanding of programming concepts

	SS_T	*df*	*MS*	*F*	*p*
Model	121.837	3	40.612	9.478	0.000***
Group	5.143	1	5.143	1.200	0.281
CT pre-test	41.383	1	41.383	9.657	0.004**
Group* CT pre-test	3.345	1	3.345	0.781	0.383
Error	141.407	33	4.285		
Total	5168	36			

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Gender difference in computational thinking

An independent sample t-test was conducted to analyze whether there was a gender difference in students' CT between different teachers' guidance. The analysis results are shown in Table5 and Table 6 that the score of post-tests was no significantly higher than score of the pre-test in minimal guidance (t=2.210, p=0.723, Cohen's d=0.253), strong guidance (t=-6.385, p=0.782, Cohen's d=0.123).

Table 5 Difference test between gender in minimal guide group

		Gender						
		Male（*N=14*）		Female（*N=3*）				
		M	*SD*	*M*	*SD*	*t*	*p*	***Cohen's d***
Minimal Guidance	CT	12.86	2.14	13.33	1.53	-2.210	0.723	0.253
	Decomposition	1.64	0.497	1.67	0.577	-0.074	0.942	0.056
	Abstraction	2.00	0.877	3.00	0.000	-1.925	0.073	1.613
	Algorithms	6.07	0.829	6.00	1.000	0.132	0.897	-0.076
	Debugging	0.86	0.770	1.00	1.000	-0.279	0.784	0.157
	Iteration	0.93	0.616	0.33	0.577	1.532	0.146	-1.005
	Generalization	1.36	0.497	1.33	0.577	0.074	0.942	-0.056

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 6 Difference test between gender in strong guide group

		Gender						
		Male（*N=11*）		Female（*N=9*）				
		M	*SD*	*M*	*SD*	*t*	*p*	***Cohen's d***
Strong Guidance	CT	10.45	2.34	10.11	3.14	-6.385	0.782	-0.123
	Decomposition	1.18	0.603	1.44	0.527	-1.024	0.319	0.459
	Abstraction	1.55	1.036	1.33	0.866	0.490	0.630	-0.23
	Algorithms	4.82	1.940	5.11	2.028	-0.329	0.746	0.146
	Debugging	1.00	0.775	0.89	0.782	0.318	0.754	-0.141
	Iteration	0.55	0.688	0.44	0.527	0.362	0.722	-0.18
	Generalization	1.36	0.505	0.89	0.601	1.922	0.071	-0.847

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

DISCUSSION AND CONCLUSION

According to the statistical analysis results of the data, the results of the students in the strong guidance group and the minimal guidance group are significantly different. It can be seen that the robot education activities of this study can be improved. However, different levels of teacher guidance have no significant impact on students' computational thinking ability. It might appear that the guiding tools for this study are still somewhat singular, and the strategies used by students are not the same. Besides, the modified program blocks are pasted into the strong guiding tools, while the girls prefer to think through pasting. Therefore, the presentation method and usage strategy of the guidance tool may also be one of the reasons that affect the result.

Moreover, the students' computational thinking ability does not show significant differences in gender. It is different from the results of Atmatzidou & Demetriadis (2016). In our study, through classroom observation, students have shown great enthusiasm for learning and interest in the whole process of robot education activities. Students can actively participate in robot education activities. The activities can mobilize the students' interest so that both boys and girls can actively participate in the activities and strive to complete the corresponding challenges.

Based on the findings of this study and the existing deficiencies, the following possible research points are proposed for possible future research directions such as the iterative teacher guidance tool can be electronically based on the characteristics of "digital indigenous" to explore the changes in students' computational thinking. Besides, in the robot education activities, the teacher's ability to guide students' computational thinking has no significant influence. Designing guiding tools to explore whether the other skills of the students in the robot education activities, such as spatial thinking ability, are influenced by the degree of teacher guidance.

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SYMPOSIA

DESIGNERLY WAYS, MEANS, AND ENDS FOR STEM EDUCATIONAL RESEARCH

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ABSTRACT

In this symposium, five panelists provide conceptual and empirical direction for exploring designerly ways, means, and ends in STEM educational research. STEM and STEAM are inadequate without recognition of the uniqueness of design. The first paper explores methodological innovations with point-of-view wearable cameras and a group of preschoolers. The paper addresses how and why children share, or may be reluctant to do so, as they design with digital technologies, from their point of view. The second paper explores preservice teachers' design of the digital self or professional image. Preservice teachers in this research inform researchers' understandings of design considerations and concerns that young professionals process as they curate their image through social media. The third paper explores instructional designers' experiences in a 3D virtual world design for the acquisition of cultural competence. Their insights challenge STEM education researchers to account for cultural nuances in design research. The fourth paper explores evidence-centred game design through a focus on *Falling Skies!*, which presents students with the problem of a mass mortality event. Drawing on a framework of inquiry-based learning and agency, the game challenges students to investigate why this happened. The fifth and final paper argues for an explicit role for design in STEM, perhaps as STEAMD. The paper draws from Cross's argument that design is unique in its ways of knowing.

Keywords: *STEM educational research, designerly ways of knowing, research methods*

Paper #1: Wearable Personal Cameras: Video Ethnography with Preschoolaged Children

This paper focuses on the unique characteristics of video ethnography with 8 preschool aged children. By using wearable person cameras, we were able to capture prosocial behaviours while children were using iPads and animation applications. Although some Research Ethics Board representatives and parents may disprove of the use of wearable, point of view video with young children, the use of researcher and wearable cameras in this setting to capture moment-to-moment behaviours and interactions was imperative to interpreting the cultural and social situations. The voices of young children have similar tones and can have speech difficulties, which are difficult to transcribe or understand without supporting audio and video and the ability to look at a child's mouth and vocal gestures. Also, the individual blue Snapcam Ion cameras were essential for the data analysis as they captured individual perspectives, with close-up microphones and footage that may not be captured in a researcher camera's angle. The objective of this paper is to explore how and why children share, or may be reluctant to do so, as they design with digital technologies, from their point of view.

Paper #2: Design of the Preservice Teacher's Digital Self

What are some primary concerns and priorities of preservice teachers as they craft, brand, and curate, or design, their digital self? How and why has the preservice teacher's digital self become a design problem? This paper reports on research with seven preservice teachers' insights into this problem. In a nutshell, through online platforms, one's private and public lives, or personal and professional images, risk collapsing or converging. Stakes are raised as students are given various cautions and warnings about this. What might raise a concern for a potential employer? What might generate concerns for young students' parents? How to professionalize the digital self? The problem is framed as a tension between the higher standard to which teachers are held and rising expectations that teachers be omnipresent in social media and technology. Findings emphasize that, for the participants, the design of the digital self is an ill-defined problem. Participants adopt fairly conventional means to design and manage their professional image. The conclusion begs a question of the higher standard in this era of SM and the intelligent web.

Paper #3: Design of a 3D Virtual Learning Environment for Acquisition of Cultural Competence in STEM Education: Experiences of Instructional Designers

This study explores the experience of instructional designers in a 3D virtual learning environment designed specifically for this research, with an objective of exploring the implications of cultural competence in the design of artifacts for STEM educational research (Zhao, 2019). The research question is: What are the experiences of instructional designers in a simulated immersive learning environment of a 3D virtual world in the design of artifacts for STEM educational research? The design of the 3D world and analysis of data draw on a framework based on Deweyan and Confucian theories of experience. Design-based research (DBR) and user experience (UX) methodologies are employed to explore the experience of instructional designers. A taxonomy of experience (ToE) established by Coxon (2007) guides qualitative data collection and analysis in this study. Users' data were distilled through nine steps to help experiences to be "seen" and to make abstract concepts comprehensible and visible.

Paper #4: Assessment for Learning in Immersive and Virtual Environments – Evidence-Centred Game Design in STEM

Creative thinking, problem-solving and inquiry skills are primary goals of teaching and learning. This paper reports on the development of an authentic performance assessment in science, technology, engineering and mathematics (STEM), *Falling Skies!*, built around an ecological, inquiry-based problem – where students are presented with the issue of a mass mortality event and are challenged to investigate why this happened. Assessment for Learning in Immersive Virtual Environments (ALIVE; alivelab.ca) is a research program that examines how 3D immersive virtual environments (3DIVEs), as assessments for learning, is designed to enable students to regulate their science inquiry abilities in real-time. Specifically, this project explores the use of 3DIVEs to provide feedback through the formative assessment of inquiry reasoning in the context of middle school life science. Ultimately, the ALIVE project aims to contribute empirical evidence of how students conduct complex logic, assisting them to become better self-regulated learners, thus providing a sense of personal agency, efficacy, and opportunity necessary to participate in STEM careers.

Paper #5: Designerly Ways, Means, and Ends: From STEM to STEAM to STEAMD

In this paper, I argue for an explicit role for design in STEM, perhaps as another, albeit less popular, iteration, STEAMD. We cannot take design for granted in STEM or STEAM and design is unique in its ways of knowing. The first section provides a background for the argument and focuses on Cross's work. We can assert from this that STEM and STEAM are inadequate without recognition of the uniqueness of design. The second section outlines risks of superficial design in STEM and STEAM. In the final analysis, we need novel methodologies as well as responsive ethics in STEAMD educational research.

Session Format

The symposium will proceed as follows (90 minutes):

1. Outline of the symposium and Brief introduction to Designerly Ways, Means, and Ends for STEM Educational Research (2 minutes)
2. Papers 1-5 (12-15 minutes each, 75 minutes total)
3. Audience questions and discussion (10-15 minutes)
4. 4. Brief Exchange among Panelists (if necessary)

PAPER #1: WEARABLE PERSONAL CAMERAS: VIDEO ETHNOGRAPHY WITH PRESCHOOL-AGED CHILDREN

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ABSTRACT

This paper focuses on the unique characteristics of video ethnography with 8 preschool aged children. By using wearable person cameras, we were able to capture prosocial behaviours while children were using iPads and animation applications. Although some Research Ethics Board representatives and parents may disprove of the use of wearable, point of view video with young children, the use of researcher and wearable cameras in this setting to capture moment-to-moment behaviours and interactions was imperative to interpreting the cultural and social situations. The voices of young children have similar tones and can have speech difficulties, which are difficult to transcribe or understand without supporting audio and video and the ability to look at a child's mouth and vocal gestures. Also, the individual blue Snapcam Ion cameras were essential for the data analysis as they captured individual perspectives, with close-up microphones and footage that may not be captured in a researcher camera's angle. The objective of this paper is to explore how and why children share, or may be reluctant to do so, as they design with digital technologies, from their point of view.

Keywords: *video ethnography, preschool, iPads, cameras, wearables*

INTRODUCTION

Video ethnography is defined as using video in research to record naturally occurring events in dayto-day life experiences and habits. The video can be analyzed and re-analyzed and can be shown and shared with others, including researchers and the participants themselves (Heath, Hindmarsh, & Luff, 2010). Hammersley and Atkinson (2007) suggest that "ethnographies of digital life itself are important aspects of contemporary social research" (p. 137) and many ethnographers attempt to employ the use of audio and video technologies to support data collection (Creswell, 2013; Erickson, 2011; Erickson & Wilson, 1982; Fetterman, 1989). When conducting research with preschool-aged children, video recordings of the ECE classroom should be a part of data collection to understand, explore, and research digital aspects of education. This paper will explore when children use prosocial sharing behaviours, from their point of view.

RESEARCH METHODS DATA COLLECTION

The current research study used video ethnographic techniques that included two researcher cameras for participant observation as well as multiple personal point of view cameras worn by participants: *Snapcam Ion*. The blue *Snapcam Ion* wearable cameras were worn when the children completed activities that were not directly led by the researcher (*Table 1*). The participants wore the cameras to capture their point of view, enhancing audio collection by having microphones close to the mouth of each participant. Also, the cameras captured moments that were not included in the shot of the researcher camera.

Table 1. The activities when participants wore a blue *Snapcam Ion* camera.

Phase	Scenario	Activity	Wore *Snapcam Ion* camera (yes or no)
Field study	1	1	No
		2	Yes
	2	1	No
		2	Yes
		3	Yes
		4	Yes
	3	1	No
		2	Yes
		3	Yes
		4	Yes
		5	Yes
		6	Yes
		7	Yes
Definitive Test	1	1	No
		2	No
		3	No
		4	Yes

PARTICIPANTS

The participants in the whole study were preschool-aged children aged three and four (n=8). The student participants were located within the Southwest of BC. Demographic information was not explicitly captured because the research was about inviting a diverse group of participants without segmenting by demographics; however, the participants represented cultural and socio-economic diversities. There were five girls and three boys. Convenience sampling was used. As the children are underage, their consent and image/video release forms were signed by their parent(s)/guardian(s). Verbal and visual checks were used throughout the study to confirm the child’s assent.

RESEARCH DESIGN

Two phases were conducted: a field study and a definitive test. During the field study, the prototype is used and the experimentation begins in an authentic (i.e., classroom) setting. The phase continues the process of collaboration with the practitioner (in this case with the teacher), as the artifact or intervention is tested in the authentic setting; the researcher gets reactions from both teacher and students, and uses the reactions to refine the product through analysis and re-design, which can cycle through until there is a 'successful' artifact or intervention. Video ethnography was incorporated directly in this phase.

During the second phase, definitive test, a retrospective analysis in which the 'successful' artifact or intervention are taken to other sites or tested with other participants to ensure validity of the product/artifact. Additionally, the analysis includes a detailed reflection on data within the design context, and information from past research, theory and practice. Video ethnography was also incorporated directly in this phase.

RESULTS

Overall, a significant amount of prosocial behaviours were observed with the preschool-aged children. *Figure 1* shows the social behaviours per participant with media and technology. All three participants exhibited prosocial and nonsocial behaviours. Prosocial group behaviour was the most common for all participants at 168 (73.0% of total behaviours). Antisocial behaviours were the least common for all participants at 6 (2.6% of total behaviours). Overall, prosocial behaviours outnumbered antisocial or nonsocial behaviours at about 186 (80% of total behaviours) to 42 (20% of total behaviours). Participant 3 displayed the most prosocial behaviours with 76 events (33% of total behaviours) and displayed the most antisocial behaviours at 5 (2.2% of total behaviours). She also exhibited the most nonsocial behaviours at 15 (6.5% of total behaviours). Participant 2 did not exhibit any antisocial behaviour.

Figure 2 displays the social behaviours comparing media and technology to no media and technology. Overall, prosocial behaviours with media and technology was the most common with 276 events (65.9% of total behaviours). The next most commonly observed behaviours were nonsocial behaviours 134 (32.0%). Comparing media and technology to no media and technology, prosocial behaviours with media and technology were the most commonly displayed 186 (44.4% of total behaviours) compared to 90 (21.5% of total behaviours) without media and technology. There were more individual prosocial behaviours without media and technology, but there were also more nonsocial behaviours, 96 (27.9% of total behaviours). Antisocial behaviours were the least common with and without media and technology, 11 (2.6% of total behaviours).

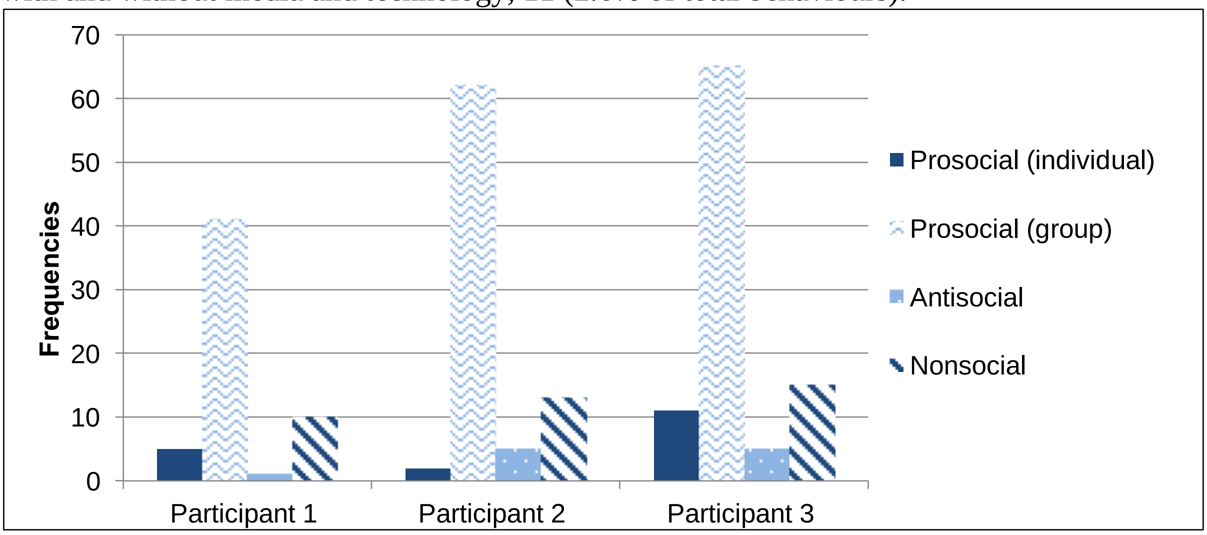

Figure 1. Frequencies of social behaviours *with* media and technology for field study participants 13.

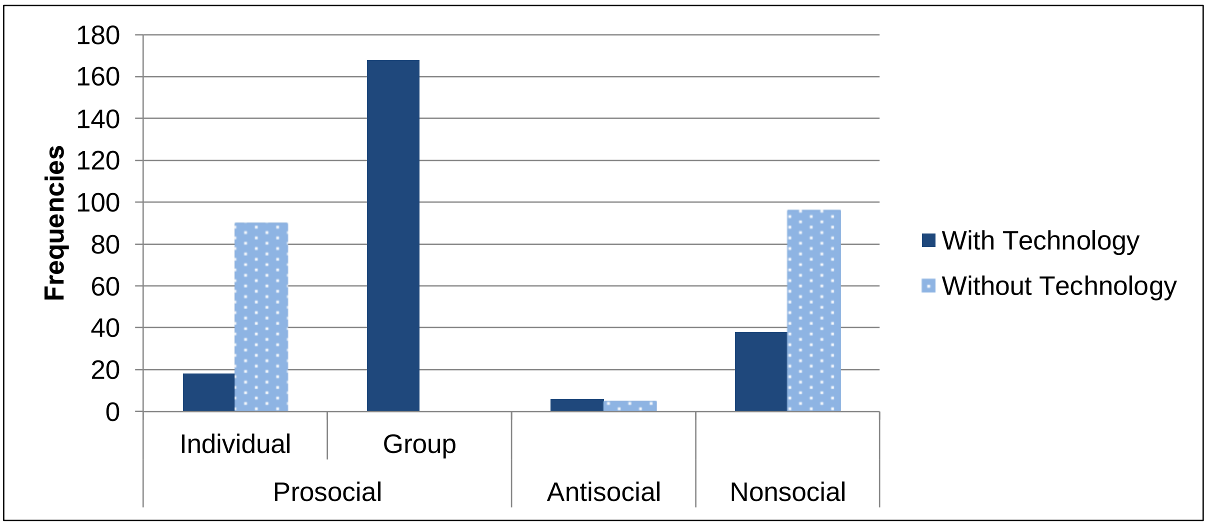

Figure 2. Frequencies of social behaviours with and without media and technology during field study.

Figure 3 shows the social behaviours per participant with media and technology during the definitive test. All five participants exhibited prosocial group behaviours 146 (70.9% of total behaviours). Participants 7 and 8 did not exhibit individual prosocial behaviours. Participant 7 did not display nonsocial behaviours. Overall prosocial behaviours were the most common with 177 events (86% of total behaviours). The least frequently observed behaviour was antisocial behaviour with only 9 events (4.4%). Individually Participant 4 exhibited the most prosocial behaviours, 14 (6.8% of total behaviours). Overall, Participant 6 exhibited the most prosocial behaviours, 47 (22.8% of total behaviours). Participant 5 exhibited the most nonsocial behaviours, 8 (3.9% of total behaviours). Participants 5 and 6 exhibited the most antisocial behaviours, 3 (1.5% of total behaviours). On average, the boys exhibited slightly less prosocial behaviours than the girls with 30-37 events (15% to 17% of total behaviours). The boys were two times (1% of total behaviours) more antisocial and nonsocial than the girls.

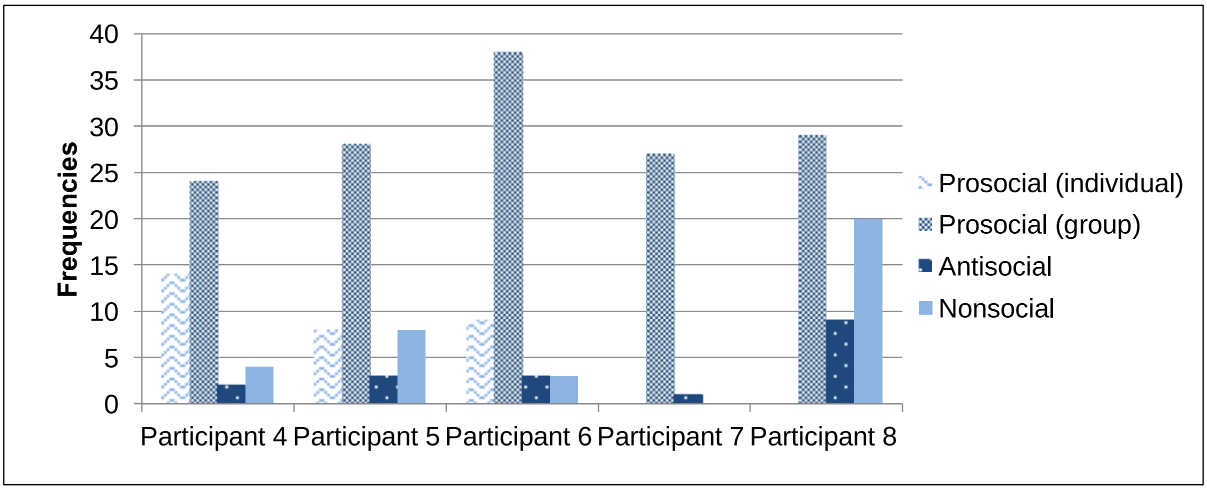

Figure 3. Participant (4-8) social behaviour counts with media and technology.

Figure 4 displays the individual prosocial sharing behaviours of showing, allowing use, and offering during the definitive test. Overall, showing was the most common sharing behaviour displayed, 20 (64.5% of total behaviours). The least common individual behaviour was allowing use, 3 (9.7% of total behaviours).

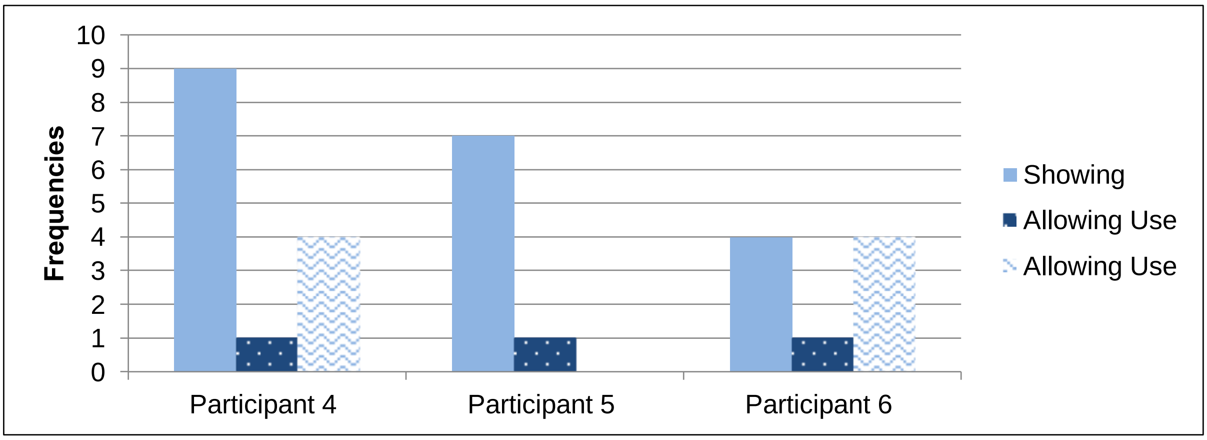

Figure 4. Individual prosocial behaviours per participant (4-6) [1].

Overall, participants across the entire study showed a significant amount of prosocial sharing behaviours compared to antisocial or nonsocial behaviours.

SCHOLARLY SIGNIFICANCE

This research study used video ethnographic methods to capture behaviours. The video recorded preschool-aged children interacting with each other using iPads in classroom settings. Multiple cameras captured different points of view. The videos assisted in capturing accurate counts of behaviours and in understanding what the children were saying and doing. To reiterate, this research used two researcher cameras and several personal point of view blue *Snapcam Ion* cameras for the children to wear. The cameras were high-definition and captured 60 frames per second, which obviously is more than a human could capture with a still image camera. The different sets of cameras were used to reduce the partial representation that a video ethnographer captures (Hammersley & Atkinson, 2007). At times, the children would move out of shot and the researcher camera would not capture the behaviours (*Figure 5*).

[1] Note: Participants 7 and 8 are removed from the figure as they did not display any individual sharing behaviours

Figure 5. Participants 5 and 8 move out of researcher camera shot.

When the children would move out of the shot of the researcher camera, the *Snapcam Ion* continued to capture what the children were doing and was essential to the data analysis part of the research (*Figure 6*).

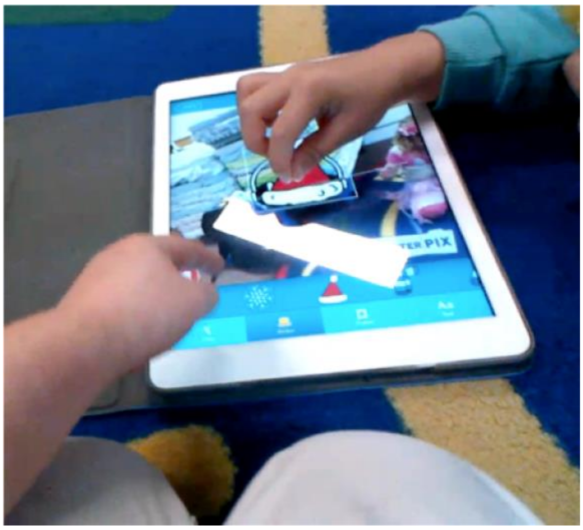

Figure 6. Participant 5's point of view camera.

At times, the point of view footage was dark or black when the children would lie down on the carpet or their shirt would cover the camera lens and some footage was lost. However, a significant amount of video footage was captured and supported the research camera. Even though there were times when the image was lost, the cameras continuously captured the audio and the cameras acted as individual microphones. NVivo was used to organize all of the footage and allowed the researcher to view, analyze, re-view and re-analyze the footage captured by the researcher and cameras (Heath et al., 2010; QSR International, 2016). Some research recommends that children can capture their own footage in participatory research (Kullman, 2012); however, typical participatory research in which children use their own cameras are for children over six years old. My research extends other research to include children under five years old. The use of wearable cameras with preschool-aged children is something fairly unique in educational research and should be tested in other ECE research. More research is needed to explore the impact of personal point of view cameras or participatory research cameras in ECE.

At times, the video footage would capture the silences that Shrum, Duque, and Ynalvez (2007) suggests are as important as the sounds captured. When the children would work 1:1 with the iPads, the focus was on their one device and there were minimal interactions with other children. During these moments, the video footage captured almost over five minutes of silence. Five minutes of silence from preschool-aged children can be pretty astounding, especially as the researcher observed limited attention spans in earlier activities, i.e., the pre-interview. Some researchers could challenge that the silences could just as easily be captured in audio recordings as much as video recordings and therefore video cameras are not needed. This is true; however, the body language alongside of the silence was important to observe. The children's focus and heads were down and they barely moved. This would not be captured in audio recordings. The captured moments were essential to the analysis of the data.

The video captured assisted in the analysis portion of the research. With audio recordings alone or hand-written field notes, the researcher would not be able to get accurate counts of behaviours. The video footage was viewed and re-viewed and coded over several sessions using NVivo software (QSR International, 2016). Being able to re-view the video and having several passes at the footage also refined the thematic coding. The captured video allowed for complexity to be addressed.

Finally, the cameras were essential to this research that audio recordings or still images alone would not be. In particular, the children's voices had a similar tone, making it difficult to decipher what child was saying what. Additionally, some of the children had speech difficulties, making it even more difficult to decipher what some children were saying. When transcribing and coding the footage, NVivo and video footage were central to understand what was being said. Also, the children would often speak at the same time, as is often the situation in preschool classrooms. If the voices were similar or unclear, watching the video footage allowed the researcher to look at the children's mouth and vocal gestures to see what words they were trying to say.

The video footage was central to this research and needs to be encouraged in future research in ECE or when working with young children. Even though some parents or Research Ethics Boards may be hesitant about children being recorded, researchers need to continue to exert and emphasize the importance of capturing children's authentic behaviours on camera for continued research.

CONCLUSION

Using NVivo software for video analysis (QSR International, 2016) allowed the researcher to view and re-view and analyze and re-analyze the captured video. If the participants went out of the shot of the researcher, their actions and especially their voices were still captured. The use of the two stationary research cameras was supported by several blue *Snapcam Ion* cameras worn by the participants. These facilitated the collection of mobile, point of view data. The blue *Snapcam Ion* cameras were relatively inexpensive and captured up to 2 hours of HD quality video every session. The extra cameras were integrated to ensure that data analysis was accurate by capturing individual point of views that would not be captured by the researcher cameras alone. the use of video ethnographic methods was imperative towards data collection and analysis. Although some Research Ethics Board representatives and parents may disprove of the use of wearable, point of view video with young children, the use of researcher and wearable cameras in this setting to capture moment-to-moment behaviours and interactions was imperative to interpreting the cultural and social situations. The use of the researcher cameras was essential to the data analysis. The voices of young children have similar tones and can have speech difficulties, which are difficult to transcribe or understand without supporting audio and video and the ability to look at a child's mouth and vocal gestures. Also, the individual blue *Snapcam Ion* cameras were essential for the data analysis as they captured individual perspectives, with close-up microphones and footage that may not be captured in a researcher camera's angle. We need to continue to explore the role of video ethnography in ECE. What does interaction with digital technologies mean to the children, from their point of view?

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PAPER #2: DESIGN OF THE PRESERVICE TEACHER'S DIGITAL SELF

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ABSTRACT

What are some primary concerns and priorities of preservice teachers as they craft, brand, and curate, or design, their digital self? How and why has the preservice teacher's digital self become a design problem? This paper reports on research with seven preservice teachers' insights into this problem. In a nutshell, through online platforms, one's private and public lives, or personal and professional images, risk collapsing or converging. Stakes are raised as students are given various cautions and warnings about this. What might raise a concern for a potential employer? What might generate concerns for young students' parents? How to professionalize the digital self? The problem is framed as a tension between the higher standard to which teachers are held and rising expectations that teachers be omnipresent in social media and technology. Findings emphasize that, for the participants, the design of the digital self is an ill-defined problem. Participants adopt fairly conventional means to design and manage their professional image. The conclusion begs a question of the higher standard in this era of SM and the intelligent web.

Keywords: *preservice teachers, professional image, self-design, higher standard*

> The school committee are sentinels stationed at the door of every schoolhouse in the State, to see that no teacher crosses its threshold, who is not clothed, from the crown of [her or] his head to the sole of [her or] his foot, in garments of virtue. (Mann, 1841, p. 319)

IMAGE OF THE TEACHER AS A DESIGN PROBLEM

As the epigraph suggests, teachers have historically been held to a higher standard of behavior, character, competence, conduct, and image, seemingly on and off duty. In most legislation regulating teachers across the world, this becomes a legal statement. For example, the British Columbia (BC) (2011) *Teachers Act* requires for certification that "the person is of good moral character and is otherwise fit and proper to be issued a certificate of qualification or an independent school teaching certificate" (s. 30[1c, ii]). Courts have consistently, though not always, decided with this standard, especially in cases of liability. An often-cited case in the North Carolina Supreme Court emphasizes it most clearly:

> Their character and conduct may be expected to be above those of the average individual not working in so sensitive a relationship as that of teacher to pupil. It is not inappropriate or unreasonable to hold our teachers to a higher standard of personal conduct, given the youthful ideals they are supposed to foster and elevate. (Faulkner v. New Bern-Craven County Board of Education, 1984)

In tension with this moral image of the teacher is a somewhat newer image as omnipresent technology user, if not advocate. Daily expectations and mandates imagine teachers, especially new teachers, as present and transparent on social media platforms, on and off duty. We may hold an image of teachers clothed head to foot "in garments of virtue," as Mann (1841, p. 319) suggests, but in tension is an image of teachers clad head to foot with tech gear (Figure 1). This paper addresses how preservice teachers negotiate this tension.

Figure 1. Techy Teacher (Freeland, 2017, CC Attribution-NonCommercial-NoDerivs 3.0 License).

Certainly, user-generated content via web 2.0 technologies is prolific; in turn, "image crafting", "self-branding", and "self-curation" are now central to the lives of children and professionals alike. Whether teachers are subject to a different level of scrutiny than other professionals (e.g., doctors, nurses, lawyers) is debatable. What seems to hold however, is that the "sentinels stationed at the door of every school house," which Mann (1841, p. 319) described, have now diffused to stations at the portal of every social medium. Commenting on the Vancouver School Board's draft "Social Media Policy," a retired superintendent of Shuswap District (southeastern BC) acknowledged that the "exploding popularity of social media sites has engendered a prurient interest in teachers' 'private' lives by both school administrators and the media" (Johnson, 2013). Design of a preservice teacher's digital self is contingent on who may be observing or scrutinizing what they do or say and how they appear online.

Teachers are aware that as lines blur between private citizen and public servant, they are left vulnerable to heightened expectations and scrutiny. As a reaction, Khamis (2016) points out that "self-branding through social media can be understood as a way to retain and assert personal agency and control within a general context of uncertainty and flux" (p. 200). Similarly, there is awareness that the design and packaging of an online professional image and digital self are required for consumption by different audiences. This relates to teachers' understanding that their image or subjectivity, as it is represented online, can either be passively maintained or actively designed. For Khamis (2016), efforts at brand management show "how private individuals have internalised ideas that were designed for the marketing of commodities, and thus represents a seminal turning point in how subjectivity itself is understood and articulated" (p. 200). Framed this way, image and subjectivity are one in the same design problem.

What are some primary concerns and priorities of preservice teachers as they craft, brand, and curate, or design, their digital self? The first section of this paper describes the participants and methods. The balance of the paper is shaped through practices that Cross (1983) lists as central to designerly ways of knowing: a) Designers tackle 'ill-defined' problems; b) their mode of problem-solving is 'solution-focused'; and c) their mode of thinking is 'constructive'. The second section emphasizes that, for the participants, the design of the digital self is an ill-defined problem. In the third section, we analyze the strategies the participants use to design and curate their professional image. The conclusion reiterates the problem of the higher standard and begs a question of its effect in this era of SM and the intelligent web.

PARTICIPANTS AND METHODS

This paper is part of a larger study conducted for a Master's degree (Forde, 2019), which included an analysis of "inappropriate use of social media" in the Teacher Regulation Branch (TRB) section of the BC Ministry of Education along with interviews of pre-service teachers.

The participants were teacher education candidates (TCs) at a large university in Western Canada. Two cohorts were invited to participate in the study and seven students consented (n=7). Five of the participants were from the elementary & middle years education program, while the remaining two were from the secondary education program. Between January 17-28, 2019, interviews were conducted with the TCs on the university's campus, each lasting for approximately 30 minutes. These TCs discussed their concerns around transitioning from TC to certified teacher and worries of discrepancies between their personal and professional images. For this article, self-design is defined as "rewriting inner, psychological, political attitudes or economic interests on external media" (Groys, 2018, p. 18) while professional image is the aggregate of key constituents' (i.e., clients, bosses, superiors, subordinates, and colleagues) perceptions of one's competence and character. This definition refers to an externally oriented, public persona that is based on reflected appraisals (how an individual thinks others perceive him or her), rather than one's self-image (how one perceives oneself) or others' "actual" perceptions (Roberts, 2005, p. 687).

TEACHERS' IMAGE IS AN 'ILL-DEFINED' DESIGN PROBLEM

The TCs all expressed an understanding that their "digital footprint," or trail of pictures (pics) and videos, audio tracks, and commentary, could be problematic in relation to their professional image, though it was extremely challenging for them to articulate the exact nature of their concerns. Instead, there was a general "feeling" that the appearance of impropriety or misconduct would be enough to cause problems. Several of the TCs made reference to teachers being held to a "higher" standard, but how high this standard is or who decides this is unclear. For instance, TC7 remarked: "they keep telling us we're held to a higher standard; in a way we should, but what are we talking about?" TC5 expressed concern that simply by "liking" a post on social media (SM) could cause "a person who makes major decisions in your life", such as potential employers, to view them in a negative light. TC6 had concerns around being a small business owner and their desire to keep this "business identity" separate from their "teacher identity" to avoid any perceived conflict of interest. TC2 expressed a strong dislike and distrust of SM in general, repeatedly mentioning that it's "unhealthy," leading to "addiction" and "narcissism:" "People, in my opinion, don't understand the ramifications of having those social media sites." This TC went on to explain that, though they still used SM with a select group, the design of his digital self was extremely private and considered, mentioning "you can never make a mistake; the mistakes you make will haunt you forever."

In short, TCs are conscious of potential problems that their SM presence poses. However, each of these TCs understand these problems based on their personal circumstances, rather than on a specific set of clearly defined issues. This represents an intuitive understanding of potential problems might and how they could best avoid them.

Though the TCs interpretation of the challenges of designing their digital self or professional image involves disparate elements, the teacher candidates are aware that there are steps they can take to mitigate these issues. All of the TCs are consciously engaged in the design of filters to regulate access to their SM content. Hence, one aspect of designing the digital self involves creating or strengthening barriers and delineating boundaries between their professional and non-professional images or identities. Of the seven, only TC4 used their real name on SM platforms, while the others used some variation of their names or a pseudonym to make it more challenging for unknown parties to be able to identify them. TC4 was confident that their privacy settings on SM platforms were a sufficient barrier to unwanted scrutiny, while all of the other TCs used privacy settings in addition to name changes for this purpose. These basic steps gave the TCs some sense of security in mitigating the *searchability* of SM content. However, even with these steps in place, the TCs were conscious that additional effort was needed to design suitable boundaries between their professional and "private" images. Like Mihailidis and Cohen (2013), several of the TCs understand that "curation is an act of problem solving," involving the organisation of a story and creation of an image to share with others in a coherent manner (p. 5).

DESIGN OF THE DIGITAL PROFESSIONAL SELF

Mihailidis and Cohen (2013) explain that the term curation was "traditionally reserved for those who worked with physical materials in museum or library settings" but that today "it has evolved to apply to what we are all doing online" (p. 3). TCs are challenged to design the digital self and create a professional image, however emergent and tentative.

TC1 expressed a desire to keep their "professional life" and "social life" separate, while acknowledging that there can be a blurring of the two online. To address this blurring TC1 is engaged in efforts to "curate and cultivate" across their SM platforms to distinguish the two, using Facebook and Instagram for more ephemeral social aspects and LinkedIn for a more durable "online persona." The design of TC5's SM presence is also shaped by considerations of privacy. They note: "I don't like the idea that my students could search me and learn things about my personal life" and that "I feel like I should have control over that with my students, how much of my personal life I want to disclose to them." TC5 also mentions deleting content from the Facebook page of their punk rock band, concerned about images "associated with heavy drinking, and partying", explaining "I didn't want to be associated with that anymore."

Safeguarding against searchability, which makes it difficult for young students and their parents to access personal images, seemingly protects the TC's professional image. Using pseudonyms and codenames help distinguish their professional image from their personal image. For example, TC4 is an avid user of SM though they have a graded system of access and representation based on who their audience is. Their Facebook profile is "suitable for grandma" and the most "professional" scrutiny, though their use of this platform is "fading out a little bit" as it was "more of a high school thing" In contrast, they use Instagram the most to "put [themselves] out there", though more consideration is given to this content in order to make it more "aesthetically pleasing". The most "authentic" representation of the TC is on Snapchat, which is reserved for "closest friends" as their content is "not curated as much."

Similarly, TC6 searched for and "cleaned up" "old unflattering photos" of themselves in constructing their professional image. TC6 explained that they are acutely conscious that their unique name, a search of which returns results pertaining only to them, raises concerns around their “professional digital presence” more pressing. They also explain that they use Facebook for “friends and family” only, while their LinkedIn account was for their professional image.

TC3 has a more positive view of SM though they made an effort to keep their “personal” and “public” images separate: “I want to be free to post what I want without students or parents seeing it.” They went on to explain that “keeping that distinction” is important because “I don’t want them coming to work and knowing what I did the night before.” TC differentiates between Facebook and Instagram and their “more professional” LinkedIn profile.

Similarly, TC7 explains that they too have long been conscious of a need to “filter things,” explaining “I don’t post things that I could be worried about everyone seeing.” They elaborated that “even before the teacher education program I would go back on my Facebook and delete really old things that weren’t really relevant to who I am now.” This TC identifies the more recent addition of LinkedIn as their “professional platform.”

ANALYSIS AND CONCLUSION

Alongside academic preparation for meeting teaching responsibilities, the TCs are engaged in the design of the digital self, which in simple terms is distributed across their personal image and professional image. Meeting the “higher standard” of teacher professionalism is a daunting challenge. Similar to regulatory codes and legislation across the world, the Ontario *Education Act* (1990) suggests how high this standard may be:

> It is the duty of a teacher and a temporary teacher... to inculcate by precept and example respect for religion and the principles of Judaeo-Christian morality and the highest regard for truth, justice, loyalty, love of country, humanity, benevolence, sobriety, industry, frugality, purity, temperance and all other virtues. (s. 264[1c])

SM and a new era of the intelligent web make it increasingly easy to monitor and scrutinize this daunting “duty of a teacher,” whether on or off duty. Concerns are warranted as articles regularly circulate with titles suggesting invasive background checks: “Employers are Googling you,” “Social Media Screenings Increase for Job Seekers,” and “Your Future Employer Is Watching You Online.” Szekely (2012) warns that our digital footprint could bring about a “zero-tolerancesociety” because “the possibility of storing information on everyone, of retrieving and using it at any time against anybody, is the perfect means to detect and sanction the slightest deviation from the ideologically, politically or commercially preferred behavior” (p. 353).

At the same time, concerns that the higher standard holds on and off the job are warranted. For instance, school boards commonly refer to a BC Court of Appeals’ decision:

> The reason why off the job conduct may amount to misconduct is that a teacher holds a position of trust, confidence and responsibility. If he or she acts in an improper way, on or off the job, there may be a loss of public confidence in the teacher and in the public school system, a loss of respect by students for the *teacher* involved, and other teachers generally. (Shewan v. Board of School Trustees, 1987)

In this era, “self-design” and “the authorship of one’s own subjectivity” are a priority for preservice teachers (Berardi, 2018, p. 330). Professionals have long understood the performative nature of what they do, and many have fulfilled careers with notable discrepancies, albeit hidden, between their personal and professional images. If the higher standard of the professional self was initially intended to drive reform of the personal self, is the design of the digital self necessarily providing impetus for a lower standard? Is there a case for higher tolerance and what potential employers or parents could overlook or what could be placed in perspective? Design of the digital self is not merely a practical matter. What is risked in this era is an increasing divergence of personal from professional images. Inauthenticity is one result, as a TC in this research expressed feeling "a bit censored" and another senses that "your hands are tied and your rights are, somewhat, removed."

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PAPER #3: DESIGN OF A 3D VIRTUAL LEARNING ENVIRONMENT FOR ACQUISITION OF CULTURAL COMPETENCE IN STEM EDUCATION: EXPERIENCES OF INSTRUCTIONAL DESIGNERS

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ABSTRACT

This study explores the experience of instructional designers in a 3D virtual learning environment designed specifically for this research, with an objective of exploring the implications of cultural competence in the design of artifacts for STEM educational research (Zhao, 2019). The research question is: What are the experiences of instructional designers in a simulated immersive learning environment of a 3D virtual world in the design of artifacts for STEM educational research? The design of the 3D world and analysis of data draw on a framework based on Deweyan and Confucian theories of experience. Design-based research (DBR) and user experience (UX) methodologies are employed to explore the experience of instructional designers. A taxonomy of experience (ToE) established by Coxon (2007) guides qualitative data collection and analysis in this study. Users' data were distilled through nine steps to help experiences to be "seen" and to make abstract concepts comprehensible and visible.

Keywords: *instructional designer, 3D virtual learning environment, cultural competence, STEM educational research, Deweyan and Confucian theories of experience, DBR, UX, ToE*

INTRODUCTION

New technologies extend the reach of instructional designers for new options. Concerns regarding instructional designers using educational technology in cross-cultural settings are growing. Extensive research suggests the need for instructional designers to be more aware of and responsive to cultural differences in the design of environments enhanced by technologies (Chen, Mashhadi, Ang, & Harkrider, 1999; Kawachi, 2000; Robinson, 1999; Bentley, Tinney & Chia, 2005). Spronk (2004) states that culture, in learning contexts, is more profound and dynamic than surface features suggest. Instructional designers are not immune from the influence of their own cultural biases. Spronk (2004) recognized that "many features of the academic culture familiar to most learners whose first language is English may strike learners from other linguistic and cultural traditions as alien" (p. 172). A range of challenges and concerns are presented to instructional designers in cross-cultural contexts. Even though instructional designers are trained in professional settings, who they are and what they bring makes a difference in how design is approached (Rogers, Graham & Mayes, 2007).

RESEARCH QUESTION

This study involves the design of a 3D virtual world or learning environment and gain understanding of the experience of instructional designers in this 3D virtual world in order to improve its design and assist other designers (Zhao, 2019). The research question is: What are the experiences of instructional designers in a simulated immersive learning environment of a 3D virtual world for the acquisition of cultural competence for students in STEM education?

THEORETICAL FRAMEWORK

According to Campinha-Bacote, the five constructs of cultural competence include cultural awareness, cultural knowledge, cultural skill, cultural encounters, and cultural desire. These five constructs have an interdependent relationship with each other and no matter where people enter this process, all five constructs eventually must be experienced or addressed (Campinha-Bacote, 1998). Campinha-Bacote (1999) defines cultural awareness as the deliberate, cognitive process in which people become appreciative and sensitive to the values, beliefs, lifeways, practices, and problem solving strategies of clients' cultures. Campinha-Bacote (1999) defines cultural knowledge as the process of seeking and obtaining a sound educational foundation for different cultures, which includes various worldviews for understanding clients' behaviors. In addition, the process of cultural knowledge also involves obtaining knowledge regarding specific physical, biological, and physiological variations among ethnic groups. Campinha-Bacote defines cultural skill as the ability to collect and assess clients' data in cultural context. Campinha-Bacote defines cultural encounter as the process which encourages people to engage directly in cross-cultural interactions with clients from culturally diverse backgrounds (1999). Campinha-Bacote acknowledges that engaging in cultural encounters can be difficult and uncomfortable at times. To address the complexity and dynamics of the real world, CampinhaBacote emphasizes intra-ethnic variation, which refers to the fact "there is more variation within a cultural group than across cultural groups" (1999, p. 205).

POSITIONALITY

I grew up in China, did my graduate studies and have been working in Canada. With my inherited Chinese cultural background, I am exposed to Western culture as a cross-cultural learner myself. For my working experience, besides as an educational researcher, I also have advanced knowledge of the complexities of instructional design with more than ten years of experience as an Instructional Designer and eLearning Technologist, I have designed learning environments by simulating complex and naturalistic settings, utilized an eclectic collection of specific approaches to the whole process, from initial problem identification, intervention design and construction, implementation, and assessment to the production of reusable products. Therefore, in addition to the researcher role in this study, I also acted as a designer and crosscultural learner with an integrated role. Throughout the multiple iterations of DBR iterative approach, I analyzed and re-analyzed the data allowing for multiple viewings of the data.

SIGNIFICANCE OF THE STUDY

The present study explores and designs a variety of practice activities in simulated, safe, and supportive environments by engaging digital artifacts (image, text, and sound) (ITS) and advanced learning technologies (ALTs) to reinforce the simulation in 3D virtual worlds. It helps the students develop sensitivity and respect for differences in beliefs and values, and further prepares culturally competent professionals in the multicultural society. For instructional designers, this study fosters new ways of learning and reflecting on their own cultural competence.

LEARNING EXPERIENCE IN THE CONTEXT OF VIRTUAL WORLDS

My research is conducted in a 3D virtual world. The virtual world is the design artefact and intervention. What is a 3D virtual world? According to Bell (2008), a virtual world is "a synchronous, persistent network of people, represented as avatars, facilitated by networked computer" (p. 3). Of course, networked computers nowadays also refer to mobile devices. Similarly, Aldridge describes virtual worlds as three-dimensional, multiplayer environments with a social context (2009). Both definitions emphasize the human and social aspects of this platform. In 3D virtual world environments, participants use avatars, the online graphical representations of themselves, to communicate and exchange data with each other through realtime voice chat or textual chat tools (Delwiche, 2006). Boellstorff's (2006) definition is that virtual worlds are "places of human culture realized by computer programs through the internet" (p. 17). Virtual worlds are places and, therefore, constitute sites for cultural production.

RESEARCH METHODOLOGY

The primary methodology was design-based research (DBR) while the secondary methodology was user experience (UX). The two were used in complementary ways to explore instructional designer experience in a 3D virtual world. The taxonomy of experience (ToE) established by Coxon in 2007 is introduced to guide data collection and qualitative data analysis in this study. In DBR, McKenney and Reeves's Design-Based Research model is adopted, in which depicted iterative process does not prescribe fixed, set pathways for iterations. Rather, many potential routes can be designed according to this model.

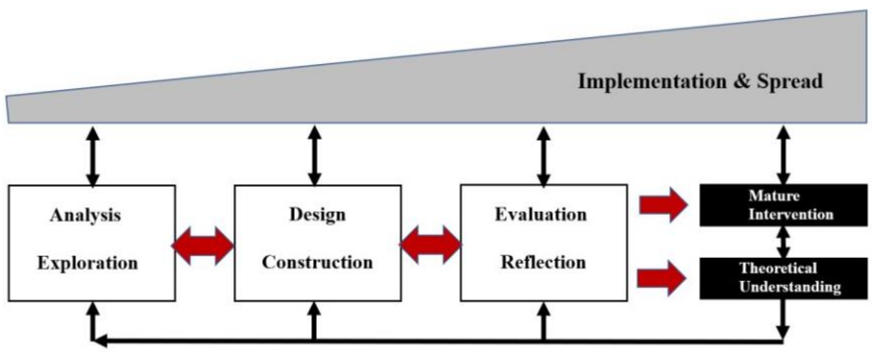

Figure 1. Generic model for design research in education. Adapted from McKenney & Reeves (2012).

A secondary methodology in this study is User Experience (UX). Touloum, Idoughi, and Seffah (2012) define UX as "something felt by the user, or by a group of users, following the use of a product (or service), or during its interaction with the product (usability and aesthetics), or even a possible use (or purchase) of a product". "We use the word 'something,'" they continue, "to refer to the broad meaning that covers the term experience (emotions, perceptions, reactions)" (pp. 2994-2995).

3D VIRTUAL WORLD DESIGN

The DBR product is a 3D virtual world designed in OpenSimulator, which is also the field site for the study. the principles of holistic experience, interaction, and continuity are embedded in the design of this 3D virtual learning environment. Deweyan and Confucian pragmatist understandings of experience prompted me to design with the importance of holistic experience and interaction in mind. Affordances of 3D virtual worlds, including simulation, embodiment, and interactivity were utilized to facilitate the acquisition of cultural competency (Anderson & Shattuck, 2012; Corder & U-Mackey, 2018; McKenney & Reeves, 2012; Reeves, Herrington, &

Oliver, 2005; Squire, 2006). The final 3D virtual world includes four main rooms: conference room, classroom, clinic, and café.

Figure 2. Four Rooms in the 3D Virtual World: Classroom, Conference room, Clinic, and Café.

DATA CODING AND ANALYSIS THROUGH TOE-SEEING

Data were collected by gathering the responses and attending to user experiences of five users (Yuliana, Fay, Sabin, Melody, and Jabez) recruited on voluntary basis, who have extensive 3D virtual world experience. Consent was obtained before participation. Recruited pparticipants were presented with a cover letter, consent form, and interview questionnaire. They were encouraged to express their experiences during the semi-structured interview, in which experiential and existential elements of the ToE helped shape the questions for instructional designers.

Interview data were entered into Microsoft Office 365 Excel spreadsheets and analyzed using the SEEing technique created by Coxon (2007), which is a structural interpretation of the experiential phenomena. The ToE-SEEing process includes nine steps to categorize and analyze users' interview data. User experience is analyzed through a series of progressive steps to extract the essences of the experience and allow them to be "seen", which provides a way to make abstract concepts comprehensible and visible. This method offers an opportunity to look deeper into the data collected while extracting conclusions (Coxon, 2007).

DATA ANALYSIS AND CONCLUSIONS

The instructional designers understood the cultural implications of the 3D world: "I think some students may not have enough skills to build objects themselves, pre-made items really help. This can reduce the learn curve. You should always have options for learners to make things differently" (Iteration 5/Jabez). Another acknowledged: "In 3D virtual worlds, for the beginners it will be very helpful if there are pre-designed items in the world to use, even for me. Actually, I do have some design background, still, I modified and used a pre-created chair in my play, which had been built by other participants. I think for junior designers, pre-created items are even more useful" (Iteration 5/Melody). A student agreed: "I like the role plays to practice cultural competency. Things are so dynamic. Decisions are made in real time. This really helped me realize the cultural context I originally situated" (Iteration 5/Yuliana).

Instructional designers and instructors in this study confirmed that virtual worlds facilitated interaction. As one noted: "I saw there were a series of buttons at the bottom of the screen, we could do editing and create objects. The potential for interactions is a lot. Once the users are more familiar with all the buttons, they will have all the interactions" (Iteration 5/Sabin). At the same time, cultural limitations of the affordance of interaction in the 3D virtual world were reported. A student reflected: "I like the 3D virtual world because it has more ways to interact and communicate comparing to traditional platforms. But the facial expressions and gestures are limited" (Iteration 5/Fay). "Interestingly, if you watch the video games kids play, the avatars are not polished at all, no real face, actually just boxes. But they are so attached to them. I think because they have the full control over it. I think more control brings more embodiment feeling" (Iteration 5/Yuliana). Enhancements were suggested from the user experiences as well. "The avatar is a bit simplified, hope to have more facial expressions" (Iteration 5/Yuliana).

Ideally, instructional designers would be culturally responsive in a general sense and culturally sensitive in a specific sense. For example, Zhang and Zhou (2010) investigated the experience of Chinese students in Canadian educational systems. Among a range a communication and social networking challenges, Chinese students are challenged to adjust to demands of group work for activities and projects. There are cultural differences in the experiences that students have in group work: instructional designers should have a level of cultural competence in recognizing the need to scaffold group work expectations and procedures. Recognizing various cultures and sub-cultures of users during the instructional design process requires cultural competence. Support can often be provided to instructional designers to recognize cultural assumptions of not only the users, but also themselves.

Instructional designers should keep in mind the challenge of diversity in their products. For example, avatars and associated features, such as clothing, should reflect cultural diversity. This adds a design challenge within 3D virtual worlds, as user content and vendor content often limit avatars and clothing to western skin features and styles. This was a limitation in the 3D virtual world I designed for this study. Upon reflection, I should have been more attentive to these specific features to reflect the diversity of the users. Nowak and Fox's (2018) extensive review found that users "select avatars they believe will help them meet interaction goals, which could include revealing or concealing elements of their identity to other users" (p. 40). Hence. It is important for designers to provide a range of choices of avatars with visible cultural or racial characteristics and roles.

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PAPER #4: ASSESSMENT FOR LEARNING IN IMMERSIVE AND VIRTUAL ENVIRONMENTS – EVIDENCE-CENTRED GAME DESIGN IN STEM

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ABSTRACT

Creative thinking, problem-solving and inquiry skills are primary goals of teaching and learning. This paper reports on the development of an authentic performance assessment in science, technology, engineering and mathematics (STEM), *Falling Skies!*, built around an ecological, inquiry-based problem – where students are presented with the issue of a mass mortality event and are challenged to investigate why this happened. Assessment for Learning in Immersive Virtual Environments (ALIVE; alivelab.ca) is a research program that examines how 3D immersive virtual environments (3DIVEs), as assessments for learning, is designed to enable students to regulate their science inquiry abilities in real-time. Specifically, this project explores the use of 3DIVEs to provide feedback through the formative assessment of inquiry reasoning in the context of middle school life science. Ultimately, the ALIVE project aims to contribute empirical evidence of how students conduct complex logic, assisting them to become better self-regulated learners, thus providing a sense of personal agency, efficacy, and opportunity necessary to participate in STEM careers.

Keywords: *Evidence-Centred Game Design (EDgD), immersive learning, assessment, feedback, science inquiry, learner agency*

INTRODUCTION

Creative thinking, problem-solving and inquiry skills are primary goals of teaching and learning (Jonassen, 1997; Shute & Wang, 2016). Current assessment approaches are inadequate at identifying how students develop creative thinking, problem-solving, and scientific reasoning – essential 21st-century skills (Shute & Emihovich, 2018). Instruction designed using learning principles related to solving authentic well-structured, and ill-structured problems is critical for lifelong learning and transfer to novel contexts (Van Eck et al., 2017). Feedback from formative assessments or assessments *for* learning carried out during instruction can help educators tailor teaching and deepen students' understanding, enabling them to self-regulate (Jaehnig & Miller, 2007; Van der Kleij et al., 2011). Research clearly illustrates that the shorter the time interval between teachers' eliciting the feedback and using it to improve instruction and for the students to use it to enhance their learning, the more significant the impact on learning (Wiliam & Leahy, 2015). Without the aid of technology, teachers' ability to provide this type of feedback on a regular, timely basis is challenging. Computer-based assessments (CBAs) have various advantages, such as the possibility of providing more timely feedback, automated scoring, and higher efficiency (Van der Kleij et al., 2011). Facilitating authentic problem solving and scientific inquiry through 3dimensional immersive virtual environments (3DIVEs) similar to video games has shown considerable promise in the assessment literature, particularly on summative assessment or assessment *of* learning (e.g., Baker et al., 2016).

Immersive game-based environments can be designed to assess science inquiry, problemsolving, and critical thinking skills (Mislevy et al., 2014; Shute & Emihovich, 2018). As an instrument of assessment, 3DIVEs can be designed to simulate authentic tasks where students apply knowledge and reasoning to situations similar to those they encounter in the real world – such as conditions that approximate how scientists and engineers work through problems (Baker et al., 2016). Summative assessment using 3DIVEs is well researched and supported in the literature (Baker et al., 2016; Shute & Emihovich, 2018). Using assessment frameworks such as evidence centred design (ECD; Mislevy et al., 2003) that focus specifically on the psychometric properties of assessments appropriately aligned with learning outcomes is critical. Further, using ECD and align it with game-based assessments *of* learning using learning analytics and educational data mining (Baker & Siemens, 2014) results in reliable student models of inquiry task performance (Baker et al., 2016). While the Baker et al. models of inquiry performance provide some utility towards assessment *for* learning, the 3DIVE that they were modelled upon was not explicitly designed for this purpose. As a result, there remain questions of validity.

Research Questions

Assessment for Learning in Immersive Virtual Environments (ALIVE; alivelab.ca) is a research program that examines how 3DIVEs, as assessments *for* learning, are designed to enable students to regulate their science inquiry abilities in real-time (See Figures 1 & 2). Specifically, this project explores the use of 3DIVEs to provide feedback through the formative assessment of inquiry reasoning in the context of middle school life science. Research questions that guide this project include the following.

RQ 1. To what extent do various methods for providing formative feedback in a 3DIVE affect students' academic achievement on a science inquiry-based task?

RQ 2. To what extent do various methods for providing formative feedback in a 3DIVE affect students' agency as measured by goal setting, motivation, self-regulation, and selfefficacy?

RQ 3. To what extent can models of student interaction within a 3DIVE predict whether a student will successfully conduct scientific inquiry and how this is related to their agency for learning?

RQ 4. How can 3DIVEs, in the context of a real-world science inquiry problem, be developed to provide formative feedback within the middle school classroom?

LITERATURE REVIEW

The key to educational reform relies on exploring alternative forms of assessment (Code & Zap, 2017). Feedback is conceptualized as information provided by an agent (e.g., teacher, peer, parent, book, internet) regarding aspects of one's performance or understanding (Hattie, 2011). For example, a teacher can provide corrective information, a peer can provide an alternative strategy, a book can provide information to clarify ideas, a parent can give encouragement, and a learner can look up the information to evaluate the correctness of a response. Feedback is thus a "consequence" of performance (Hattie, 2011). The literature on the effectiveness of feedback suggests complex relationships between the feedback intervention, task, learning context, and individual differences (Shute & Emihovich, 2018) affect the magnitude of the feedback effects (Hattie, 2011). However, primary studies published to date have reported insufficient data to meaningfully examine this complex relationship (Van der Kleij et al., 2015).

In a recent meta-analysis, Van der Kleij and colleagues (2015) examines to what extent various methods for providing item-based feedback in a computer-based learning environment (CBLE) affect students' learning outcomes. Shute (2008) distinguished different types of feedback which, Van der Kleij et al. further classified as knowledge of results (KR), knowledge of correct response (KCR), and elaborated feedback (EF). Their meta-analysis aimed to provide multiple effect sizes, one for each type of feedback (KR, KCR, EF) at four different feedback levels (task, process, selfregulation, self; see Theoretical Framework). Also taken into account is the level of learning outcomes (lower-order vs. higher-order), which is a relevant variable when examining feedback effects in a CBLE (Van der Kleij et al., 2011). In the results of their meta-analysis, Van der Kleij and colleagues found that EF was more effective than KR and KCR. Still, this hypothesis could not be meaningfully tested due to the small number of observations and insufficient power. Results consistently showed that more EF led to higher learning outcomes when compared to lower learning outcomes. However, most EF was aimed at the task and process levels, making it difficult to draw any generalizable conclusions. Further, since the results also show an uneven distribution of EF across the feedback levels, this indicates a lack of overall research on specific groups in which EF may be practical (e.g., feedback at the self-regulation level).

Given the high levels of variability in the effectiveness of feedback in CBLEs, more research is needed examining how feedback is appropriately received and how to design CBLEs to enable an increase in the frequency, types, and impact of feedback in the classroom. Given the low number of studies in secondary education settings reported in Van der Kleij et al. (2015), the degree to which the conclusions of this meta-analysis apply to younger learners is questionable. Finally, for the limited studies available, the results show somewhat smaller effect sizes in school settings than in higher education, suggesting that feedback might function differently within this context—ALIVE project research aims to bridge these gaps.

THEORETICAL FRAMEWORK

Models of feedback in CBLEs need to consider their multidimensional nature. This multidimensionality of feedback forms the framework on which this research is based. It has been established that one dimension of feedback involves the *type of feedback* (KR, KCR, EF), which we will include as the foundation of our framework. However, to provide meaningful results, we also need to take into consideration the assessment context (e.g., science inquiry), level of feedback (Hattie, 2011), as well as CBLE design impacts on learner agency (Code, 2020), and individual differences (Hattie, 2012; Stevenson et al. 2013).

Science Inquiry

Authentic performance assessment in science, technology, engineering and mathematics (STEM) requires students to apply scientific reasoning and knowledge in a way that resembles real-world inquiry contexts and is central to the modern curriculum (Code et al., 2012; BCMOE, 2018). Existing assessment frameworks built around knowledge acquisition are limited in their ability to evaluate *how* inquiry processes develop. However, cognitive models of inquiry enable researchers to examine these processes *in situ*. Models of STEM inquiry are structured around theorizing, identifying questions and hypothesizing, accessing data and investigating, and analyzing and synthesizing (White, Collins & Frederiksen, 2011). Building upon this model of inquiry, interactions in a CBLE specifically ones that are enabled by 3DIVEs – must keep three aspects of assessment in mind (Pellegrino et al., 2001): (1) the model of student cognition in the domain being assessed (e.g., life science); (2) the set of beliefs about the kinds of observations that will provide evidence of students' competencies (e.g., 3DIVE trace data); and (3) the interpretation process for making sense of the evidence (e.g., design framework). As 3DIVEs can feasibility be designed for summative assessment (Baker et al., 2016), leveraging these findings, we can consider how formative assessment and interaction design using this technology can potentially get us closer to evaluating *how* students engage in inquiry processes.

Level of Feedback

At the task or product level, feedback is about how well a task is being accomplished, such as distinguishing between correct from incorrect answers, acquiring more information, and building more surface knowledge. This type of feedback is most common, is often called corrective feedback, and encompasses 90% of teachers' questions (Hattie, 2012). The second level of feedback aims to create the product or complete the task (e.g., inquiry). Such feedback can lead to alternative processing, cognitive load reduction, strategies for error detection, and cueing to seek more helpful information (Hattie, 2012). Third, feedback at the self-regulation level (students' monitoring of their learning processes) can enhance students' skills in self-evaluation and provide greater confidence to engage further in a task. When students can monitor and self-regulate their learning, they can more effectively use feedback (Zimmerman, 2008). Finally, the fourth level of feedback is directed toward praising the self (e.g., Well done!). Praise can comfort and support and is welcomed by students; however, research at this level is mixed at best (Skipper & Douglas, 2015).

Learner Agency

On the axiom that 'learners are agents', it follows that an understanding of human agency is necessary to appreciate learning (Code, 2020). Agency is an emergent capability manifested in a students' ability to interact with personal, behavioural, environmental, and social factors in the learning context (Martin, 2004; Bandura, 2006). Agency enables students' influence on decisionmaking around *what* and *how* something is learned. In other words, learner agency is the capacity of students to act and engage with factors in the learning environment, ultimately enabling student voice and choice in the learning process. Agency is inherent in students' ability to regulate, control, and monitor their learning. Research further suggests that agency mediates goal orientations, student perceptions of the learning environment, social identification, the learning strategies they use, and overall academic performance (Code, 2020). Providing students greater choice and voice in the curriculum through technologies designed to enable inquiry learning improves engagement in the learning experience, empowering students to become agents in their education.

EVIDENCE-CENTRED GAME DESIGN

Assessing complex interactions requires a comprehensive framework for making valid inferences about learning. One such framework is Evidence Centered Design (ECD; Mislevy et al., 2003), which provides a formal, multilayered approach to designing assessments as arguments (Mislevy et al., 2014). The ECD framework helps to make explicit how high fidelity and rich assessment data in 3DIVEs is established through iterative cycles of analysis, design, development, implementation, and evaluation instructional design decisions (Figure 1).

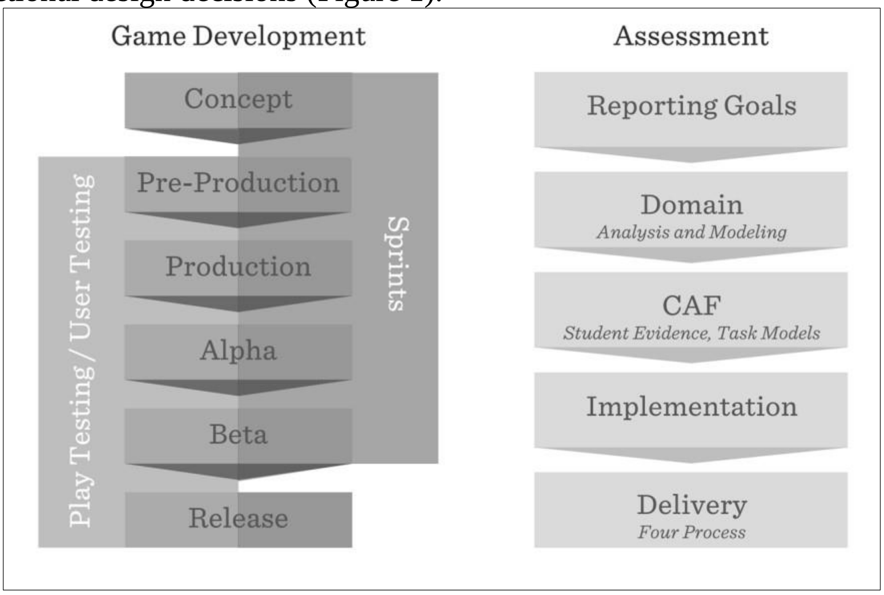

Figure 1. Game development and assessment design frameworks (Mislevy et al., 2014)

Falling Skies! The prototype

A prototype 3DIVE, *Falling Skies!* (Zap & Code, 2015; Figures 2 & 3), was developed using the Unity3d Game Engine and was readily accessible using a web browser with the Unity Web Player installed. *Falling Skies!* is built around an ecological, inquiry-based problem – where students are presented with the issue of a mass mortality event of blackbirds in a village and are challenged to investigate why this happened (Code & Zap, 2017). Students are presented with several probable causes of this die-off – an ecological problem mirrored from a real-life case study (Robertson, 2011).

Students can freely traverse through the 3DIVE using an avatar (Figure 2), speak to villagers, access reference resources, collect samples (Figure 3), and perform tests on these samples in a simulated laboratory setting. The students can review the results of their tests and take notes to help them later hypothesize what they think caused the die-off of this bird species. This 3DIVE is aligned with the BC curriculum and was designed as a *summative* assessment.

Figure 1. Choosing a character in Falling Skies! Figure 2. First-person view in Falling Skies!

Falling Skies! The remix.

A remix 3DIVE, *Falling Skies! 2.0* (FSV2; Code et al., 2021) is currently in development using the Unity3d Game Engine and will be available as an iOS app optimized for the iPad. Similar to the prototype, FSV2 is conceptualized around an ecological, inquiry-based problem – however, in this update, students are presented with the issue of a mass mortality event involving red-headed woodpeckers. Students are given several probable causes of this mortality event – an ecological problem mirrored from a real-life case study (Government of Canada, 2021). This 3DIVE is aligned with the BC curriculum and is being designed as a *formative* assessment using the ECD and the formative assessment framework previously illustrated.

INFLUENCE & IMPACT.

The potential of this research to make a considerable impact in education is multifold. This project will specifically deepen our understanding of the design and implementation of 3D immersive technologies in the classroom and provide evidence for these technologies' role in providing formative feedback towards making teaching and learning more effective and efficient. This understanding encourages ways of teaching and learning necessary in the knowledge-based economy of the 21st century. Ultimately, the ALIVE project will contribute empirical evidence of how students conduct complex reasoning, assisting them to become better self-regulated learners, thus providing a sense of personal agency, efficacy, and opportunity necessary to participate in STEM careers.

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PAPER #5: DESIGNERLY WAYS, MEANS, AND ENDS: FROM STEM TO STEAM TO STEAMD

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ABSTRACT

In this paper, I argue for an explicit role for design in STEM, perhaps as another, albeit less popular, iteration, STEAMD. We cannot take design for granted in STEM or STEAM and design is unique in its ways of knowing. The first section provides a background for the argument and focuses on Cross's work. We can assert from this that STEM and STEAM are inadequate without recognition of the uniqueness of design. The second section outlines risks of superficial design in STEM and STEAM. In the final analysis, we need novel methodologies as well as responsive ethics in STEAMD educational research.

Keywords: *STEM educational research, designerly ways of knowing, research methods*

Let us agree that deliberate, formal integration of engineering, mathematics, science, and technology dates to the mid nineteenth century and the rise of polytechnics in England, Germany, France, and the United States among other counties. Of course, for the sake precision, this excludes a longer history of practitioners, such as Da Vinci, whose work demonstrates unmatched integration. For more precision, interrelations among these four disciplines were increasingly formalized in World War I and II. And for even more precision, their ordering in the form of science, technology, engineering, and mathematics (STEM) was in the mid 1990s. For instance, upon review of England's national examination and awards systems, Dearing (1996) concluded that there are four areas of study in the upper level (A level) of high school:

- science, technology, engineering and mathematics [STEM];
- modern languages (including Welsh for students for whom it is not their first language);
- the arts and humanities (including English and Welsh); and
- the way the community works (including business, economics, government and politics, law, psychology and sociology). (p. 22)

Integration within each of these four areas (e.g., within STEM) is challenging enough while deliberate and formal integration across these four and other areas is quite difficult for students and teachers, to say the least. However, as STEM was popularized through the late 1990s, iterations were introduced and rationalized (e.g., STE**A**M, STE**E**M, STE**H**M, letters for **A**rts, **E**nvironment, **H**umanities, etc.). At times, these iterations are symbolic reminders that STEM disciplines are enriched by other disciplines, such as the arts, and at other times they are substantive challenges to integrate.

Through the 2000s, STEM education was prioritized in government policies, perhaps best profiled in Obama's White House policy initiatives during his first and second terms (e.g., "Educate to Innovate," 23 November 2009-November 2016). The US government is now moving to expand these initiatives. In mid-June 2019, the House introduced H. R. 3308— "Building STEAM Education Act of 2019"— to amend the "American Innovation and Competitiveness Act and the National Science Foundation Act of 2002." The aim is "to incorporate art and design into certain

STEM education programs." At the same time, H. R. 3321— "STEM to STEAM Act of 2019"— amends "the STEM Education Act of 2015 to require the National Science Foundation to promote the integration of art and design in STEM education, and for other purposes." The bills aim to "promote creativity and innovation." Although both recognize the importance of design, D is merely assumed by the A in STEAM. As Yakman (2017) acknowledges, "the A is becoming popular to be used to refer to as design and fine, musical and performing arts" (p. 286).

This paper problematizes the necessity and role of design in STEM. On one hand, design is taken for granted as inherent in the TE of STEM disciplines, as in "technological design" and "engineering design." It is implicit in "research design" in investigations and methods, "instructional design" (or curriculum, learning design, etc.), or the use of "design projects" in STEM education. On the other hand, design is taken for granted as part of art when accommodated in the corrective of STEAM. I argue that this taken for grantedness of design is inadequate and misleading. With Cross's (1982) influential paper, "Designerly Ways of Knowing," I argue for an explicit role for design in STEM, perhaps as another, albeit less popular, iteration, STEAMD (Price, 2012). The first section provides a background for the argument and focuses on Cross's work. We can assert from this that STEM and STEAM are inadequate without recognition of the uniqueness of design. The second section outlines risks of superficial design in STEM and STEAM. In the final analysis, we need novel methodologies as well as responsive ethics in STEM educational research.

DESIGNERLY WAYS OF KNOWING

Snow (1959/1998) notoriously made a distinction between "two cultures." As he noted, the distinction was not new but had become pronounced through the 1950s. The two cultures are:

> Literary intellectuals at one pole— at the other scientists, and as the most representative, the physical scientists. Between the two a gulf of mutual incomprehension— sometimes (particularly among the young) hostility and dislike, but most of all lack of understanding. They have a curious distorted image of each other. Their attitudes are so different that, even on the level of emotion, they can't find much common ground. (p. 4)

Although the two cultures of non-scientists and scientists shared characteristics and benefited from each other, they "almost ceased to communicate" (p. 2). For all the opportunities to reflect and write, including in "A Second Look," Snow (1959/1998, 1963) fails to consider design as a third culture. Nor does he consider engineering or technology. The thesis continues to be analyzed, defended, and tested in many ways but perhaps the most effective is Cross's analysis.

With insight drawn from the Royal College of Art's (RCA) (1979) *Design in General Education*, Cross (1982) proposed design as a middle ground or way between Snow's (1959) "two cultures." As he put it, "even a 'three cultures' view of human knowledge and ability is a simple model. However, contrasting design with the sciences and the humanities is a useful, if crude, way of beginning to be more articulate about it" (p. 221). "The 'third culture' is not so easily recognized," he asserted, "simply because it has been neglected, and has not been adequately named or articulated" (p. 221). Cross differentiated key activities and methods in design from the humanities and sciences:

> First, "the phenomenon of study in each culture is" ○ in the sciences: the natural world ○ in the humanities: human experience ○ in design: the man-made [*sic*, artificial] world (p. 221)

Second, “the appropriate methods in each culture are” ○ in the sciences: controlled experiment, classification, analysis ○ in the humanities: analogy, metaphor, criticism, evaluation ○ in design: modelling, pattern-formation, synthesis (p. 221)

He reasoned that “perhaps it would be better to regard the ‘third culture’ as technology, rather than design. This ‘material culture’ of design is, after all, the culture of the technologist— of the designer, doer and maker” (p. 222). Nonetheless he says, there are distinct “designerly ways of knowing.”

The core problem, Cross (1982) says, is that “of being more articulate about what it means to be ‘designerly’ rather than to be ‘scientific’ or ‘artistic’” (p. 222). The “world of design, he continues, “has been badly served by its intellectual leaders, who have failed to develop their subject *in its own terms*” (p. 223). Although the sense that there was something unique from “artistic” or “humanistic” to “designerly” to “scientific” thinking was not original, Cross (1982) persuasively clarified this uniqueness. Designerly ways of knowing are “embodied in the *processes* of designing” and “the *products* of designing” (p. 224). He identified five aspects:

- Designers tackle ‘ill-defined’ problems.
- Their mode of problem-solving is ‘solution-focused’.
- Their mode of thinking is ‘constructive’.
- They use ‘codes’ that translate abstract requirements into concrete objects.
- They use these codes to both ‘read’ and ‘write’ in ‘object languages’. (p. 226)

We can quibble with these distinctions as one quibbles with distinctions between science and technology or between the arts and humanities. Cross (2001a, 2001b, 2004, 2006) stressed that the ontological uniqueness of design cognition is extremely important. Design intersects art, craft, and engineering, but is unique (de Vries, Cross & Grant, 1993). The argument thus far is that we cannot take design for granted in STEM or STEAM and design is unique in its ways of knowing. The argument in the balance is that STEM and STEAM are challenged to avoid a superficial treatment.

SUPERFICIAL DESIGN

Like the slippage of artistic into “artsy” or “craftsy,” scientific into “sciency,” and technological into “techy,” designerly can easily slip into “designy” or “stylie.” Although some analysts defend the symbolic importance of designy, stylie, and techy actions and features, sometimes called “fashionable,” these adjectives are primarily used to suggest something problematic. For instance, options to stylize avatars and configure gadgets can be important design features but stylie avatars and techy gadgets are often dismissed as superficial or trivial. They may be symbolic for users but distract from more substantive design problems. Critical STEM educators may be the most dismissive, arguing that personalizing avatars and customizing gadgets are insubstantial, albeit expressive, design experiences (Petrina, 2000).

Design thinking’s resurgence in the early 2000s has been especially vulnerable to criticisms that it trivializes design. Ideo’s (2006) rendering of a concise four-step method of design thinking facilitated the resurgence but was subsequently marginalized as superficial:

1) Define the problem ←→ 2) Create and consider many options ←→ 3) Refine selected directions ←→ Repeat (optional) ←→ 4) Pick the winner, execute.

One of its biggest advocates back-pedaled and tagged design thinking a "failed experiment" and "process trick" that many mistakenly hoped would change business and education (Nussbaum, 2011). Walters (2011) wrote that "design thinking isn't fairy dust." She added a few years later that an inference of design thinking is "if you follow the steps carefully, you'll have success. There's a sneaky trick here though, in that even failure is couched as success. So if a product fails in the market, it's not a failure, it's *learning*" (Walters, 2014). Schwab (2018) notes that "part of the problem is that many people use the design thinking methodology in superficial ways." An Ideo representative confessed that design thinking and its representation reduced to "anything from getting a bunch of Sharpie markers and Post-its and putting them in rooms for brainstorms, to having new dress codes, to programming play into the week." Design thinking in this way ends up being "a theatrical thing that people can point to and say, 'oh we did that'" (Hendrix, quoted in Schwab, 2018).

A potential victim of these critiques is the democratization of design or assertion that everyone is a designer. This inclusive notion is articulated at length by Norman (2004):

> We are all designers. We manipulate the environment, the better to serve our needs. We select what items to own, which to have around us. We build, buy, arrange, and restructure: all this is a form of design. When consciously, deliberately rearranging objects on our desks, the furniture in our living rooms, and the things we keep in our cars, we are designing. (p. 224)

Criticism of design thinking, represented by renditions such as Ideo's, extend to analysis of these big tent notions. For instance, one critic qualified the notion, stating that "everyone can participate in the design process, but that doesn't necessarily make them a designer" (Treder, 2015). As the RCA was making the case for formal inclusion of design as a subject in the schools, similar cautions were raised. Gorb (1980) observed that how we define design is crucial and cautioned that "it is important to restrict the scope of the designer (and so the definition of design), to things, rather than ideas; and indeed to artefacts" (artificial things) (p. 147). "By restricting designers to 'things', he explained, "we are deliberately excluding them from the design of ideas or concepts; not of course as individuals, only as designer" (p. 147). A less worrisome definition of design then is "*the planning process for the things you make*" (p. 148).

For STEM educators, who are necessarily invested in child, youth, and novice designers, a tempting response to these critiques is scaling design capability (ability, aptitude, judgment, literacy, skill, etc.). To be sure, a valid scale of design capability— or STEM or STEAM capability— remains a holy grail for researchers (Petrina & Guo, 2007). Assessment and measurement efforts are important as institutional and personal decisions rely on valid measures (e.g., written test of design capability plus test of 3D modelling). Various scales accommodate a continuum or range from novice to expert, which in turn convey *how* everyone is a designer (e.g., Knowledge and Employability Studio, 2006). McKay's (2010) scale differentiates among what seemingly everyone can do or knows from what students of design and professional designers can do or know. For instance, if everybody "can identify general, superficial problems with a design," an intermediate designer "can identify many interaction and visual design problems [and is] aware of what makes a design good."

Perhaps most important for STEM researchers is the scope of design. On McKay's (2010) scale, everybody "thinks of design in terms of technology" but intermediate and advanced designers think of design in terms of features, personas, scenarios, and tasks. Gorb (1980) identifies a scope expanding from product to environment to information to identity design, including corporate identity (pp. 150-151). The reminder is that design of artifacts does not merely resolve in architectural, engineering, graphic, and product design. Educators are quick to add instructional design (ID), which may or may not include curriculum design (CD) and learning design (LD). Yet this returns us to the taken for grantedness of design in STEM. If all education is design then are all educators designers?

The argument in this paper would be superficial if only about acronyms, such as an iteration from STEAM to STEAMD. The paper would be incomplete without acknowledging initiatives to include design in the practice of STEM education. Meaningful and substantive design-based learning (DBL) and Db-STEM activities in classrooms, labs, outdoor environments, and workshops are notable (e.g., Bartholomew et al., 2018; Chang & Hsu, 2015; Yakman, 2017; Yakman & Lee, 2012). As Gorb (1980) acknowledged, "in most countries 'design based learning' seems always to have been present across their educational spectrum." We should make sure, he added, "that the design way of learning plays a significant part in the education of all the young people" (p. 153). The challenge in this paper is primarily to STEM or STEAM researchers to differentiate between meaningful, substantive design and superficial design learning and instruction. This includes a challenge to recognize designerly ways of knowing and a scope of design that includes an expansive definition of artifacts.

CONCLUSION

I argued that design is taken for granted in STEM and STEAM, and this risks superficial treatment. I summarized Cross's (1982) groundbreaking insights into designerly ways of knowing to counter taken for grantedness and raise the question of parity. Hence, STEAMD is a necessary iteration for acknowledging this and to reiterate the importance of design as discipline and way of knowing. The argument concludes with a challenge to STEM and STEAM researchers to create novel methodologies and responsive ethics to account for designerly ways, means, and ends of learning and teaching.

This paper grounds a symposium that follows with conceptual and empirical direction for exploring designerly ways, means, and ends in STEM and STEAM educational research. The second paper explores how a group of pre-schoolers and their productive imaginations shape researchers' methods and how we investigate the role of design in STEM early education. The third paper TBA. The fourth paper explores a group of university students' insights into cultural competence in instructional design practices, specifically in the design of avatars in a virtual world. Their insights challenge STEM and STEAM education researchers to account for cultural nuances in their research. The fifth paper explores the problem of designing digital or online presences and the self-censorship that is tending to characterize this process for professionals. Teacher candidates in this research inform researchers' understandings of design considerations and concerns that young professionals process as they represent themselves through social media.

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CHANGING THE LANDSCAPE: STEM EDUCATIONAL REFORM THROUGH CROSS-DISCIPLINARY APPROACHES

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SYMPOSIUM ABSTRACT

The increased complexity of globalization has impacted developments such as AI, climate change, displacement, and inequality, and will require intricate and multifaceted approaches to both comprehend and promote change. STEM has led successful efforts to promote global and societal change, yet reports reveal a call for educational reform to promote cross-disciplinary problem-solving (Mohr-Schroeder et al., 2015). Three researchers specializing in sustainability education, inquiry-based learning, digital literacy education, and educational policy will demonstrate the benefit of interdisciplinary instructional practices and conjoining competencies to encourage STEM literacy and re-invigorate growth in STEM related careers. The format is demonstrative and conversational, beginning with a brief overview of past STEM education initiatives and the evolving needs of the global context. The key objectives are: 1) to explore the interdisciplinary nature of STEM; 2) to examine diverse learning environments impacted by STEM education (i.e., K-12, post-secondary, teacher education, and digital spaces); and 3) to profile advancements in STEM education curriculum and pedagogical practices through the application of new methods, competencies, and policies. To conclude, focus questions will be displayed to encourage conversation. Each session will offer approaches and practices for the self, the classroom, and higher education by exploring intersections between sustainability education, the inquiry learning process, digital literacy, educational policy, and STEM education to connect research with practice. These studies contribute to the exploration of connections between classroom, context, learning within the self and society to reform STEM education.

Keywords: *Sustainability education, inquiry-based learning, digital literacy education, educational reform*

SYMPOSIUM OUTLINE (60 minutes):

A. Introduction by Chair (3 minutes)
B. Research Papers (13 minutes each):
    1. STEM as Integrated Part of Inquiry Rich Learning by Yu-Ling Lee
    2. Aligning Competencies within Sustainability and STEM by Kshamta Hunter
    3. Digital Literacy Fostering Secondary School STEM Education by Lesley Liu
C. Conclusion by Chair (3 minutes)
D. Discussion and Questions (15 minutes)

INDIVIDUAL SESSION ABSTRACTS STEM as Integrated Part of Inquiry Rich Learning by Yu-Ling Lee

This session will explain how a small liberal arts university in Canada, reconceived their curriculum into an inquiry-based model. More specifically, how STEM is an integrated part of an inquiry rich learning model as part of a liberal arts core curriculum. The university utilized a liberal arts core curriculum in which all students would enroll in specific courses that were pedagogically and methodologically designed with an inquiry-based model. The liberal arts core curriculum is divided into six key inquiry models: aesthetic and performance, quantitative and computational, historical and archival, experiential and embodied, cultural and linguistic, and social and global. The university's inquiry model ensures that all students must complete various STEM courses so that they can develop ways of knowing about the world that is mathematical and scientific. Students learn to model problem solutions using computing notations, analyze quantitative information, and conduct research analyses to answer meaningful questions. STEM education, for this university, is a way of knowing that is readily integrated as part of an inquiry rich learning model.

Aligning Competencies within Sustainability and STEM by Kshamta Hunter

This session will share the key sustainability competencies approach and framework to achieving the proposed United Nations' 17 Sustainable Development Goals (SDGs) and their alignment with STEM initiatives. The sustainability competencies have been identified and highlighted as one key approach to achieving the SDGs through education for sustainable development (UNESCO, 2017). Competencies are the amalgamation and interplay of knowledge, skills, values, and perspectives, including ethics, emotions, as well as social and behavioral components (Lozano et al., 2017). This section of the symposium will map and highlight the key competencies supported through the three sustainability-oriented courses offered at a university in Canada. The study investigated the impacts of sustainability-oriented courses on students' awareness, competency development and actions. Through an indepth qualitative analysis that provides students' views on their own learning, this study examined students' understanding of sustainability concepts and how they implement the strategies they learned in these courses with focus on course content and pedagogical attributes that influence students' competencies for sustainability. Results show the impact of sustainability courses on students via three main avenues: student views and attitude, student motivation and agency, and difference in student responses to and understanding of issues discussed. This study shows how and whether sustainability-oriented courses are impacting students' conceptions of sustainability concerns, and therefore enhancing their competencies to tackle sustainability challenges. The results provide a framework for the adaptation, further modification, and development of the sustainability curriculum and pedagogical approaches at the postsecondary level of STEM education and beyond.

Digital Literacy Fostering Secondary School STEM Education by Lesley Liu

With STEM education and personalized learning requiring multi-disciplinary approaches, cloud-computing is becoming an instructional technology trend due to its improved accessibility and ease of collaboration. This session explores how digital literacy practices in a secondary school classroom can impact online interactions and classroom collaboration within a technology lab. This session will first examine how a class of Grade 8 students conducted research and created cloud-based spaces for a technology driven project. A cloud-based productivity service was implemented in a Grade 8 classroom, which recorded all student created artifacts. In addition to the artifacts, data was collected through pre-study and post-study interviews. Using ethnographic methods, an in-depth analysis of classroom sessions, and group interviews, the study found that student created spaces encouraged self-regulation practices and gave insight into student-led initiatives of cyberbullying prevention. The findings demonstrate that the process of designing online spaces encouraged digital literacy practices and cyberbullying awareness. Issues regarding technical difficulties and student behaviors that affected the collaborative process were examined and discussed. This session ends with methods and techniques for incorporating cloudbased collaborative spaces, encouraging digital citizenship through STEM curriculum, and pedagogical methods for secondary school classrooms through STEM education.

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INNOVATIVE SHOWCASES

A SAFER RAINBOW FLAME DEMONSTRATION

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RELEVANT ONLINE RESOURCES

https://pubs.acs.org › doi › abs › acs.jchemed.8b01010

PROPOSED TIME ALLOCATION

Twenty minutes.

ABSTRACT

The rainbow flame demonstration is often used to inspire the general public during outreach event activities and to illustrate aspects such as electronic transitions, the electromagnetic spectrum, energy and atomic structure to our high school and undergraduate students. This demonstration traditionally involved burning an organic solvent containing a salt in an open container, to produce a strong, vividly coloured flame. The use of this demonstration is now strongly discouraged due to safety concerns. Between the years of 1998-2017, the *Journal of Chemical Education* reported 32 accidents, with 164 injured due to this demonstration. Although alternative approaches to the traditional flame demonstration have been developed, none matches the convenience of use and vibrant colours of the old method. We undertook a re-examination of the rainbow flame demonstration to develop a new method which addresses the safety concerns and restores the convenience of use and brilliance of colour. In this presentation, we will discuss a new rainbow flame demonstration, which we recently published in the *Journal of Chemical Education* (https://doi.org/10.1021/acs.jchemed.8b01010). We will address the previous safety concerns and illustrate how its improved portability, allows for the demonstration to be applied in new situations to aid student learning.

Keywords: *high school/introductory chemistry, first-year undergraduate/general, second-year undergraduate, demonstration, inorganic chemistry, public understanding/ outreach, safety/hazards, atomic spectroscopy, descriptive chemistry*

GOALS AND OBJECTIVES
Background

The flame demonstration, also known as the rainbow demonstration or rainbow flame test is visually appealing and used by instructors to display atomic emission phenomena that occurs in common items such as neon lights and fireworks.[1,2] The demonstration is also used to reinforce topics of: quantum theory of matter, descriptive chemistry, and elemental analysis.[3] The long history and variations of the demonstration was summarized by Bretz and Mayo who reported that between 1928 and 2015, the *Journal Chemical Education* alone published 32 different methods.[4]

All variations of the demonstration rely on the same principle: a salt is introduced into a flame to generate the atomic emission (or colored flame).[4] The difference is the matrix supporting the salt and the source of the flame. With the most common method, a small amount of salt and ~10 mL of an accelerant, usually methanol, is placed on a Petri or ceramic dish and the accelerant is ignited.[5] Although this method produces a flame that is both strongly coloured and visually appealing, its use has been strongly discouraged due to safety concerns. Between 1998-2017, there were 32 documented accidents with 164 people injured, including severe injuries.[6,7] To address and improve the safety, the *American Chemical Society* released a video highlighting a method that removed methanol but this approach only allows for showing one colour at a time.[8,9] A recent publication in *Education in Chemistry* promoted the replacement of methanol with ethanol, but incidents resulting in injury have also been reported using this solvent.[7,10]

Goal/Objective

To make this flame demonstration practical and safe, we devised a list of criteria including:
(1) a controlled flame, (2) a low risk procedure, (3) produce brilliantly coloured flames, (4) have a convenient setup/clean up, (5) be portable, (6) have a long-lasting flame (more than 2 min), and (7) embrace some of the principles of green chemistry.[11] Via the use of a ultralight camping stove and insulating firebrick strip we were able to develop a method satisfied the above criteria (see Figure 1). This method also uniquely allowed for the observance of multi-coloured flames (Figure 2).

Figure 1. The colored flame in the order of fuchsia (LiCl), yellow (NaCl), lilac (KCl), orange/red ($CaCl_2$), blue/green ($CuCl_2$) and red ($SrCl_2$) (via the ultralight camping stove)

Figure 2. The mixed colored flame from saturated firebrick sticks containing $CuCl_2$ (blue/green)/NaCl (yellow), $CuCl_2$ (blue/green)/$CaCl_2$ (orange/red), $CuCl_2$ (blue/green)/LiCl (fuchsia), LiCl (fuchsia)/$SrCl_2$(red), NaCl (yellow)/LiCl (fuchsia), NaCl(yellow)/$CaCl_2$ (orange/red).

CURRICULUM CONTEXT

The rainbow flame demonstration is a valuable education tool that can be used to enhance the science curriculum of the K-12 grades and undergraduate programs. It can also be used with the general public to explain specific topics or generate an interest in science by using different levels of instructions for different audiences. The rainbow flame demonstration can use used to illustrate general topics including: energy transfer (i.e. atomic emission, production of light), quantum theory of matter, descriptive chemistry (i.e. properties of atoms), laboratory safety, oxidation reactions, analysis techniques, green chemistry, solubility products and electron configuration. Within these examples, specific situations can be explored such as a discussion on atomic emission can be used to explain everyday items such as fireworks or neon lights, with this demonstration providing a visual connection to the topic.

The updated British Columbia Science K-12 Curriculum includes a list of four "Big Ideas" that should be taught at each grade. These "Big Ideas" include several that can be reinforced by the rainbow flame demonstration and include:[13,14]

Science 1: "Light and sound can be produced and their properties can be changed"
Science 1: "Matter is useful because of its properties"
Science 3: "Thermal energy can be produced and transferred"
Science 4: "Energy can be transformed"
Science 8: "Energy can be transferred as both a particle and a wave"
Science 9: "The electron arrangement of atoms impacts their chemical nature"

Within each "Big Ideas" the specifics of the curriculum offer more opportunities to use the rainbow flame demonstration. For example, in the grade 4 Science 4 curriculum students learn that energy comes in various forms and that devices are able to transform energy. This includes a discussion on common devices, such as glow sticks and flashlights. In this context the rainbow flame demonstration is another example of such a device.[13,14] The grade 12 chemistry curriculum includes a discussion on analysis techniques, green chemistry and electron configurations, all topics reinforced by this demonstration. [13,14]

The improved safety and portability of this method allows for this demonstration to be used as a teaching tool outside of the laboratory setting. This is applicable to the K-12 curriculum as well as undergraduate programs with discussion covering different complexities at an advanced level. Preliminary results show that the use of this demonstration in an undergraduate science course for non-science majors improved the student understanding of colour and energy transfer.

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MODES OF AUDIENCE ENGAGEMENT

We will show the audience how to perform the rainbow flame demonstration using our new method. A select number of audience members may be called upon to try the demonstration and illustrate how a “rainbow” of colours can be generated.

MAXIMUM NUMBER OF AUDIENCE PARTICIPANTS

As we will illustrate the correct use of the demonstration, there is no limit to the audience size.

SPECIAL RESOURCES AND REQUIEMENT FROM THE STEM 2020 ORGANIZERS

No special requirements. We would require common items such as a laptop, projector, table and fire extinguisher (We do not plan to use the fire extinguisher. It is only for safety).

RELEVANCE AND SIGNIFICANCE TO THE STEM FIELD AND CONFERENCE AUDIENCE/EXPECTED IMPACT FOR STEM PARATICIPANTS

The menthol or ethanol-based rainbow flame demonstration is a very common demonstration in post-secondary schools, high schools and science centers. Based on the safety concerns it use should be stopped. Due to the beauty of the coloured flame this demonstration was popular and it was an effective teaching tool. With our method the rainbow flame demonstration can again be safety performed to inspire students and the general public.

THE STEM HIGH SCHOOL PROGRAM: PRACTICAL APPLICATION OF A PBL FRAMEWORK IN A TRADITIONAL SECONDARY SCHOOL CONTEXT

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ABSTRACT

Research supports the effectiveness of deep inquiry frameworks like project-based learning (PBL) in achieving important improvements in student outcomes. The new British Columbia K-12 curriculum is based in deep inquiry but there are few examples of its practical application. STEM High School is a test case of successful PBL programming for grades 8-12 that exists within a traditional high school setting. This presentation aims to share what inquiry and PBL looks like when theory meets the realities of the classroom and typical school structures. The specific aim of this showcase is to highlight strategies and lessons learned in the development of a highly stable and successful PBL model. Participants will be better able to navigate the implementation of their own inquiry and PBL programming. Specifically, we will discuss and share resources for PBL program architecture, designing projects, and student assessment.

Keywords: *STEM, pbl, project based learning, assessment, inquiry, K-12, secondary, high school*

INTRODUCTION

The Science, Technology, Engineering and Math High School program (STEM) is the first of its kind in BC and is demonstrating the transformational impact that a student-centered and interdisciplinary PBL program can have on student learning. STEM uses an inclusive model that has adopted the affordances of technology and the new curriculum to provide students with the skills to succeed in a complex and accelerating world. Drawing from established literature on STEM education theory, our contribution shifts the focus from the traditional, teacher-centered educational approach to a model that emphasizes student connection and the authentic development of core competencies through real-world projects like autonomous drones and solar farms.

This model is a student-choice option within a traditional high school setting and was developed to be replicable by using shared structures like schedules, professional development, curriculum, and courses. Starting with a single cohort (group of students with a common STEM schedule) in 2014, we have grown to five cohorts with 130 students spanning grades 8-12, of which 33% are girls. Students have engaged in over one hundred student-driven projects that connect them to careers and issues in their communities and teachers have learned how to best position themselves in that complex process. The school has seen an increase in enrolment, and STEM graduates are achieving unprecedented postsecondary success.

RELEVANT EDUCATIONAL RESEARCH

The rationale of our inquiry model is based on primary educational research in constructivism, social learning theories, and cognitive science. This is most strongly connected to the Learning-for-Use framework proposed by Edelson (2000) which offers three main findings relevant to our model.

Authentic learning is student initiated.

Cognitive science has shown that although we can consciously monitor learning to some extent, the actual construction of knowledge occurs at an unconscious level that only the student can initiate (Edelson, 2000). Although exams and tests can create an external drive to recite a body of knowledge, it does not stimulate authentic, "strong" concept development because the student may not be intrinsically motivated. Many students achieve good test results with low engagement (Zyngier, 2008), but shortly after it becomes "inert knowledge" with low retention (CTGV, 1992; Strobel & Van Barneveld, 2009). Students are motivated by effective feedback (Hattie & Timperly, 2007), project design (Veletsianos, 2011), personal relevance (Fernandes et al, 2014; Zyngier, 2008), and high quality scaffolding of tasks (Davis, 2010; Lee, Blackwell, Drake & Moran, 2014).

Student learning is embodied and takes time.

The development of cognition is an evolving physical/sensory experience influenced by genetics and life experiences. Each student comes to class with a pre-existing cognitive structure that have evolved to form their unique, situated understanding of the world, complete with firmly rooted misconceptions (New London Group, 1996). Continued development requires constructing knowledge and connections through iterative, direct experience (Edelson, 2000). Also, new concepts must be seen as compatible with existing cognitive structures and be tested for usefulness before they are adopted by the learner (Winn, 2003). Although teachers feel pressure to "cover the content", relating new ideas or overthrowing misconceptions takes time. The consequence of our current "mile wide, inch deep" focus on content is that students often fail to master any of it (Jacobsen & Wilensky, 2006). Finally, metacognitive activities have been shown to be critically important to the development of radical conceptual change and understanding (Confrey, 1990; Davis, 2010; Vaughan, 2013).

Learning is a social activity.

Connected knowledge domains are not a private collection of words and concepts transmitted passively. Rather, they are formed by communities of practice that share a culture, symbols, and a distinct way of communicating. Sense making is made through discourse with other learners and is a key element of professional research communities (Barber, 2015; Driver, 1994). Also, cooperative learning tends to amplify connections and leads to more successful problem solving overall (CTGV, 1992). We also know that successful group work need be modelled and facilitated (Vye, 1997) and can have unique student-assessment challenges (Lee et al, 2014).

IMPLEMENTATION OF A SECONDARY SCHOOL STEM INQUIRY MODEL

Our innovation is the development of a program that represents a total commitment to student-centered learning based in research literature. When engaged in deep learning that reflects their interests and the authentic practices of the STEM community, we see student outcomes that surpass that of traditional education. This new focus has challenged many of our practices, and continues to redefine our role as teachers.

Our "Flex Glove Translator" is a prime example of PBL in action. A team of three STEM 9 girls selected and formed their own mixed-ability group with three self-determined goals: to learn about circuits, increase their confidence with coding, and help in the community. Teachers guided their ideation with a flexible framework that has agnostic curricular competencies (i.e. "use appropriate technology to collect and analyze good quality data.") that align with the course outcomes and provincial curriculum. This group was inspired by a non-verbal student in the neighbouring "Life Skills" program whose use of American Sign Language (ASL) makes communication challenging for non-signers. During the research phase, the team scoured the web for high quality references before combining tutorials on "flex sensors" with converting digital signals to text, making a "glove that talks". They presented this idea to the teacher and with approval and guidance they forecasted needs, delineated roles, and built a schedule. Over four weeks the team independently explored the basics of ASL, how to read schematic diagrams, wiring circuits, soldering, coding, and linear functions to calibrate their sensors. Each day began with a group meeting then individual or group work, depending on the stage and needs of the project. They monitored their daily progress and made adjustments when problems arose, occasionally asking for help from the teacher. Once a week, they had a scheduled assessments in the form of interviews. In one, they presented their prototype and reported that their circuit wasn't working. The teacher suggested to check their soldering and they were shown how to use a multimeter to check for continuity. They resolved this problem and many others, completing a wearable glove that could codify some basic ASL hand gestures. Their project was presented with pride at a year-end gala community event. The interview assessments were formative in nature, and the final product and presentation were used as a snapshot of learning for the report card. In a reflective assignment about the experience, one of the girls wrote:

> I've gained leadership and confidence throughout the year. Towards the beginning of the year, I did not engage as much in the projects because I was shy and other students in my group took the leader role…working with different classmates, they included me and asked for my ideas and opinions. That gave me a boost of confidence in my ideas and what I'm doing. My capstone helped me grow an interest in tech and engineering and it's maybe something I'd want to pursue in the future.

In designing and executing PBL, our role as teachers is quite different from our experiences in more prescriptive, content-focused classes. Our key source of inspiration for project ideas is to probe student interest, combine subjects, and seek inspiration from authentic uses of science, technology, and mathematics. Solar farms, climate change, robotics, self-driving cars, genome sequencing, plastic waste, and hydroponics are past inspirations that contain obvious problems statements and desired outcomes. Most project development sounds like: "Students know that fossil fuel dependency is a serious problem. We could plan a solar farm, but how do we do this as efficiently as possible for this context?" After six weeks of dedication our STEM 12 students presented a paper and prototype to the international Spellman Clean Energy competition and reached the semi-finals from a pool of over 500 entries.

We find that planning projects is easier when competencies are considered before content because it avoids overly constraining the problem. The "21st century" competencies recognized by professionals in STEM fields are relatively universal and have the advantage of being content-agnostic. Different projects lead to the same learning goals, and be clearly assessed, while allowing a premium on studentinitiated and differentiated learning. PBL programming requires different tools and perspectives and we still experience some discomfort in the "messy middle" of open questions. Although the teachers should have key domain-relevant experience, we find that it is inauthentic and not necessary to already "know the answer". The teachers work together and also encourage students to work in teams, using the tools of all STEM professionals: internet resources, calculators, spreadsheets, notes, and any other form of distributed cognition required. Starting with competencies and student interest is not the same as ignoring content. Problem solving cannot occur in the absence of facts and knowledge so we have the role of introducing a "balanced diet" of content for the students, sometimes by direct instruction or suggestion.

Finally, our assessment is frequent, flexible, and used to guide self-regulation during the inquiry cycles. Our students like that these are "not for marks" because it makes it safe for them to explore. They have adopted the phrase "Fail Fast, Fail Often" during the prototyping stage to recognize that learning is naturally iterative. Learning goals are clearly defined (e.g. estimate reasonably, screen ideas against criteria and constraints, use knowledge of scientific concepts to draw conclusions that are consistent with evidence) and students are responsible for their role, and to the group as a whole. In our experience, interviews that focus on what students "do" and "say" affect outcomes more positively than teachers' evaluation written evaluation of written work.

IMPACT AND REPLICABILITY

Impact

Student-centered and inquiry learning is central in research literature but not yet common in practice (Khan, 2007; Mergendoller, 2018). Our intervention does not exist in antipathy toward traditional education yet we are commonly asked to compare STEM student outcomes against that background. We have chosen "student ownership of learning" and self-regulation as a framework to consider the impact of our STEM intervention. Prior to their STEM experiences, the teachers in our program had a combined experience of nearly 60 years of content-focused, teacher-at-the-center pedagogy with which to compare outcomes.

At the senior level STEM students have lower dropout and truancy rates. It is more common at all levels to see students commit time beyond normal hours to complete a project. School counsellors have commented on a lower rate of needed support for our students even though the demographic crosssection matches that of the rest of the school. External guests comment on the quality of student presentations, citing breadth of knowledge and ease of communication. In all years, meta-cognitive assessments contain powerful student statements of ownership and a sense of pride in their work. We receive letters from parents who want to share what a profound difference the program has made for their child, often in contrast to struggling in a main-stream setting. We provisionally connect all of these data to a general "sense of purpose" inherent to increased student agency.

Mathematics in STEM is based in "learning-for-use" and is completely embedded within the context of projects and problem solving. The University of Waterloo's Centre for Education in Mathematics and Computing contests are an external validation of this approach. Their annual problem solving contest was written by nearly 90,000 students in 2019, representing about 4% of all Canadian high school-aged students. Within that subset, our STEM students either matched or exceeded the national average as well as out-performing their peers within the school.

When a project really “clicks” for a student, they demonstrate learning in powerful and noticeable ways. A much higher proportion of our students now participate in science fairs and have achieved the school’s first regional, provincial, and national placements, most notably for the creation of a low-cost early skin-cancer detection device. We attribute this success to the passion for projects, and the amount of time students spend practicing authentic skills and attitudes of the STEM community. Senior students are also securing desired post-secondary placements at a higher rate and we have been directly contacted by institutions for the names of graduates. Awards, scholarships, and internships have also increased in frequency and scope well beyond our experiences in the main-stream setting, including our first TRIUMF’s research internship, multiple $30,000 entrance scholarships, and the Loran Scholarship in 2018, valued at more than $100,000. In every case, students have highlighted powerful project learning experiences in their personal applications. These successes extend into post-secondary with early admission to special engineering teams, additional scholarships, and landing STEM careers for our first ever 2014 senior cohort.

Replicability

This program was designed within a public secondary context and is highly replicable. It required “buy-in”, time, and rearrangement of existing resources. In order to control the program growth, we started with a single split 11/12 cohort in the first year. In the second year, we created a grade 8 cohort which tracked through following years until the program spanned all grade levels. This strategy gave us the time we needed to develop new educational material, on-board new staff, and to address challenges and opportunities as they arose. It also allowed the instructors to grow into their new roles, and provided a stepwise mechanism for integration with other school activities to minimize disruption to existing operations. This approach enables students, parents and teachers to understand that the program model is proven, stable and will result in positive learning outcomes.

The evolution of STEM High School continues to be highly iterative, collaborative, and professionally rewarding. Our model has been explored by many educators through workshops, site visits, and research, but could be shared more widely. We believe that with appropriate leadership, any high school in British Columbia could use our model to develop their own student-centered PBL program and significantly improve student outcomes.

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AUGMENTED REALITY FOR STEM LEARNING: ENGAGING MINDS WITH TECHNOLOGIES THAT INVITE AND IMMERSE

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2. Simon Fraser University

ABSTRACT

Integrating augmented reality (AR) tools with STEM curriculum opens-up novel possibilities for developing course assignments that invite diversity of thought, differences in worldviews, and creative explorations with media and technology. This *Innovative Showcase* will be valuable for members of the STEM community to explore a flexible approach for integrating AR technologies to enhance teaching and learning in classroom and lab settings, applicable for a range of academic disciplines. The Showcase will display assignments contributed by 144 undergraduate and graduate students from six education courses. Students were challenged to create, code, and curate AR experiences that represent the course keywords in a new way, and a new medium. The researchers will demonstrate how the students designed and programed AR scenes that overlay digital information on top of the keywords, thereby augmenting learning with a focus on digital storytelling and personalized definitions. Not only is this easily-adaptable assignment enjoyable to teach and meaningful to do, but it also builds community by bringing people, art, science, knowledge, and technology together. We will demonstrate an approach to AR pedagogy that is suitable for guiding and supporting learners with a range of technical skills, from beginner to advanced levels. STEM2020 attendees can use their devices to explore the exemplars on display or learn how to make their own interactive experiences. We invite participants to share their questions and perspectives on the affordances and constraints of using AR tools to meet teaching and learning goals.

Keywords: *STEM education, augmented reality, immersive learning, educational technology, digital pedagogy*

GOALS AND OBJECTIVES

The purpose of this research project is to evaluate how integrating AR technologies with a course curriculum transforms the student learning experience. We developed a flexible and easily-adaptable AR design assignment as an integral part of the curriculum in courses specific to the study of educational technology and learning design, within the Faculty of Education at Simon Fraser University and the College of Education at the University of Saskatchewan. Students worked collaboratively in design teams to represent and define the course keywords in AR with an emphasis on critical thinking and creative expression. They learned how to design and program scenes that overlay digital information on top of real-world images, thereby augmenting user experiences with compelling narratives that interact with both physical and virtual environments. Each AR project augments learning with a series of well-designed scenes, including definitions, infographics, games, music, narratives, photo galleries, quizzes, videos, websites, and more. Examples of the course keywords include artificial intelligence, coding, creative coding, dark patterns, design thinking, digital activism, digital literacy, digital literature, digital storytelling, eLearning, fake news, game-based learning, immersive education, intelligent tutoring systems, metacognition, mobile learning, MOOCs, STEM, STEAM, and virtual reality. We will demonstrate a range student-created exemplars during the *Innovation Showcase* to provide a depth of understanding and stimulate conversation.

RELEVANCE AND SIGNIFICANCE

While there are many technological options to engage students and enhance the learning environment, there are also considerable challenges with integrating technology in meaningful and inclusive ways in STEM labs and classroom settings. Our flexible and open-ended AR assignment has adequately addressed these issues in six different university courses. The design-based learning challenge is suitable for interdisciplinary learners and scalable for varying levels of experience and technical expertise.

Building on the theoretical perspectives of Akçayır & Akçayır (2017) and Dunleavy & Dede (2014), recognized leaders in the use of augmented reality for educational purposes, the research project that we will display addresses two primary questions:

1) How can AR design and production enrich a course curriculum and foster a better student learning experience (e.g., supporting creative thinking, engagement, distributed cognition, experiential learning, psychological immersion, visualization techniques)?
2) What are the affordances and constraints of using AR as a tool for improving teaching and learning effectiveness (e.g., what does student-generated content contribute to the course objectives and outcomes)?

The research team collected data that focused on how the students learn and interact as they are researching, collaborating, and designing their personalized AR experiences (within the context of the labs where classes are scheduled). See Table 1 for a high-level view of the AR design assignment. Using a mixed-methods approach, we conducted post-pre surveys and recorded field notes during the design modules to collect evidence of students' unique expressions and experiences of learning. Additionally, we compared and analyzed the student-created AR projects to discern findings that are grounded in the realities of students' artifacts and coconstructed knowledge. Each AR code has a comprehensive data dashboard to view all activity and monitor performance (e.g., total scans, average scan duration, time, location, and device platform).

Table 1: AR Assignment Metadata

Learning Outcomes	Students will be able to code and curate educational AR experiences that demonstrate knowledge of the course content and keywords
Audience	Scalable from high school or undergraduate, first graphics class, to advanced graduate courses
Dependencies	Introductory programming knowledge
Prerequisites	Build on prior labs that focus on user experience (UX) and user interface (UI) design principles for learning
Strengths	Students enjoy presenting their work to peers; significant mentorship opportunities occur as learners support each other to solve design and technical challenges
Weaknesses	Students with weak design skills may find it challenging to get beyond the basics of making immersive content with high educational value
Variants	Unlimited design options for the AR scenes

Assessment	**Educational Value:** Definitions are relevant, thought-provoking, scholarly, and meaningful **Technical Capabilities:** Programming is logical, efficient, debugged **UX/UI Design:** Visual design principles, usability testing, satisfying user experiences **Teamwork:** All members are respectful of team roles and supportive of shared goals **Overall Impact:** Level of effort, ingenuity, creative risk-taking, and technical challenge

PERSPECTIVES & THEORETICAL FRAMEWORK

Foundational to this research is the perspective that learners of all ages benefit from opportunities to be the coders, creators, and inventors of the media and technologies that make our world, thereby, taking an active role in contributing to and shaping our technological futures in the making. This view includes education and support for using leading-edge creative technologies in innovative, responsible, and critical ways (MacDowell, 2017; MacDowell, Ralph, & Ng, 2017). While the field is new and the technology is continually improving, many students are embracing technology as quickly as it is released. Not only does AR provide meaningful opportunities for personalized and interactive education, there are also powerful learning opportunities for students to take ownership of their learning as they design, build, and share their AR experiences.

AR refers to an enhanced version of reality made available by the integration of digital information with the user's real environment in real time, differently from virtual reality (VR) which replaces the user's surroundings with an entirely simulated setting (Dunleavy, 2014; Saltan & Arslan, 2017). The AR keyword assignment is based on constructionism, an approach to learning that maximizes student agency and emphasizes designing, building, coding, and inventing as ways of knowing. Knowledge is actively constructed by learners experimenting with diverse ideas, tools, codes, materials, and perspectives; and further developed through reflections, observations, and interactions with others (Kafai, 2006; MacDowell, 2017). Constructionism is a hands-on approach for generating collaboration diversity and a sense of belonging in the class. As critical friends, students carefully critique each other's work; hence, they are inspired by and learn from the team.

RESULTS AND DISCUSSION

This study contributed to a university's goals for enhancing the student learning experience and transforming how we view each other and the world. We involved six classes in co-creating knowledge and shared our innovative course assignment to help create a more connected and vibrant campus. Additionally, this project offered an opportunity for students' design works to be recognized and acknowledged by peers and the university community. Our preliminary research findings evidence that the student learning process was empowering, inspirational, unexpectedly fun, useful for making meaningful connections with peers, and valuable for generating a collaborative spirit and a sense of belonging in each of the courses. 100% of the students surveyed agreed that the course assignment was relevant for enhancing their design and technical skillsets. As Alan reported, "I was encouraged to use my imagination and intelligence which does not often happen in my courses. I enjoyed the process of playing with ideas and interpreting knowledge in a new medium." Janet summarized her learning experiences: "Great opportunity to define the course keywords through visual explanations."

Furthermore, valuable team-building and mentorship opportunities resulted as learners supported each other to solve design and technical challenges. As Navroop reflected on the transformation of his thinking: "The AR design process deepened my understanding of the course material, and I learned by collaborating with colleagues and having a shared purpose." Danielle reported, "In retrospect, I like that I was respected by the people in my class because I could help them with tech support." While the AR tools contributed to the instructor's innovative pedagogy and ability to empower student learning, some students struggled with the social and technical aspects of creating immersive content in a collaborative learning environment.

Long-term goals include building on the research findings to develop a new AR/VR project that focuses on environmental media and engaged citizenship. Student teams will be challenged to design immersive digital experiences related to understanding and taking action on making the world's 17 Sustainable Development Goals (SDGs) a reality. The SDGs are global priorities that are essential for humanity and the planet, however progress is slow and no country in the world is on track with a plan to meet these goals (UNESCO, n.d.; United Nations, n.d.). While they are our best hope and vision to work together to make the world a better place, the SDGs are concepts that are difficult to teach in ways that make learners mobilize and take action. As universities are drivers of innovation and societal change, we need to come up with new ideas for making the SDGs more visible on campus, as well as to integrate them into coursework in meaningful ways.

AUDIENCE ENGAGEMENT AND EXPECTED IMPACT

This *Innovative Showcase* will be valuable for members of the STEM community to explore a flexible approach for integrating AR technologies to transform teaching and learning in diverse lab settings and classroom learning environments. Integrating augmented reality (AR) tools with STEM curriculum opens-up novel possibilities for developing course assignments that invite diversity of thought, differences in worldviews, and creative explorations with media and technology. STEM 2020 attendees will have an opportunity to experiment with AR technologies, as well as discuss their questions with the research team.

We hope our research project will inspire and support teachers, researchers, and instructional designers to develop student learning experiences that enable powerful forms of learning beyond traditional barriers of classroom walls and screens. Not only is our flexible and easily-adaptable AR assignment enjoyable to teach and meaningful to do, but it also builds community by bringing people, art, science, knowledge, and technology together. Participants will be invited to share their perspectives on the affordances and constraints of using AR tools to meet teaching and learning goals pertaining to their courses and educational contexts. The research team will discuss how to enhance student engagement, inclusion, and ingenuity by utilizing AR as a tool to build community through making and sharing personalized digital experiences with peers. As we live in an increasingly visual and digital society, interest in AR/VR for education is simultaneously increasing; thereby reinforcing the need for new pedagogical approaches and making this session relevant and timely.

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BRIDGING BIOLOGY AND COMPUTER SCIENCE TO ENGAGE HIGH SCHOOL STUDENTS IN SOLVING REAL-WORLD PROBLEMS

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ABSTRACT

In our increasingly data-driven society, high school students must learn to integrate computational thinking with science practices in order to solve complex real-world problems. However, it is difficult for educators to design and implement integrated STEM / computer science curricula, because each side has little understanding of the terminology, key concepts, tools, and approaches that the other side has to offer. We have tackled this STEM / computer science integration problem for a particular STEM field, biology. We have created a transdisciplinary team of biologists, computer scientists, and educators, comprising high school and university faculty and students, to design and implement the integrated Bio-CS Bridge Curriculum. In this Innovative Showcase, participants will learn how our team uses a Citizen Science research project to motivate the curriculum, which engages students in using and developing computational tools and approaches to address a real-world environmental problem, pollinator decline and loss of biodiversity. Participants may join in if they wish on their own devices, as we demonstrate our mobile bumblebee - flower identification web app, visualize and analyze data in our publicly available database to generate and test biological hypotheses, and build and run simple ecological computer simulations. We hope to inspire others to use and adapt our curriculum, which will be freely available online, as well as to build transdisciplinary collaborations of their own.

Keywords: *biology, computer science, ecosystem, pollinator, biodiversity, transdisciplinary, webapp, simulation, visualization, curriculum*

INTRODUCTION, RELEVANCE, AND SIGNIFICANCE

The need for integrating computational thinking and approaches with STEM practices in educating our youth has been emphasized by several major scientific organizations, particularly in the life sciences (American Association for the Advancement of Science, 2011; National Research Council, 2009, 2012). Our goal in developing the Bio-CS Bridge Curriculum has been to bridge and integrate scientific practices such as experimental design and hypothesis testing with computational approaches to data collection, analysis, and visualization, as well as modelling, simulation, and software design (Fig. 1), while engaging students by addressing a complex real-world problem, pollinator decline and loss of biodiversity. The curriculum is standards-based, and modular; it can be used in both introductory and advanced biology and computer science classrooms. Students can use our computational tools ‘out-of-the-box’, learn to modify them, or build their own tools, depending on the goals of a particular class and student background. The curriculum has been developed by a transdisciplinary team of computer science and biology high school teachers and university faculty with funding from the US National Science Foundation, and it is currently being implemented in seven high schools in Massachusetts, US.

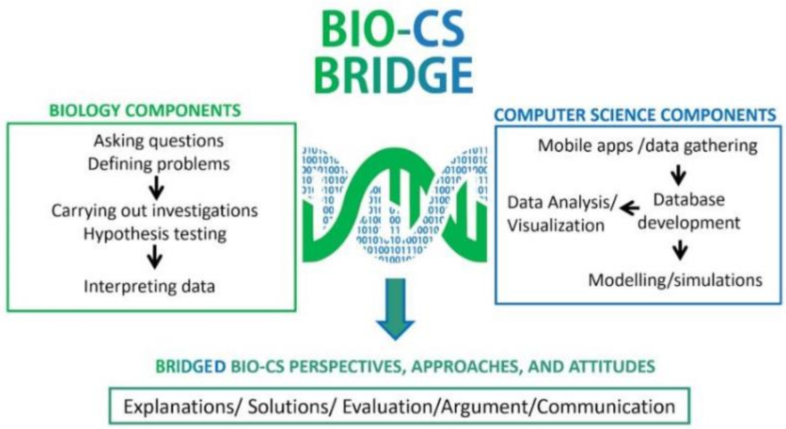

Fig. 1. Scientific practices and computational approaches are integrated in the Bio-CS Bridge curriculum.

GOALS, OBJECTIVES, AND IMPACT OF THE SHOWCASE

The Innovative Showcase will first provide a brief history of how our transdisciplinary team came together, and how we are using a university-driven Citizen Science research project to motivate an integrated biology / computer science high school curriculum. We will then provide an overview of the curriculum components, including both biology and computer science aspects. Participants will be introduced to the freely available curriculum, which is modular. Teachers and students can use 'out-of-the-box' components such as our web app, data visualization, analysis, and simulation tools to collect and analyze pollinator and flower data, and test hypotheses about ecosystems; and/or they can learn the programming skills to build their own simple agent-based simulations, learn web design, and develop web apps (Fig. 2). Participants are welcome to use our computational components as we go along during the session, and they will leave with curriculum that is ready to use in the classroom. Our overall goal is to inspire participants to use and adapt our curriculum, as well as to consider developing their own transdisciplinary teams and integrated curriculum.

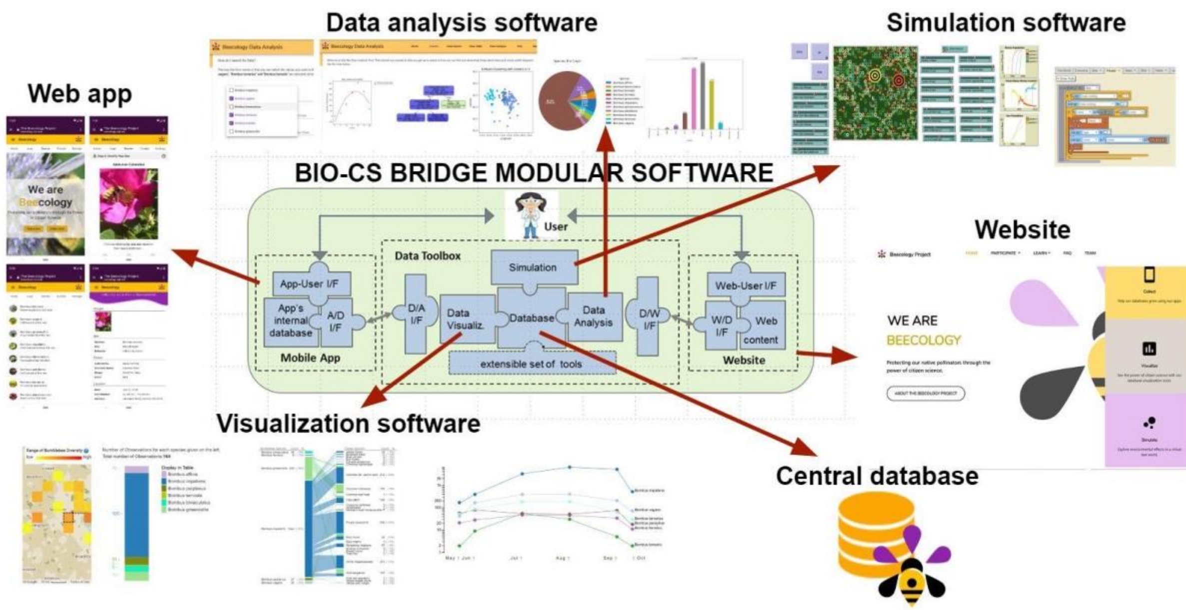

Fig. 2. The modular computational components of the Bio-CS Bridge Curriculum.

LOGISTICS

Relevant online resources:

Our project includes two web sites:

- The biocsbridge.wpi.edu site explains the Bio-CS Bridge Project, and highlights examples from our Bio-CS Bridge integrated curricular modules.
- The beecology.wpi.edu site describes the Beecology Citizen Science Project, on which our integrated curriculum is grounded. It is home to our bumblebee – flower identification web app, as well as visualization, simulation, and analysis tools.

Proposed time allocation: 90 minutes

1. Introduction to the Bio-CS Bridge Project (15 minutes)
2. Using the Beecology webapp to identify and log bumblebee-flower data from videos (20 minutes)
3. Hypothesis testing with Beecology data using visualization and analysis software tools (20 minutes)
4. Building and using computer simulations to make predictions about ecosystems (20 minutes)
5. Discussion: adapting the curriculum and building your own transdisciplinary team (15 minutes)

Modes of audience engagement:

- Participants can choose to simply follow along as we describe our transdisciplinary team and integrated curriculum approach and demonstrate our software tools and curriculum modules.
- Participants can choose to visit our websites during the session and use our web-based software tools as we demonstrate them, and they can download and run free simulation software.
- Participants can engage in a discussion on how they could adopt, adapt and/or extend (parts of) our university / high school collaboration and bridged curriculum frameworks to their own situations.

Maximum number of audience participants:
No limit

Special resources and requirements from the STEM 2020 organizers: We just need wi-fi and a projector.

ACKNOWLEDGEMENTS

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THE STEM MENTORING CAFÉ – YOUTH ENCOUNTERS WITH STEM EXPERTS

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ABSTRACT

A society that is literate and proficient in science, technology, engineering and math (STEM) is needed to discover innovative solutions to challenges such as climate change, food security and clean energy production. However, STEM awareness is lacking in youth, with many students losing interest by the age of twelve resulting in a loss of potential STEM innovators. It is important to provide opportunities that allow students to engage with STEM professionals, leading to a better understanding of career opportunities in STEM. The STEM Mentoring Cafe provides students aged 11-13 an opportunity to engage in conversation with STEM experts. This interaction provides an opportunity to break down misconceptions about different STEM careers. Furthermore, participation by women in the STEM Mentoring Café provide girls strong role models. The showcase will allow conference attendees to participate in an abbreviated STEM Mentoring Cafe followed by a feedback session.

Keywords: *STEM, underrepresented, gender gap, achievement gap, diversity*

INTRODUCTION

STEM plays an essential role in society with economic, social, ethical and legal implications. Rapidly developing fields such as artificial intelligence, clean energy, personalized health and cybersecurity present challenges that require workers with STEM skills and a STEM literate population. More importantly, STEM skills allow a society to respond to challenges and opportunities that do not exist at this time.

Those with STEM degrees earn more versus those with non-STEM degrees, notably degrees in engineering fields (Dodge, 2015). Yet, only 10% of those employed in Canada have a STEM credential (Dodge, 2015). In 2012, Canada ranked in the lower half of OECD countries with the proportion of people with a science or engineering degree in the 25-34 year old range. STEM education goes beyond preparing students for careers in STEM. STEM skills such as math, critical thinking and problem solving can be transferred to non-STEM fields with a positive impact on earning potential (Dodge, 2015).

Globally, STEM based companies are facing a shortage of qualified workers, especially technology companies. This shortage stifles expansion and innovation as companies may be in a position to grow but are unable to find enough qualified applicants. Linked to this shortage is the lack of diversity in

STEM fields - women, visible minorities, persons with disabilities, Indigenous people, and immigrants are underrepresented in many STEM fields. Diversity can drive innovation by bringing in different perspectives including different educational, cultural, and gender experiences. If the employee base does not represent the user base, products may not meet customer needs (Merifield, 2017).

Training the next generation of STEM workers needs to start well before students enter postsecondary programs as STEM identities (positive and negative) emerge before children enter elementary school. Plugging the leaks in the STEM pipeline requires the deconstruction of misconceptions about STEM, inclusive policies and the participation of STEM role models in the education of children. Several organizations provide STEM enrichment for pre-kindergarten to grade twelve children in British Columbia. These include school visits by STEM experts, summer science camps, STEM centres, and Science Fair competitions. Our group participates in several of these initiatives and in 2016, offered a new STEM engagement program.

STEM IDENTITIES

Supporting STEM programs at the post-secondary level is essential to ensure that Canada can train enough qualified individuals to meet the STEM job and innovation demand of the coming decades. However, efforts must begin at a much earlier age as science achievement gaps start a young age (Morgan, 2016). Several factors affect the development of a student's identity in regards to STEM including gender stereotyping, socio-economic background, who they know, school location, and the dichotomy of students that will pursue post-secondary training versus those that do not (Morgan 2016). As a student's STEM identity is formed at an early age, this can affect the number of students that enter post-secondary STEM programs. Also, students that lack a STEM identity may be less able as adults to understand public policy issues that require STEM literacy and reasoning skills such as climate change, hydraulic fracturing, and genetic engineering (Chambers, 2018).

Several factors may place a child at a disadvantage prior to school entry and result in achievement gaps, including (Morsy, 2015; Olitsk, 2006):

- Lack of access to informal learning opportunities
- Parents' irregular work schedules
- Inadequate access to health care
- Poor nutrition

It is difficult to determine which are the key factors that affect science achievement and the development of resilient science identity. Achievement gaps may remain stable, broaden or narrow as a student progresses through school. Improvement in achievement may be a result of several factors (Morgan 2016):

- Being in an environment with increased informal learning opportunities
- Supplementary programs for lower achieving students
- Improvement in language and literacy skills

The development of STEM identity is influenced by structures that exist within a classroom, school and school district. A school that divides students into a group that will go to college or university and a those that will not may push some students away from STEM. A student that does not see themselves going to college or university may no longer see the purpose of studying STEM topics. Categorizing students becomes a disciplinary system, creating either a sense of belonging or isolation.

STEM MENTORING CAFE

If a child does not know people in STEM they are less likely to know about the diversity of STEM careers that exist. In Chambers (2018), when volunteers from different STEM backgrounds made classroom visits, less than 1% of children surveyed recognized the volunteer's STEM career. To address this issue, our group introduced a STEM engagement event to connect students with STEM experts in a speed mentoring format. The event was designed to increase interest and excitement in STEM topics.

The event provides students one on one contact with experts from a variety of STEM fields. These conversations and connections inform the students at a variety of levels (Gamse, 2016):

- Breaking down misconceptions about a particular field or job (ex: engineer)
- Breaking down stereotypes based on gender, (dis)ability, or ethnicity (ex: women can be physicists)
- Connecting classroom material to a real world context (ex: numeracy in the workplace)
- Opening options by demonstrating the range of opportunities available

The event is structured to educate and inspire the students but there are also benefits for the STEM experts:

- The opportunity to practice their communication skills with a non-expert audience
- The opportunity to raise awareness of underrepresented groups in STEM including women, visible minorities, LGBQT+ persons, disabled persons, and immigrants
- The opportunity to network with individuals from different STEM fields

Organization of the STEM Mentoring Cafe

The STEM Encounter has STEM experts seated at different tables based on their field (e.g., physics, genetics, engineering). Students in small groups are seated at a table and engage in conversation with the STEM experts. After ten minutes, the students rotate to a new table. The students visit four to six tables during an event. STEM experts are recruited from industry, postsecondary institutions, networking events, and referrals by colleagues.

To provide strong role models for girls, we ensure at least half of the STEM experts at all events are women. We also work to have participation from underrepresented groups including Indigenous peoples, LGBQT+ community, immigrants and disabled persons. By interacting with role models that reflect a student's background, the goal is that the student gain confidence and be inspired to pursue their STEM interests.

SUMMARY

To date, our organization has hosted eleven STEM Mentoring Cafes (three of them girls only events), reaching approximately 600 students. Students receive valuable interaction with STEM experts and deconstructs misconceptions about who can work in STEM. The program has enriched the lives of all involved – students, STEM experts, teachers, parents and our organization. The program encourages students to consider STEM as they progress in their learning, although we have no expectations all the students become scientists or engineers. We hope they emerge from the experience with a greater appreciation for the diversity of opportunity in STEM.

Innovative Showcase Details

Proposed time allocation

- 90 minutes

Modes of audience engagement

- Audience members will participate in an abbreviated STEM Mentoring Café followed by a discussion

Maximum number of audience participants

- 20 participants

Special resources and requirements from organizers

- A venue space large enough to accommodate 4 tables that can seat 8 people. Enough space between the tables to allow conversation

Relevance and significance to the STEM field and conference audience

- Engagement with STEM needs to start in children. The STEM Mentoring Café works to inspire and inform youth aged 11-13. The showcase will provide an immersive experience and an opportunity to provide feedback.

Expected impact for STEM participants

- Provide the participants a model of STEM engagement for youth

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WORKSHOPS

USING DIGITIZED SCIENTIFIC COLLECTIONS TO ENGAGE STUDENTS IN AUTHENTIC, OBJECT-BASED SCIENCE INVESTIGATIONS

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2. *Natural History Museum of Utah*

ABSTRACT

Engaging middle school learners in meaningful and authentic science investigations that offer experience in disciplinary practices is a critical challenge for STEM education. Research Quest and EPIC Bioscience are online learning environments that use real objects and specimens from museum collections to engage students in science investigations using 3D models and digitized researcher materials. An interdisciplinary team of domain scientists, museum educators, learning scientists, and curriculum specialists developed these investigations to align to Next Generation Science Standards (NGSS) and to engage students in the learning about the nature of science, as outlined by the National Research Council. After a brief discussion of the theoretical foundations underlying the use of digitized museum collections as the basis for inquiry-based, authentic science investigations in classrooms, participants will engage in a hands-on (guided) exploration of collections-based investigations in two domains: palaeontology and entomology. Hands-on experiences with the online learning environment will form the bulk (90%) of the workshop. Research Quest and EPIC Bioscience investigations demonstrate the instructional potential of digitized collections to engage students in authentic research practices with real objects that have demonstrated scientific value. Investigations are freely available online (researchquests.org), supporting more equitable access to collections-based learning for STEM education. Participants will leave the workshop with: A new vision of how digitized museum objects can transform students' educational experiences in science; an understanding of how digitized scientific objects and specimens can enhance student engagement with authentic research questions; and a working knowledge of how to scaffold student learning in online, inquiry based investigations of digitized science collections

Keywords: *online learning environments, 3d models, science investigations, object-based learning, middle school, digitized museum collections*

Relevant Online Resources

This workshop will introduce participants to Research Quest (www.researchquest.org), a free online learning environment that engages learners in hands-on investigations that utilize digitized scientific specimens from museum collections and are aligned to Next Generation Science Standards (NGSS). EPIC Bioscience encompasses a new set of research investigations that will be available within Research Quest; EPIC Bioscience investigations focus on questions of biodiversity aligned to NGSS standards and using digitized museum specimens from entomology, vertebrate biology, and botany. Current investigations are designed for middle school implementation, but are adaptable to multiple grade levels. Teachers create a free account and students log into the learning environment with the access code provided by their teacher (individual student accounts are not needed). In addition to the investigations themselves, online resources include teacher implementation guides, student research notebooks, and assessment rubrics.

Amount of Time Needed

The amount of time needed for this workshop is 110 minutes (1 hour, 50 minutes). This will provide participants with sufficient time to engage in guided, hands-on experiences with the science investigations in two domain areas (palaeontology and entomology). Participants will share their findings and engage in discussion of how these hands-on investigations align to science practices and critical thinking processes that are crucial to STEM learning.

Goals and Objectives

A significant critique of classroom learning has been that it is "decontextualized from direct experiences with objects" (Dierking, 2002, p. 4). Using objects from scientific collections for classroom learning has potential to redress issues with decontextualized instruction as well as to enhance learner engagement in science education. Indeed, research on learning in museums has shown positive impact of collections objects on learner engagement and satisfying user experiences (Schwan, Grajal, & Lewalter, 2014). Research has confirmed that bringing museum objects into the classroom can increase student engagement (Wyner, Koch, Gano, & Silvernail, 2010), but authentic objects are difficult to integrate into classroom instruction as access tends to be limited in scope and duration. Creating new opportunities for meaningful, object-centered STEM inquiry requires innovative approaches that greatly enhance classroom access to scientific collections in addition to scaffolding meaningful research experiences surrounding these collections. Learning environments that leverage the rapidly growing availability of digitized museum collections have strong potential to transform the depth, quality, and frequency of object-centered research in classrooms. These learning environments – accessible online – also have the potential to democratize educational access to scientific collections, providing contextualized, object-based STEM investigations to populations who are underserved by traditional museum visits (including underrepresented groups and rural audiences).

It is a particularly opportune time to develop learning environments for classroom use that are grounded in the investigation of scientific objects, as digitization of collections is a major initiative at modern museums (Clough, 2013; Primary Research Group, 2015). Digitization campaigns have been launched by numerous research, national, and professional organizations dedicated to scientific and scholarly pursuits, including the National Science Foundation (NSF). Via the Advancing Digitization of Biodiversity Collections program, NSF is anticipated to spend $100 million over a decade to digitize specimens and data from all U.S. biological collections and make resulting materials available online (Gropp, 2012). However, despite general enthusiasm about the educational potential of digitized collections objects (Neely & Langer, 2013), little has been done to scaffold and support the use of digitized collections objects in ways that are aligned with the full range of NGSS science practices. Some citizen science projects use digitized collections as a data source, but the scope and effort involved in these science activities are purposefully limited and simplified for public participation. Students engaged in citizen science often collect and submit data, but do not analyse it themselves or attempt to use findings to form their own evidence-based arguments. Although there is clear merit in connecting scientific data to real world questions and in exposing students to scientists involved in authentic research, it is likely that there is significant value in using real world questions to engage students in conducting their own object-based research in a scaffolded learning environment.

There have been efforts to provide existing (second-hand) datasets to classroom teachers to support opportunities for student data analysis and interpretation, but students can have difficulty in understanding how the data was obtained and engaging in high-quality discussions around secondhand data (Hug & McNeill, 2008). Students need opportunities to collect their own data to address meaningful questions. The current learning environment has been developed from the standpoint that research with digitized collections objects makes it uniquely possible for students to tackle important, real world problems using tractable data gathered from actual scientific specimens. With appropriate online scaffolding, data gathering and analysis from digitized collections objects and specimens can help students delve deeply into documenting and analysing evidence, using patterns of findings to develop well-supported, evidence-based arguments (Butcher, Larson, & Lane, 2019; Butcher, Runburg, & Hudson, 2017). Findings show that students are highly engaged by investigations with digitized specimens (Butcher, Hudson, & Runburg, 2018; Butcher, Runburg, et al., 2017) and that students using digitized specimens for inquiry-based investigation supports critical thinking processes (Butcher, Hudson, & Runburg, 2017) and outcomes (Butcher, Runburg, et al., 2017). Student interactions in the online environment also can be used to predict developing understanding (Poitras, Butcher, Orr, Hudson, & Larson, 2019), with potential to personalize learning with digitized objects in the future.

Models of Audience Engagement

Audience members will be guided through an immersive experience in the online learning environment, using digitized objects to gather data and to develop an evidence-based argument relevant to target research questions. Audience members will be asked to work in collaborative pairs (although solo work is possible, if preferred) to gain an experiential understanding of how the online investigations support communication and scientific discourse during data collection, analysis, and interpretation. Participants will be asked to gather relevant data from digitized objects and specimens, to document their findings, develop an argument with their partner, and share insights about their findings. At the end of the workshop, participants will reflect on their investigations and the impact of digitized museum objects/specimens for learning about science practices, STEM content, and critical thinking.

Maximum Number of Audience Participants

The maximum number of audience participants is approximately 100, although we can accommodate a larger group if desired with advanced notice. To facilitate optimal participant experiences and sufficient support, we aim for one facilitator per 25-30 participants.

Relevance and Significance to the STEM Field and Conference Audience

This workshop will address key theoretical foundations of learning with digitized objects and scaffolding scientific investigations in an online learning environment. We will briefly present key findings from classroom research, showing the potential impact of online science investigations with digitized collections objects on students' learning outcomes and discourse processes. Hands-on exploration will provide a model of how digitized collections objects can serve as the basis for authentic science investigations that also are aligned to NGSS's 3D learning model. This workshop should appeal to three conference audiences:

- Educators interested in the potential of digitized collections for authentic STEM learning
- Researchers interested in when/how an online learning environment can support students' critical thinking and learning about domain content and evidence-based reasoning

- Museum educators and curriculum designers interested in developing educational resources with their own digitized collections

Expected Impact for STEM Participants

Following brief discussion of theoretical foundation and classroom research results, participants will engage in a hands-on exploration of the online learning environment. Participants will use Research Quest and EPIC Bioscience to gather and analyse their own data within two investigations (palaeontology and entomology). Participants will leave the workshop with:

- A new vision of how digitized museum objects can transform students' educational experiences in science, increasing understanding and ownership of complex data with relevance to real scientific questions.
- An understanding of how digitized scientific objects and specimens can enhance student engagement with authentic research questions, using virtual tools and collection techniques to gather data directly from scientific collections.
- A working knowledge of how to scaffold student learning in online, inquiry-based investigations of digitized science collections, using personal experiences with hands-on data collection and analysis as the basis for reflecting on students' learning needs and processes for supporting effective scientific discourse.

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MAKING THE STORY OF STEM LEARNING VISIBLE –MATHEMATICA, RASPBERRY PI AND ARDUINO AS NARRATIVE TOOLS FOR SYSTEMS ENGINEERING

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ABSTRACT

This active workshop will implement a range of simple circuits and code fragments as building blocks for learners to design, conduct, analyse, critique and display meaningful research. The pedagogical context will be provided by the Systems Engineering Study Design of the Victorian Curriculum and Assessment Authority. This Australian Study Design is a deep STEM offering for matriculation level learners. The study rewards candidates for risk-taking in their development of integrated electromechanical responses to design briefs that are modelled and situated in a systems environment that is informed by environmental, social and psychological contexts. The Systems Engineering Study Design rewards risk-taking through its rubric-assessed processes of Intention Development, Modelling, Agile Iteration of Response, Testing, Project Management and Comprehensive Evaluation of Response, Processes and Performance. The study rewards candidates for their multimedia narratives about their recognition of those moments when the response to the design brief did not go to plan. Wolfram Systems Modeler and Mathematica has been rolled out on a state-wide basis to facilitate effective learner engagement with the Victorian Assessment and Curriculum Authority Study Designs for a range of Learning Areas. This workshop will work with participants to explore how these software offerings and their integration with Raspberry Pi microcomputers and Arduino microcontrollers allows STEM learners to demonstrate achievement using an ePortfolio complete with images, text, video, simulations, research, modelling and calculations within the Wolfram Mathematica environment.

Keywords: *systems engineering, STEM, ePortfolios, mathematica, systemmodeler, risk-taking*

Goals and objectives

To introduce participants to the Victorian Curriculum and Assessment Systems Engineering Study Design that rewards risk-taking in STEM education through an Intention Development, Modelling, Agile Iteration of Response, Testing, Project Management and Comprehensive Evaluation of Response, Processes and Performance rubric moderated process.

To introduce the voltage divider circuit as a platform for low-cost, student-designed circuits to measure temperature, light and force.

To build a simple voltage divider network circuit for interfacing with an Arduino microcontroller and Raspberry Pi microcomputer.

To calibrate sensors using the spread sheet capabilities of Mathematica.

To use SystemModeler and Mathematica to model a voltage divider network and simulate its ideal performance.

To use SystemModeler and Mathematica to interface with a live voltage divider network and visualise its real-time response.

Modes of audience engagement

Hands-on construction of key low-cost, basic circuits for collecting data by learners.
Programming and modelling activities using Mathematica and SystemModeller.
Introduction to online resources to support such activities.
The construction of an ePortfolio incorporating multimedia learner narrative content, simulations and data.
Discussion concerned with the moderation of ePortfolio records of evidence against rubric criteria, particularly with respect to ePortfolio features that demonstrate risk-taking in the STEM process.

Maximum number of audience participants

Twenty.

Special resources and requirements from the STEM 2018 organizers

Data projector for the presenter.
The presenter will bring sufficient Raspberry Pi microcomputers, Arduino microcontrollers and other components for all participants. There are no software requirements.

Relevance and significance to the STEM field and conference audience

Risk-taking in learning is predicated upon learners challenging their concept formation. The theme of the conference – Changing the Story, is a call for all of us to develop effective processes that allow learners to take a narrative approach to their records of evidence of achievement. This workshop will work with participants to explore an approach that rewards risk-taking during concept formation through a structured Intention Development, Modelling, Agile Iteration of Response, Testing, Project Management and Comprehensive Evaluation of Response, Processes and Performance rubric moderated process.

Expected impact for STEM participants

Confidence to transform their partnership with the learners that they work with, by valuing ePortfolio, multimedia evidence that elicits learner experiences throughout the concept formation process.

BEYOND OBSERVING: THE MULTIPLE USES OF A NEW INTEGRATED STEM EDUCATION OBSERVATION PROTOCOL

Emily Dare[1], Joshua Ellis[1], Elizabeth Ring-Whalen[2] and Gillian Roehrig[3]

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2. *St. Catherine University*
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ABSTRACT

As integrated STEM education becomes increasingly prevalent in primary and secondary education, there is a need to better understand what integrated STEM education is and how it is implemented in the classroom. Currently, there are no observation protocols for K-12 science classrooms that have adopted integrated STEM strategies, likely due to the variety of definitions that exist. However, the literature related to STEM education suggests various overlaps in definitions, including: the use of real-world contexts to situate learning, the emphasis of student-centred pedagogies, the development of 21st century skills, and connections across STEM disciplines. Given the rapid adoption of STEM education across the globe, there is a need for an observation protocol designed specifically to understand the implementation of integrated STEM in K-12 classrooms. We have developed an observation protocol (STEM-OP) for integrated STEM instruction that can be used by both researchers and educators. This 2-hour workshop is designed to inform members of the STEM education community about the development of our protocol and provide participants with an opportunity to learn to use the protocol by watching and scoring a selection of classroom video from an integrated STEM lesson. Ample time will be provided for feedback, including discussion of the multiple uses of this protocol.

Keywords: *STEM education, instrument development, integration, k-12 education*

Introduction

As science, technology, engineering, and mathematics education – often collectively referred to as STEM education – moves towards an integrated approach in primary and secondary schooling, there is a need to better understand what STEM education is in order to implement it in practice. A review of the literature reveals a wide variety of approaches to STEM education that include: STEM as a replacement term for science and mathematics (Breiner, Harkness, Johnson & Koehler, 2012; Sanders, 2009), STEM as a pedagogical shift toward an integrated approach (Breiner et al., 2012; English, 2016; Honey, Pearson, & Schweingruber, 2014; Kelley & Knowles, 2016), curriculum changes that reflect the work of STEM professionals (Breiner et al., 2012; Labov, Reid, & Yamamoto, 2010; Sanders, 2009), and curricula that emphasize an engineering design challenge (Bryan, Moore, Johnson, & Roehrig, 2015). Despite these variations in definitions, there are some common elements, including: the inclusion of an engaging, real-world context (e.g., Breiner et al., 2012; Brown, Brown, Reardon, & Merrill, 2011); explicit connections between science, technology, engineering, and mathematics and modelling them as they would be used in STEM careers (e.g., English, 2016; Herschbach, 2011; Honey et al., 2014; Kelley & Knowles, 2016); the intentional development of 21st century competencies (e.g., Bryan et al., 2015; Honey et al., 2014); and an emphasis of student-centred pedagogies (e.g., Bryan et al., 2015; Breiner, et al., 2012; Labov et al., 2010; Sanders, 2009). In short, integrated STEM education is a complex combination of content and pedagogy, making it difficult to capture and define.

While defining STEM education has proved challenging, assessing the quality of integrated STEM instruction in classrooms proves even more elusive. This is most likely due to the lack of a protocol designed specifically for such teaching. Protocols that measure inquiry-based teaching, such as the Reformed Teaching Observation Protocol (Sawada et al., 2002), have been used in lieu of a STEM-specific protocol, but this choice comes with challenges and limitations (Ellis, Dare, Roehrig, & Ring-Whalen, in review). Current observation protocols tend to focus on one discipline, which is problematic when STEM instruction addresses multiple disciplines. The work presented here is part of a funded project whose end goal is to disseminate an integrated STEM observation protocol for use in K-12 science and engineering classrooms.

Workshop Focus

As integrated STEM education becomes increasingly prevalent in primary and secondary education, there is a need for an observation protocol designed specifically to understand the implementation of integrated STEM in K-12 classrooms. Despite the existence of various definitions STEM education, as noted above, the literature related to STEM education suggests overlaps in these definitions which can be used to develop such an instrument. With the support of a federally funded grant, we have developed an observation protocol for integrated STEM instruction (STEM-OP) that can be used by both educational researchers and educators at various levels; at the end of the project, this protocol will be a valid and reliable instrument for research purposes. This workshop is designed to inform attendees from the STEM education community about the development of our new observation protocol and provide them with an opportunity to learn to use the protocol by watching and scoring classroom video of integrated STEM lessons. Additionally, attendees will have opportunities to provide the presenters with feedback on the instrument.

Relevance and Benefits of Attending

Science teaching and learning in K-12 education is changing and the work described above is helping to address the gaps that exist. The observation protocol has been designed to be used in K-12 science and engineering classrooms that integrate STEM disciplines in lessons and units. The instrument was designed with different stakeholders in mind and for use in a variety of educational contexts to increase the quality of K-12 STEM education and education research. To this end, the protocol was designed not only for summative and evaluative purposes, but also for formative and reflective purposes. For instance, educational researchers may benefit from having an instrument available for them to carry out research and continue to improve science and STEM education in a variety of ways armed with an instrument designed to assess integrated instruction. Science teacher educators may benefit from using the instrument as a way to teach their pre-service teachers about STEM education and as a tool to use in professional development to guide in-service teachers in STEM education. District science coaches may also use this tool to engage in reflective practice and cognitive coaching with science teachers. Because of the variety of uses that this instrument is targeting, this workshop will be of interest to participants working in a variety of contexts. In short, this workshop will be of interest to members of the STEM education community who are interested in learning more about what integrated STEM education is and how to observe it in K-12 classrooms. This workshop would be suitable to methods instructors, field experience supervisors, education researchers, school administrators, and more.

Description of Workshop Activities

The following sections outline the agenda for a 90-minute workshop and a requested maximum of 35 participants. The actual length of time proposed for each activity may vary according to how many individuals attend the session. The aim of this workshop is to not only inform those in the STEM education community about the development of our observation protocol, but to provide workshop attendees an opportunity to use and discuss the protocol. Further, by attending this workshop, attendees will:

- Identify their own definition of STEM education

- Understand that defining STEM is challenging
- Evaluate their own thinking of STEM education
- Critically examine the items of the STEM-OP
- Reflect on the use of the STEM-OP in their own work

The workshop activities are designed to first engage attendees in their own thinking of what STEM education is, identify common features across different models of STEM education, examine protocol items, use the protocol while watching a portion of classroom video, and share implications that this instrument might have on their practice. Each activity allows us to formatively assess attendees' progress towards the learning objectives and attendees' summative learning will be assessed through an online survey at the end of the session.

What is STEM education? (approx. 30 minutes). The session will begin by problematizing STEM education, beginning by asking attendees to share their conceptual model of STEM education as a visual representation. In anticipating that there will be various models shared by attendees, attendees will then share their models with others in the room and identify common features among the models. Attendees will then work in small groups and use large Post-it papers to list what they would want to see in a classroom that claims to be implementing integrated STEM instruction. After sharing these lists with the whole group, the presenters will then discuss the challenges in the development of this instrument, which included a full literature review, discussion and consensus among the project team related to protocol items and levels, piloting of the instrument with classroom observation videos, and factor analysis.

Sharing and using the protocol (approx. 60 minutes). The observation protocol will be shared with attendees for their review and use in the workshop. In its current form, the protocol is 13-items and uses a 5-point (0-4) Likert-scale. Each item includes a brief description of the item, a set of guidelines for scoring the item, and detailed descriptions for each level of the scale. Assuming a group of 30 attendees, four groups of 7-8 attendees will be assigned 3-5 items to become "experts" on; if possible, groups should consist of members with a variety of expertise to showcase that this instrument is versatile in its use. Each group will be joined by one of the presenters and, through discussion, the groups will work together to understand how to score the items they have been assigned. In order to further attendees' understanding of the items and how to score them, several example classroom scenarios will be shared as prompts for which the group needs to score. Once attendees have familiarized themselves with their assigned items and their associated levels, a segment of classroom video (10-15 minutes) will be played, which will require a computer and speakers. During this time, attendees will focus on their assigned items and use the protocol to score the video segment.

Reflection and discussion (approx. 30 minutes). After using the protocol to score classroom video, attendees will share how they might use this protocol in their own research and teaching to improve understanding and implementation of integrated STEM education. Because the protocol was designed for a variety of purposes in mind, including as an aid to assist teachers and schools in better understanding what integrated STEM education is, it is important to address the protocol as non-evaluative. The facilitators will guide a discussion about the variety of uses of this instrument.

Continued Learning

At the end of the workshop, attendees will be asked to complete a short survey to provide feedback related to the protocol and its potential use in their own work, whether it is for research, teaching, leading professional development about STEM education, or developing K-12 STEM schools. Attendees will also be provided with contact information of the presenters so that they may follow up with the protocol as it continues to evolve within the project.

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USING GOOGLE APPS TO CREATE AN INCLUSIVE SCIENCE CLASSROOM

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ABSTRACT

This workshop will give STEM teachers practical, ready-to-use ideas to help make their science classrooms more inclusive. The workshop will incorporate the following tools: Google tools, such as Google Read&Write, Google Docs Voice Typing, Chrome extensions (such as, WikiWand), Google Slides, and a specific activity entitled “Sci-Cabulary” (a focused activity on creatively teaching science vocabulary to students). Participants will partake in demonstrations of these tools and discuss how they can engage their students with them. Participants will also be given time to trial the various tools and ask questions. These demonstrations will be presented by a Learning Assistance Teacher who was previously a Math, Science, and Chemistry teacher. This will also be an excellent opportunity for teachers to share how they are already working towards an inclusive design with their fellow teachers. STEM is an exciting and fulfilling area in education. It should be accessible to all students, regardless of their learning challenges or language proficiency. Through taking this workshop, participants will be inspired to use technology to make STEM accessible to all!

Keywords: *Google, inclusion, vocabulary, accessible, technology, inclusive, science*

Relevant online resources

One of the main demonstrations will be a science vocabulary activity (sci-cabulary) that focuses on interactive, accessible and relevant vocabulary teaching in science. The following links provide a demonstration of the activity, as well as a template and example.

Screencastify video demonstration
Example
Template

Many other Google tools will be showcased. Some can be seen in the figures below.

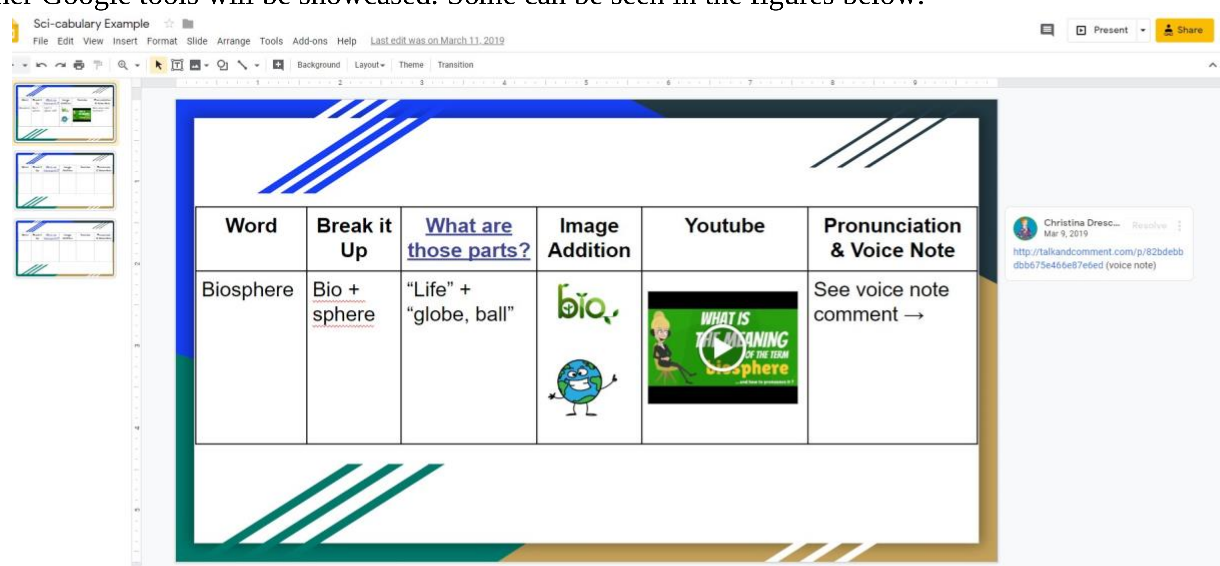

Figure 1: Screenshot of Sci-Cabulary example in Google Slides.

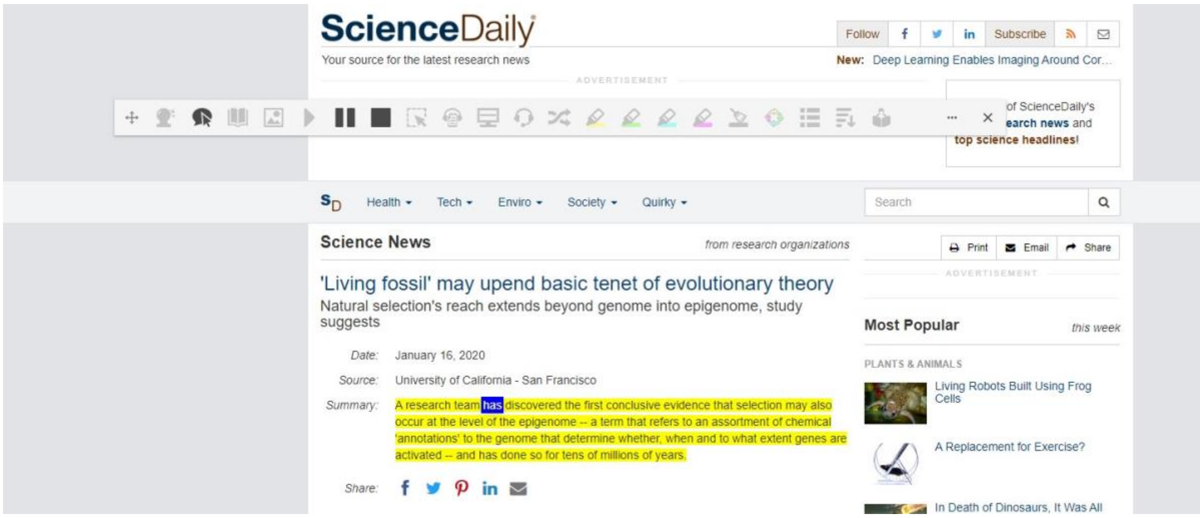

Figure 2: Screenshot of [Google Read&Write]() being used.

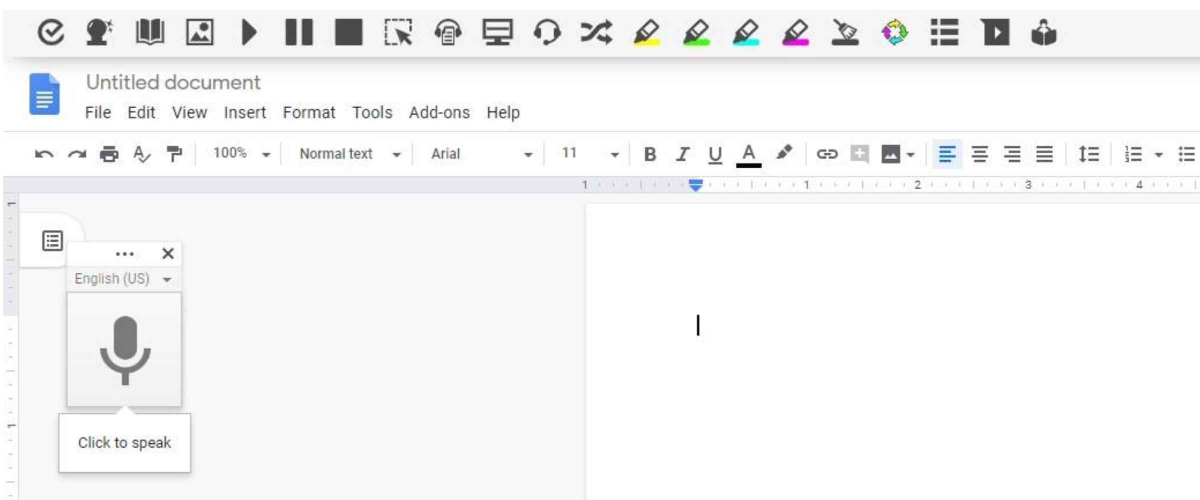

Figure 3: Screenshot of Google Docs Voice Typing combined with Read&Write.

Proposed time allocation

The time needed for this workshop will be 1 hour. This will allocate enough time for explanation of the apps as well as time for participants to “play” with the various tools shown.

Goals and objectives

1. To learn to use multiple Google apps that will assist in creating an inclusive science classroom.
2. To be inspired to ensure their classroom is accessible to students of all ability and English levels.
3. To appreciate the importance of vocabulary in science.

4. To share with one another how they are already making science accessible to their students.
5. To create a community of STEM educators who are willing to support each other in using these tools.

Modes of audience engagement

A demonstration of various Google apps that provide the ability for an inclusive science classroom will be shown. This will be done in pieces throughout the workshop, giving time for participants to attempt each task and ask questions, while circulating.

Maximum number of audience participants

A maximum of 30 participants at a time would be ideal.
Target audience: STEM teachers and support teachers with students of various ability levels in their classrooms.

Special resources and requirements from the STEM 2018 organizers

Participants will require: a computer/laptop/Chromebook, headphones/microphone access, as well as access to a Google account.
The presenter will require: projector, HDMI dongle, projector screen.

Relevance and significance to the STEM field and conference audience & Expected impact for STEM participants

This workshop relates to the goal of reaching as many students as possible within the area of STEM and '*changing the story*' of what a typical STEM student is. In order to reach all students, our science classrooms must be inclusive, and cater to the many different learning needs teachers have in their classroom. An inclusive classroom is defined by Cairns as, "...an educational setting where students from different backgrounds and with different abilities learn together…"
(2017). However, Cawley, Hayden, Cade and Baker-Kroczynski (2002) stated, "...neither special education nor science education has developed and validated comprehensive programs of science education to meet the needs of students with severe EDs [emotional disturbances] or LDs [learning disabilities] in the GE [general education] classroom" (p. 425). Technology is one of the ways we are attempting to meet these needs. Mosito, Warnick and Esambe (2017) said, "Computer technology is one of the tools recognised for its potential to enrich learning experiences of learners with an intellectual impairment" (p. 1). This workshop will equip teachers with tools to help make their STEM classrooms more inclusive and engaging.

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WHAT IS HIGH-QUALITY STEM?
THE DEVELOPMENT AND APPLICATION OF AN INTEGRATED STEM RUBRIC

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ABSTRACT

Integrated STEM provides multiple benefits to student learning. However, not all classroom educators have access to clear guidelines and tools to implement highquality STEM successfully. The workshop will share with participants the iterative development of a rubric for high-quality integrated STEM experiences, developed for a STEM Certificate Course at Worcester Polytechnic Institute (WPI), and revised based on input from course participants. Educators who reviewed the rubric found that it provides clear guidelines on what constitutes high-quality STEM. Workshop participants will work in groups to unpack the eight elements of the rubric, and use is to evaluate three integrated STEM projects (advanced, accomplished, and not meeting standards of quality). Participants will discuss how the developed rubric could be applied (as is, or with modifications) to their own work, and propose further revisions to the rubric. The workshop will follow cooperative learning pedagogy, and is relevant to PK-12 educators (both teachers and administrators) as well as researchers and STEM curriculum developers.

Keywords: *integrated STEM*, *rubrics*, *iterative development*, *high-quality STEM projects*

As STEM teacher educators for many years, one of the questions we often hear from teachers during workshops is: “What is STEM Education?” Teachers are not alone in their confusion, as administrators and researchers debate this very question. The definition of STEM education varies greatly, from teaching and learning experiences that include elements of the four subjects (science, technology, engineering, and mathematics), to a more holistic view, characterizing STEM education as relevant, authentic problem-solving experiences that make connections between the school, community, and the real world (Breiner, Harkness, Johnson & Koehler, 2012; Bybee, 2013; English, 2016; Tsupros, Kohler & Hallinen, 2009).

The National Academy of Engineering and National Research Council (2014) reviewed the state of STEM integration with the goal of establishing a clear research agenda. Among its recommendations, the report emphasizes the need to develop common language to describe STEM integration. Integrated curricula provide multiple benefits to student learning. Ring-Whalen, Dare, Roehrig, Titu, and Crotty (2018) summarize these benefits, among them the application of content in context which contributes to better understanding of concepts, the development of student ownership on their own learning, and the improvement of students’ problem-solving skills.

Yet, the variety of models and frameworks for STEM integration, and the lack of shared language and clear conceptions may create obstacles to implementing integrated STEM by teachers (Nadelson et al., 2013; Ring et al. 2017). There is a clear need for STEM integration tools to assist educators in creating and evaluating high-quality STEM experiences with their students.

The Development of the Integrated STEM Challenge Rubric

During the past two years the Authors developed a STEM Educator Certificate Course at Worcester Polytechnic Institute (WPI). The course is open to all educators and administrators (PK-12) and aims to provide participants with the knowledge and skills to develop high-quality integrated STEM projects. The development of the course and the rubric evaluating participants' projects, followed iterative process of development – testing – evaluation – and revision.

After review of multiple frameworks, we selected two main documents to frame the course and rubric: the *STEM Education Quality Framework* (Pinnell et al., 2013), and the *Massachusetts Model System for Educator Evaluation: Classroom Teacher Rubric* (2018). The initial course modules were developed to be aligned with these documents, and the course rubric was drafted based on the course modules. Applying the participatory design approach (Auerbach, 1992), in which the end users of the rubric (course participants) take part in shaping its development, we asked course participants to revise the initial rubric draft to be more meaningful for them. The revised rubric was used to evaluate that cohort's projects, and was revised two more times during the second and third courses. An overview of the rubric's elements is provided in Table 1. The rubric for high-quality integrated STEM projects is the focus of the proposed workshop.

Table 1: Integrated STEM Challenge Rubric - Overview

Integrated STEM Challenge Rubric Overview *			
1	**Integrity of the Academic Content** Is content-accurate, aligned to the relevant content standards, and engages students in one or more of the STE-M practices	5	**Engaging Students of Diverse Backgrounds** Designed to engage the minds and imaginations of students of diverse academic, physical, learning, demographic, and environmental backgrounds. CRT, SEL strategies are incorporated.
2	**STEM Challenge Assessment** Includes learning targets that are aligned with standards and practices. The rubric provided to students contains most essential learning targets.	6	**Quality of Technology Integration** Provides students with hands-on experience in using multiple technologies. (Examples: computer hardware and software, calculators, probes, scales, microscopes, rulers and hand lenses to name just a few)
3	**Application of the Engineering Design Process** Requires students to demonstrate knowledge and skills fundamental to the engineering design process (e.g., brainstorming, researching, creating, testing, REDESIGN, etc.).	7	**Individual Accountability in a Collaborative Culture** Requires students to work and learn collaborating in structured teams with defined expectations and allows time for reflection on both individual and team work.
4	**Connections to Non-STEM Disciplines** Helps students connect STEM knowledge and skills with academic standards from other disciplines. Students are expected to read, write, and communicate throughout the challenge.	8	**Connections to STEM Careers** Places students in learning environments that are connected to the real world and helps them to better understand and personally consider STEM careers.

* Adapted from Pinnell et. al (2013).

The Proposed Workshop

The proposed workshop will share with participants the most updated version of the Integrated STEM Challenge Rubric, developed for WPI's STEM Educator Certificate Course. As described above, the rubric was developed through an iterative process, and revised based on feedback from educators who participated in the course.

Workshop participants will work in groups to unpack the eight elements of the rubric and use it to evaluate two integrated STEM projects of varied quality. Participants will discuss how the developed rubric could be applied (as is, or with modifications) to their own work, and propose further improvements to the rubric.

The workshop will follow cooperative learning pedagogy, and will employ multiple instructional modes, including small group tasks, individual reflection, short presentation, comparison and analysis of STEM rubrics and frameworks, and group sharing sessions. The goals, objectives, and instructional components are described in table 2.

Table 2: Workshop's Goals, Objectives, and Modes of Audience Engagement

Goals	Objectives	Modes of Audience Engagement
Participants exchange ideas and get to know colleagues	Participants are engaged in hands-on STEM challenge	Introductory design challenge, small group work (*15 min*)
Participants expand their definition of high-quality integrated STEM	Participants define integrated STEM Education and exchange ideas with their group members	Individual reflection, small group discussion, group presentation (*5 min*)
Participants enhance their knowledge of Integrated STEM frameworks	Participants compare and contrast frameworks for integrated STEM education	Cooperative learning task, involving analysis of frameworks and poster creation (*10 min*)
Participants learn about the STEM Educator Certificate Course developed by WPI's STEM Education Center	Course components are shared with participants	Short presentation, review of handouts (*10 min*)
Participants expand their knowledge about the developed rubric for integrated STEM	Participants review the 3 iterations of the rubric	Short presentation, review of handouts (*5 min*)
Participants get firsthand experience using the rubric to evaluate integrated STEM projects	Participants use the most updated version of the rubric to score 2 STEM projects	Small group task, group share (30 *min*)
Participants make connection between the rubric and their current work	Participants consider how the rubric can be used in their work and propose revisions	Individual reflection and note taking, sharing thoughts with the group (*15 min*)

Proposed time allocation: 1.5 hours (please note: the proposal was revised from 2 hours to 1.5 based on the request from organizers, but we would love to have the full 2 hours, if time allows).

Maximum number of audience participants: 40

Special resources and requirements from the STEM 2020 organizers: This workshop requires a room that is suitable for group work (tables that allow groups of 4-5 people to work together), projector, screen, and audio speakers.

Relevance and significance to the STEM field and conference audience: This proposed workshop is suitable for educators of all grade levels, school/district administrators, STEM education researchers, and STEM curriculum developers. Educators and administrators will be able to apply the presented STEM rubric and frameworks to their own teaching and contribute their experience to the discussion. The authors hope that educators will find the rubric and frameworks adaptable for their own teaching. STEM researchers will learn about the iterative process that was taken to develop the rubric as well as the frameworks that were used as foundations for the rubric. In addition, researchers may find the elements of the presented rubric relevant to their work. Lastly, STEM curriculum developers will be able to adapt the rubric to their curriculum and use it to evaluate STEM instructional materials.

Expected impact for STEM participants: As describe in Table 2, the goals for this workshop include growth in participants' knowledge and practice using the rubric. The task-oriented workshop and the cooperative learning pedagogy will enhance personal connection among participants as well as deep learning experience around shared interests.

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ARTIFICIAL INTELLIGENCE AND DIGITAL CITIZENSHIP

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ABSTRACT

This workshop will introduce educators to the concepts behind Artificial Intelligence (AI), through computational thinking and interactive games and activities. The workshop aims to give participants the tools and knowledge needed to understand what AI is, how it affects our daily lives, and how it shapes our online experiences. Our main learning objectives are as follows: develop familiarity with AI concepts such as training process, training data and confidence level; develop familiarity with computational thinking concepts like decomposition, abstraction and pattern recognition in the context of AI; and practice reframing a problem so that it can be solved using AI. The workshop begins with an "unplugged" activity that demonstrates how image recognition works in Artificial Intelligence models. We then introduce a number of the foundational concepts of AI with a continued focus on machine learning in general and image recognition specifically. Participants will then get to train their own AI system using text and images to discover strategies for building a successful model. There will be a specific focus on identifying potential areas of bias when training an AI system, what this can do to the results, and why it is essential to be aware of these biases when interacting with AI systems in our daily lives. We will be using both publicly available (Teachable Machine) and proprietary training models in our workshop. Finally, we will use the concept of a "preference bubble" to discuss how AI systems can affect our online behaviour and aim to develop techniques to recognize when this is happening and what we can do to counteract it. Participants will be given curriculum extension activities that they can use in their own classrooms. All our activities are designed to help students develop safe online habits, maintain a healthy relationship with their screen time and protect their digital privacy. Participation: What will the participants get out of this presentation? What participant involvement do you anticipate? How will it help others think about STEM in education? Provide three key points that will entice participants to your presentation. This workshop is designed primarily for K-8 educators, but is applicable for higher grades as well. It is hands on (unplugged, BYOD, and discussion activities) and interactive, and leaves educators not only with the curriculum we cover but also a set of extensions.

Keywords: *AI, artificial intelligence, computational thinking, algorithmic thinking, algorithm literacy*

COMPUTATIONAL THINKING ACTIVITIES FOR PRE-LITERATE CHILDREN

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ABSTRACT

Computational thinking skills are a crucial part of problem solving, scientific inquiry, and coding. Although it is important to expose children to these skills early on, very few activities have been designed for the pre-literate age group. This workshop introduces 6 activities that teach a computer science concept through hands-on activities suitable for pre-literate children as well as older children. These activities are intuitive, low-cost, interactive, and readily integrated into the K-6 curriculum. Post-questionnaire results indicate that everyone is more likely to consider coding activities with their children and to recommend a future activity to their friends and family. Our hopes in this workshop is to provide participants with the materials, concepts, and instructions needed to execute these activities in their own classrooms.

Keywords: *computational thinking, unplugged activities, arts and crafts, encryption, algorithms, coding, animation, photo forensics, human-computer interaction*

Proposed Time Allocation: *90 minutes*

Computational Thinking for the Pre-Literate Age Group

Recent research has emphasized the need to foster computational thinking skills at a young age. Many approaches make use of software tools (e.g., Scratch) to encourage coding for older children. Recent research and commercial products also promote using physical objects (e.g., LEGO Mindstorms, Ozobot) to engage children in activities where they can modify and observe changes of an object in the physical world. While software programming tools are effective at promoting programming concepts, they require mastery of abstraction skills and are not appropriate for young children at a pre-literate age. On the other hand, commercial toys remain costly to purchase and their design are often limited to solving mazes. There is a need for a larger variety of low-cost activities that allows young children to gain exposure to computational thinking skills. To this end, we have designed six low-cost activities that allow children to learn about computational thinking concepts through the use of arts and craft materials (although some activities involve the use of a smartphone or a computer). In this workshop, we present these novel activities, their outreach context, and our experience with them.

Outreach Event Context and Activities

As part of a larger university community outreach event, our department organized a "Computer Science Booth" for our visitors in the fall of 2019. Visitors vary in age, background, and interests. Our booth promoted the theme of "Kids Can Code" and was advertised to various local daycares, schools, public bulletin boards, and social media.

We designed six stations for visitors. Each station focused on a unique computer science concept, involved a hands-on kid-friendly activity, and accompanied by more sophisticated worksheets and scientific explanations suitable for an older age group. The concepts and hands-on activities for the stations were: encryption, algorithm, coding, animation, photo forensics, and alternative user interfaces. Each of these activities are described below. Participants in this workshop will learn the concepts involved in each of these stations and be given materials to do the activities involved.

The Encryption Station

Encryption is the process of sending secret messages in a way that only the people involved will understand. That means, if I want to send a secret message to you without others understanding it, you and I have to decide on a way to change how we talk and then only talk in that way. When we change a regular message into a secret message, that message is "encrypted". Morse code is an example of how messages can be encrypted using combinations of short sounds and long sounds for each letter.

- **Task:** Spell your name on paper. Listen to what the name sounds like in Morse code on a smartphone app. Pick a key ring and pipe cleaner. Match each letter of the name into the corresponding Morse code. Chain up a round bead for a short sound and a long bead for a long sound. Tie a knot to complete the keychain.
- **Materials Needed:** International Morse code alphabet, pipe cleaners, key rings, round beads, long beads, Morse code app on smartphone
- **Creates:** A beaded keychain
- **Advanced Exercises:** Provide the Ceaser cipher (both original and encoded letters) and ask for encryptions for sample messages such as "SENIORS ROCK MY SOCKS". Alternatively, ask for a decoding of secret messages such as "WRGDBLVVRFROG". Additionally, get together with a friend of family member and develop your own method of encryption.

The Algorithm Station

An algorithm is a recipe for solving a problem. According to the "four colour theorem", any line picture that resembles a map (with neighbouring regions sharing borders) can be coloured with four colours while ensuring that regions of the same colour do not touch each other. In fact, some pictures only need three or two colours.

- **Task:** Pick a colouring sheet. Colour white areas using four (or fewer) different colours. Be sure the areas with the same colour do not touch each other.
- **Materials Needed:** A variety of colouring sheets.
- **Advanced Exercise:** Among the various pictures shown, identify the ones that can be coloured with only three (or two) colours while ensuring the regions of the same colours do not touch each other.

The Coding Station

Coding is a group of instructions that solve a problem. In a maze, the problem is to get from start to finish, and the instructions are the sequence of arrows used to get through the maze. When a problem is too big, we can break it up into smaller problems and solver each "subproblem" one at a time. When we finish solving all the subproblems, that means we have also solved the big problem.

- **Task:** Solve the maze on the printed worksheet. Next, review the grid maze taped on the floor and sequences of arrows to get through the maze. Note that only one sequence will get to the end of the maze, while others are distractors. Execute the sequences to see which one gets to the end of the maze.
- **Materials Needed:** A printed grid maze, green tape (for the grid), black tape (for the maze)
- **Advanced Exercises:** Solve additional grid mazes (printed on paper) by identifying the sequence of arrows needed to get through the maze. Alternatively, use graph paper to create their own mazes to challenge others to see if others can solve their mazes.

The Animation Station

Animation is how we make a sequence of pictures appear as a moving image. Each of these individual pictures in a sequence is called a “frame”. These frames look like a moving animation because our brains process the individual pictures together into a coherent story.

- **Task:** Visitor reviews examples of animation and thinks of something they want animated (e.g., a person flying in the sky). Depending on the age of the visitor, a volunteer may draw a simple animation or help the visitor draw part of the initial frame and then complete the remaining frames of the desired animation. To create an animated GIF, the volunteer uploads the individual frames onto www.ezgif.com, processes them into an animation, and then downloads the animated GIF file for the visitor to keep.
- **Materials Needed** (for flipbook animation): a 3”x3” sticky pad and dark colour pen
- **Materials Needed** (for animated GIF): a digital tablet and pen, drawing software, Internet access
- **Creates:** A flipbook animation or an animated GIF
- **Advanced Concept:** Explanations of programming computer animation using an apple catcher game. Concepts include the geometry of moving images (e.g., falling apple) and collisions (e.g., eating apples).

The Photo Forensics Station

Did you know that some pictures that look real are fake, and some pictures that look fake are real? Why do you think people make fake pictures? Sometimes we can guess whether a picture is real or not. When you’re not sure, you can use tools to help you figure out if a picture has been modified. Do you want to take a picture that shows you riding an elephant, dancing in a bubble, or walking on water? We can use that picture and show you how it has been modified.

- **Task:** Choose a photo background. Pose in front of the green screen and take a picture. See yourself in the chosen background. Analyse the image to see how it would compare to a real photo.
- **Materials Needed:** Green screen cloth, camera, green screen app, green screen backgrounds, online access to fotoforensics.com .
- **Advanced Exercises:** Determine whether additional pictures are real or fake. Discuss the concept of “error level analysis” that shows areas of a picture with different levels of compression, indicating areas that have been modified. Discuss the concept of “rainbowing” where images showing areas of red and blue indicate the file has been resaved repeatedly.

The Alternative User Interfaces Station

Many devices have computers in them, such as phones, calculators, iPads, and even cars. The design of these devices and whether we operate them by touching, typing, or talking to them are all methods that come from a research area called “human computer interaction” (HCI). Most computer interaction involves a mouse and keyboard. New techniques involve speech and gestures. A fun part of HCI explores the use of common household objects for interaction. Makey makey is a small device that lets you use household objects as buttons for the computer. It uses an electric circuit and wires to tell the computer which object is connected to which button. So if you connect a banana to the space bar, then pressing on the banana will be interpreted as pressing the space bar.

- **Task:** Select the household objects you want to use and assemble a custom piano. Learn to play a song by following the music sheet and using the custom piano.

- **Materials Needed:** Makey makey kit, software set to a piano, household objects such as food with conductive textures (e.g., fruits and timbits), sample music sheets.
- **Creates:** A digital song made from the fruits piano
- **Alternative Exercise:** Did you know that virtual reality is also part of HCI? It is an environment that lets us experience a simulated world that is not physically present. Try on a Google cardboard to experience riding a roller coaster or flying off a cliff.

Post-Event Feedback and Discussion

All of our stations were full for the three hours of the event. Our survey results indicate that the activities were well-received and more similar activities in the future can benefit young children. In particular, we asked visitors (or their parents) to complete a feedback survey when they leave our booth. Overall, we had 24 completed surveys at a response rate of 75%. To summarize, we created the word cloud below showing a single word or a short phrase that respondents felt most represented their experience.

Lastly, one of the parents of a 4.5 year old later contacted me on Facebook to share a unique story:

> When we left the [events] on Saturday, on the drive home [A] asked: "Dada, when we get home, can we build something with Scratch on your computer?" She hasn't been interested at all in that before, we've taken a bunch of books out from the library over the last two years, each time she says she's interested while we're there, and then get zero interest when we get home. But when we got home from the events Saturday, she was super-excited to go to the laptop together, and we spent 45 minutes building some new Scratch games together, and she was interested and excited the whole time and directed the entire process.

We believe the success of these stations are founded on the connection between familiar activities, such as arts and crafts, to coding concepts. Our next steps include developing more related activities and creating toolkits for teachers to use in their classrooms. Future studies include getting teacher feedback on these activities and assessing long term student engagement.

NEW STORIES FOR OLD: PERIMETER INSTITUTE RESOURCES AND OPPORTUNITIES FOR MODERN PHYSICS IN JUNIOR AND SENIOR HIGH SCHOOL SCIENCE

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2. *Richmond School District (38), Canada*
3. *The Perimeter Institute for Theoretical Physics, Canada*

ABSTRACT

The inclusion of modern science in the curriculum at all levels increases student interest and opens up the possibility of new narratives and the chance to celebrate more diverse scientists and perspectives. An objection to including, for example, modern physics topics is that it is hard to teach well, and many teachers feel they lack background in these topics. We will demonstrate resources developed by the Perimeter Institute (PI) that are engaging and sound, enabling teachers to more easily explore these exciting topics with their students. This workshop models the inclusion of advanced topics at an introductory level by surveying the resources developed and demonstrating them in practice, focusing on modern physics topics related to cosmology (the expansion of the universe) and particle physics (with a focus on elementary particles). Workshop participants will engage in hands-on activities using fully customizable, and free, PI resources. Facilitators will share strategies on how they incorporated these PI resources into their practice, and participants will have opportunities to discuss their own experiences and ideas. At the end of the workshop, participants can walk away with tangible ideas and resources that they can incorporate into their practice.

Keywords: *Perimeter Institute, modern physics, physics teaching, introductory science, cosmology, elementary particles, hands-on*

STEM is continually changing and growing, full of exciting new developments. Few of these make it into our curricula, however, which often is decades (or more!) behind the cutting edge of these fields. It is our contention that the addition of modern science in the school curricula is important, not only to give students a truer understanding of how the universe works (important though that is), but also because it offers a chance to show the diversity of people involved in modern research, as opposed to the mostly monotone and monocultural ‘standard’ cast of classical physics (Rifkin, 2016). However attempts to add, for example, modern physics to the curriculum at all levels have met resistance both from teachers (who feel they do not know the material well enough to teach it) (Tyler and White, 2015) and from some physicists (who fear that poor teaching will do more harm than good) (Siddiqui and Singh, 2010). Most teachers of general science are not physics specialists, and indeed many of those teaching specialized physics classes do not have a specialized academic background in the subject. A survey by the American Institute of Physics found that only about a third of those teaching physics courses in the U.S. had physics degrees, for example (White and Tyler, 2014). Similar issues apply in other STEM fields.

It is reasonable that many teachers may feel under equipped to teach areas such as modern physics, which has the reputation of being esoteric and challenging. In spite of this research (and the presenters’ personal experience) suggests that modern physics concepts can be taught much earlier than they generally are, with positive conceptual and affective impact (Foppoli et al, 2019). This workshop aims

to promote modern physics in school curricula by making resources more accessible for teachers to incorporate into their practice. These resources, developed by an exciting collaboration between expert physicists and expert teachers through the Perimeter Institute for Theoretical Physics, intend to expose students to interesting topics in modern physics and engage student participation. Although we will workshop only a few of these resources we will provide a survey of other materials available.
The topics in modern physics that will be covered in this workshop include (1) cosmology and the expansion of the universe and (2) particle physics. We will show and engage you in both original and modified use of these resources to provide a means how it can be introduced in the classroom.
The resources can be found on the Perimeter Institute website (https://resources.perimeterinstitute.ca/collections/all) and specifically:

- The Expanding Universe (Perimeter Institute, 2014)
  Modeling expansion of the universe (using manipulatives and transparencies)
- Beyond the Atom (Perimeter Institute, 2012)
  Discovering the patterns in properties of subatomic particles that lead to the discovery of quarks and gaining insight into how quarks form particles through pedagogical (and fun) games

The ultimate aim of this workshop is to empower the participants to teach modern physics in their classrooms and to understand the opportunity that this provides to engage and empower their students. By workshopping easily used and sound materials, participants will discover resources to help them to present these topics with confidence and to appreciate the possibilities offered by these topics.
The presenters represent a wide range of experience in using such modern science resources in their practices. They will be able to share both success and struggles related to incorporating modern science resources into their classrooms.
All participants will walk away with a set of resources (including all materials used in the hands-on activities) to take home and access to a multitude of fully customizable PI materials that they can conveniently download online.

Maximum number of audience participants: 30
Workshop duration: 1 hour and 30 minutes

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COMPUTATIONAL THINKING ACROSS THE CURRICULUM

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ABSTRACT

Like the design thinking process, computational thinking is a problem-solving strategy that is applicable across multiple subject areas, as well as design thinking process. Explore ways of integrating computational thinking across several content areas. Suitable for formal and informal educators, this workshop will engage you in hands-on activities that use technology to demonstrate how computational thinking can be applied in subjects such as language arts, physical education, science, and math**. Please bring your laptop or tablet to the session.**

Keywords: *computational thinking, ADST, interdisciplinary, programming, design thinking process*

Marina Bers (2017) argues that coding is a creative, expressive endeavour. Seymour Papert coined the term "constructionism" to describe the ways learners construct new understandings in the act of creating tangible objects. The maker movement is rooted in the constructionist approach to learning which has implications for how formal and informal educators might envision coding and computational thinking inside and out of the classroom. Computational thinking, like science, is not something only experts can do. Computational thinking is a problem-solving strategy that enables us to re-think the problems we encounter in our daily lives (Code BC) and gives learners a common language to describe their metacognition. Computational thinking is an accessible entry point to consider how programming might be introduced into the curriculum. Being digitally literate involves understanding that we are not just passive consumers of technology and media; we, as educators, can help learners to creatively engage with technology and critically analyze media to construct meaning.

This two-hour workshop enables educators to explore computational thinking as a problem solving process that can be applied to learning across the curriculum. Educators will have the opportunity to try different learning activities, with and without devices, including writing an algorithm to 'code" a peer and trying different programming tools including Scratch, Scratch Jr, and Twine. Educators will leave the session with an understanding of computational thinking, its application across disciplines, and its relevance to the design thinking process and related curricula. We aim to empower educators to re-think what it means to code and to recognize that coding does not have to be an add-on to educational practice; rather, it can be integrated in ways that encourage students to engage with coding to learn, rather than merely learning to code.

This workshop is most suitable for educators who work with school age children as all the activities may be adapted for different grade levels. The maximum capacity is 36 participants. We would require a room with a screen, projector, and speakers, and enough tables and chairs to allow for group work.

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SEM MICROSCOPY IN THE CLASSROOM: A WORKSHOP MODELLING INQUIRY-BASED NANOSCIENCE

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ABSTRACT

Our workshop presentation goal will be to share the innovative inquiry-based pedagogical approach we have developed using a portable scanning electron microscope (SEM) in a classroom setting. Research shows that students engaging in guided, inquiry-based science develop more confidence in their knowledge and a deeper understanding of the content they experience through inquiry learning (Aktamis et al., 2016; Brickman et al., 2009; Shih, Chuang, & Hwang, 2010). Nanotechnology in general is a high interest field with career potential that many students find interesting and engaging (Butkevich & Gury, 2016). We'll demonstrate how we facilitated self-directed lab experiences for students across a wide variety of grade and ability levels. Ample time will be devoted to participant experimentation at the nanoscale using one of the two portable SEM machines we are bringing with us. While our machines warm up and generate images and graphs, we will showcase our ongoing research on inquiry-based SEM experimentation in the classroom and share a sampling of classroom SEM successes. Attendees will have the opportunity to mirror student experiences with the SEM- creating their own SEM images (up to 30,000x magnification) and electron dispersive spectroscopy (EDx) graphs. We encourage participants to bring their own items in to be viewed using the SEM- from natural to manmade, bread moulds to bullet casings, micro-electronics to insect anatomy. Bring it on!

Keywords: *inquiry learning, discovery learning, nanotechnology, nanoscience, science literacy*

Background and STEM Significance:

This project came about as a result of a partnership between three organizations: Alberta Innovates, NRC Nano (the nanotechnology branch of the National Research Council), and CMASTE (University of Alberta's Centre for Mathematics, Science and Technology Education). Alberta Innovates funded the project, NRC Nano provided the microscopes and maintenance work, and CMASTE supplied the teacher/facilitator and project coordination. The unique opportunity to bring a rare and expensive piece of technology into K-12 science classrooms allowed our team to explore inquiry learning in a new context. Inquiry learning has been shown to increase student confidence and engagement in learning (Bell, Smetana, & Binns, 2005; Minner, Levy & Century, 2009). There is even acknowledgement that the draw of inquiry learning can often be that students are using the same technology tools as the scientists they emulate (Harris & Rooks, 2017).

For nearly all of our student population, this is the first time they had seen, let alone actively used, a scanning electron microscope. Understanding microscopy (including SEM) is a required curriculum component for all Alberta science students, but access to SEM technology is typically unheard of. Virtual

SEM microscopy has been done (Childers & Jones, 2015; Chumbley et al., 2013; Potter et al., 2001), but inquiry is more difficult when it is confined to the programming constraints of an ancient online tool. There is no literature on actual usage of an SEM in a K-12 environment.

Overall, our project has visited nearly 30 schools and engaged over 1,000 Alberta students in multiple municipalities and rural areas. More recently, we've added a research component to our project to examine the effect of our inquiry approach and to abstract the most successful elements of SEM inquiry learning. Surveys have been completed by K-12 teachers and students participating in our projects. Results are still being analysed, but so far seem to track with current research into inquiry learning. Authentic exposure to scientific tools and instruments resonates with students (Brickman et al., 2009). Brickman notes that students gain confidence when exposed to inquirybased learning environments, even when those strategies produce unexpected or unexplained results (2009). Anecdotally, this comment is consistent with student feedback- they would much rather use a genuine tool and see murky or inconsistent observations than work from a textbook lab and achieve the boring, albeit expected result. Shih et al. (2010) add that there is added benefit to integrating digital and physical science tools. The continuity of handling and preparing a physical sample before visualizing it digitally using the SEM allows students to much more accurately grasp the scale and process of their science. Simply showing them prepared images of the same sample would not have the same effect.

Goals and Objectives:

With this presentation, we hope to engage our audience in an in-depth look at how inquiry based STEM education can look when we can utilize high-level, post-secondary technologies. We intend to mirror our classroom inquiry process and allow our attendees the opportunity to fully immerse themselves in the SEM. Though our research and observations will be mentioned, the focus of this workshop will be to explore the microscope and allow attendees to evaluate for themselves how the SEM might look in the classroom. We intend to give new perspective on inquiry learning through the lens of a new and interesting technology tool.

Audience Engagement:

We strongly encourage our audience to bring in small items that they are interested in seeing under the SEM. Our audience will be briefly instructed on the operation of the SEM microscope and its software. Then, they will be encouraged to use it themselves. Attendees will be allowed to prepare microscope slides, calibrate them for use in our SEM machines, and then visualize them. Samples can be cut, slices, smeared, or dabbed onto carbon-based slide stickers. There are very few restrictions on what can be imaged with the machine and samples require no previous preparation. We can accommodate two participants at once per microscope (four total), as one person can use the slide controls to move the samples and one person can use the computer to focus and zoom the microscope. Both microscopes (Hatachi TM-3000 model SEMs) can accommodate 5 prepared samples at once (10 total), allowing us to save a great deal of time while the devices establish a vacuum. Overall, we wish to demonstrate how much power these tools have in motivating students, generating interest and creating great images (Appended Figures 1, 2, 3, and 4 below are samples of student-generated images). Attendees will be able to keep captured images and EDx analysis graphs via google drive or USB.

Recommended Workshop Time:

- 1.5 Hours, we would take more time if it was made available.

Maximum Participants:

- 30 Participants, participation in the actual running of samples is limited by the number of SEM machines (2) that we have available. Our audience can be larger if interest dictates, but there will be less microscope participation per capita.

Special Resources Required:

- 2x Hatachi TM-3000 microscopes, slides, and collection tools (all provided courtesy NRCNano), One of the machines has an additional EDx (Electron Dispersive Spectroscopy) addon
- Multiple projection units would be ideal, but we can work with one if required
- We require VGA hookup to projector. Hatachi software must be run on the NRC computers that come with the SEM's and they only have VGA output ports

Impact for Participants:

Participants should walk away from our session with an understanding of the inquiry learning models we used in the classroom. We wish to demonstrate the power such a unique technology tool has on classroom discovery, even for students who traditionally lack interest in science fields. We hope our successes in the classroom are inspirational and instigate conversations on how an inquiry-based approach might work with other classroom technologies. We also hope to encourage participants to seek out the partnerships that have allowed this project to succeed.

Appendix 1: Student-Generated SEM Images

Figure 1: Image taken in Eaglesham, AB. Shows a small mite resting on the leg of a spider.

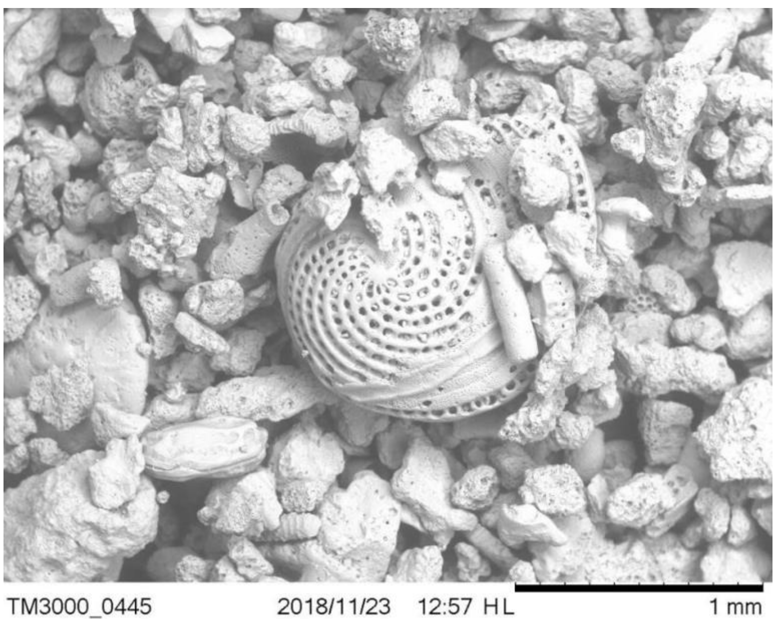

Figure 2: Image taken in Beaumont, AB. Shows a sampling of coral-heavy sand from a beach in Dubai.

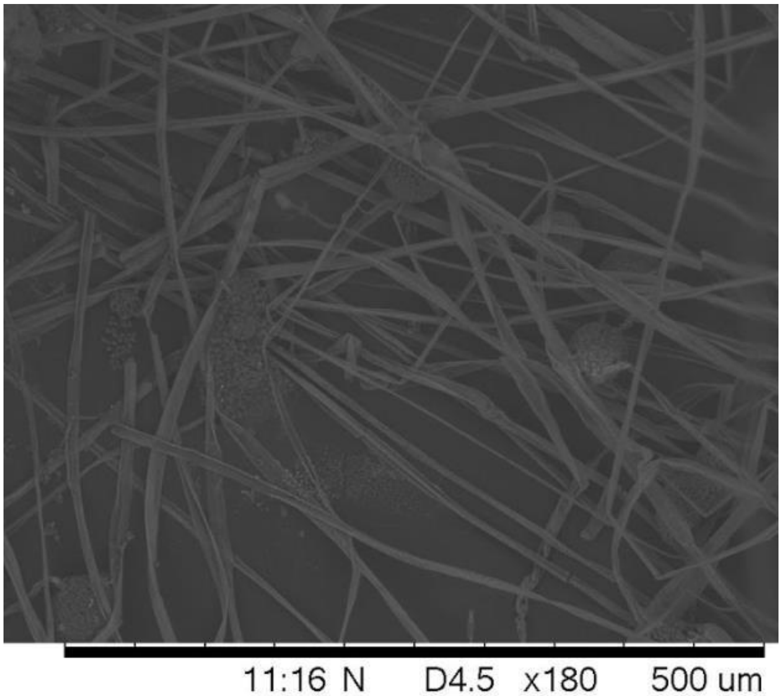

Figure 3: Image taken in Edmonton, AB. Shows fungal hyphae and spore clusters scrapped from a mould that was growing on potting soil.

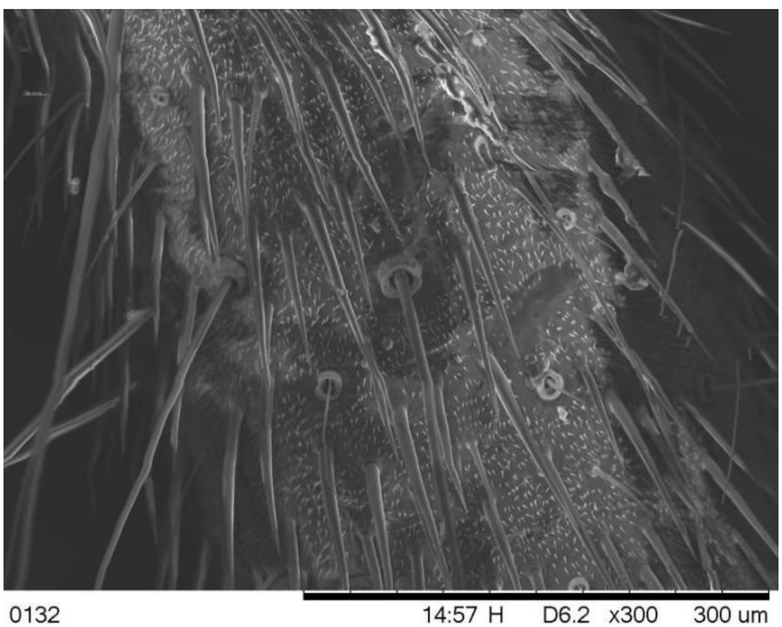

Figure 4: Image taken in Edmonton, AB. Shows various hair structures and the associated pores on a cricket

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INCREASING STEM STUDENTS' INTELLECTIVE CAPACITY WITH PROCESS ORIENTED GUIDED INQUIRY LEARNING (POGIL)

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ABSTRACT

Building intellective capacity (the increased power the brain creates to process complex information more effectively) is a primary path toward reducing the achievement gap for culturally and linguistically diverse students (Hammond, 2015). POGIL (Process Oriented Guided Inquiry Learning) is an active learning pedagogy that provides rich opportunities for all students to practice the information processing tasks that expand intellective capacity (Simonson, 2019). Attendees who recognize the achievement gaps among diverse student groups in STEM courses will benefit from participating in this effective pedagogy first-hand. Teams of participants will practice collaborative learning strategies and engage in the kind of sense-making tasks that increase intellective capacity. They will complete three short POGIL activities as they experience a student's perspective of this pedagogy. The workshop facilitators have extensive experience using POGIL with secondary students from a range of cultures, English language learners, high functioning students with Autism Spectrum Disorder, and students with a variety of learning and emotional challenges. Participants will leave with the basic skills to begin implementing POGIL in their own courses. The session will end with an opportunity to discuss participants' situation-specific concerns.

Keywords: *achievement gap, active learning, collaborative learning, intellective capacity, POGIL*

In her book *Culturally Responsive Teaching (CRT) and the Brain*, Zaretta Hammond identifies building intellective capacity as a primary path toward helping close the achievement gap for culturally and linguistically diverse students. In his book *POGIL: An Introduction to Process Oriented Guided Inquiry Learning for Those Who Wish to Empower Learners*, Shawn Simonson presents classroom-tested practices that directly support Hammond's recommendations. The POGIL pedagogy provides rich opportunities for expanding our students' intellective capacity.

Zaretta Hammond (2015) identifies focusing on increasing students' information processing skills as the most effective way to build students' intellective capacity - the increased power the brain creates to process complex information more effectively. Hammond's information processing model consists of three stages: input, elaboration, and application (pp. 124-127). These stages directly align with the structure of POGIL activities: exploration (of information), concept invention, and application (Simonson, 2019).

POGIL is a research-based instructional method that focuses equally on the development of students' interpersonal skills and the mastery of STEM content (Simonson, 2019). Carefully designed guided inquiry activities lead students through the learning cycle that their brains follow naturally (Zull, 2002).

POGIL activities are usually developed around visual models to allow information processing and sense-making by all students. Students are immersed in a rich environment of reading, writing, speaking, and listening as they interact to build mastery of important STEM concepts. While completing POGIL activities, students engage in talking-to-learn, analysing nonlinguistic representations of concepts, reflecting, self-management, trust-building, and cognitive routines – all behaviours that Hammond (2015) identifies as effective in increasing intellective capacity. The activities identify critical check-in points in the learning cycle so that students increase their confidence in learning.

Students work in teams of three or four to develop their own understanding of STEM concepts. Each team member takes on a precisely described role in the team's learning. The student role cards provide visual cues and sample scripts to support students who need additional scaffolding. The roles provide a framework for structured interactions among team members, increasing the effectiveness of collaborative learning for all students (Carter, et.al. 2010; Wong, Sisco, Chung, and Stanton-Chapman, 2015). POGIL's collaborative strategies allow students to support each other's learning. The workshop leaders have used these strategies effectively with English language learners, students with learning disabilities, students with emotional challenges, high functioning (verbal) students with Autism Spectrum Disorders, and gifted students.

Instructors in a POGIL classroom act as facilitators of student learning rather than dispensers of information. These teachers engage in Hammond's (2015) recommendations of creating safe learning spaces, building learning partnerships, and establishing alliances between teacher and students to promote each student's positive academic mindset (pp. 71-120).

Participants will develop a student's perspective of the information processing power of POGIL as they implement the team roles used in this collaborative learning strategy. They will actively explore the features of the Process Oriented Guided Inquiry Learning pedagogy by completing two POGIL activities: "Exploring Roles Used in POGIL Teams" and "Mathematical Models of Waves" (Sullivan, 2020).

The workshop will include a short question and answer session to allow time for participants to clarify and process their new learning. Participants will leave empowered to begin implementing POGIL in their courses. Participants will be invited to register with The POGIL Project, a nonprofit science reform organization that supports secondary and college/university instructors as they strive to implement effective active learning strategies in their courses. The POGIL Project offers more advanced workshops to help POGIL practitioners improve their facilitation skills and learn to write POGIL activities.

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COLLABORATION: A CHANGE CATALYST FOR FUTURE GENERATIONS OF STEM PROFESSIONALS

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ABSTRACT

Collaborative systemic approaches that strengthen capacity, spark interest, and create support systems can increase females' aspirations to enter and persist in science, technology, engineering and mathematics (STEM). The goal of this workshop is to equip participants with research-based strategies to increase gender equity in STEM and enhance collaboration across STEM stakeholders. Attendees will engage in activities that promote reflection on their current practices as well as future goals. Through collaboration scenarios and structured networking activities, attendees will learn how to harness the power of collaboration across multiple stakeholders within their community. In addition, attendees will also learn how to assess their program or community, identify factors that influence females in STEM, and implement effective collaboration strategies. Each attendee will receive free ready-to-use tools, strategies, and resources to guide them through changing the story of future young females who enter their classrooms, programs, and workforce. Transformational change is possible at a systemic level when STEM professionals possess a holistic STEM mindset and collaborate with one another. The journey towards changing the story is a collective effort. Attend this 90-minute workshop and become a change catalyst for future generations of STEM professionals. (Maximum 50 participants)

Keywords: *collaboration, k-12 teachers, professors, afterschool educators, systemic change, mindset shift, females*

Relevance to STEM Field

The story to include females in STEM areas, that were traditionally male, has a long history. However, the plot of this story, impacted by historical crises and societal perceptions, has never climaxed to include females as a natural part of the storyline. The narrative has evolved from advocates examining factors that influence individuals' decisions to also include other stakeholders who examine how these factors can be influenced at a systemic level. A collective, collaborative approach, where all stakeholders co-author a narrative could change the future for females in STEM. The success of such co-authoring is dependent on knowledgeable stakeholders, reciprocated collaboration, and an agreed-upon framework. This workshop highlights factors that affect female decisions in STEM, emphasises the importance of collaboration and presents several systemic frameworks that can be utilized to address the underrepresentation of females in STEM.

Female Interest in STEM

A number of factors that influence female interest in STEM have emerged over the last two decades. Professional development offerings for science, technology, engineering and mathematics teachers have instigated a new attentiveness to create classroom environments and develop projects that are more appealing to females. Jolly, Campbell and Perlman (2004) identified three broadbased themes within STEM research that impact student success in STEM and created the *Engagement, Capacity and Continuity (ECC) Trilogy*. When students are fully engaged, possess the capacity to succeed and have support to pursue their interest, they are more likely to be successful in STEM. However, the deficiency or absence of any of the factors within the *ECC Trilogy* can impact a student's interest in pursuing a STEM career (Jolly et al. 2004; Weber, 2012). To ensure females students' interests are positively impacted throughout their education and career paths, communities can employ collaborative approaches.

Gender in STEM: A Systemic Issue

Numerous researchers have examined factors that influence female interests in STEM fields. From such studies, organizations have fashioned specific strategies that target the root causes of underrepresented females in STEM. Some organizations have come to realize that creating an inclusive environment, curriculum, and culture within a classroom does not guarantee females will enrol in a course or program. As a result, many organizations have emerged to introduce STEMrelated informal learning experiences. Every individual or organizational effort invested in encouraging females to consider a career pathway into a STEM field is admirable. However, an alternative to tireless silo efforts is utilizing a systemic strategy that initiates collaboration across sectors. Ideally, communities that provide a synergized structure for stakeholders to share knowledge, data, and resources will strengthen and sustain female interest in STEM from elementary school into the STEM workforce.

Collaboration

In the 21st century, it is safe to assume many initiatives and organizations recognize the benefits of collaborating with others when they are trying to create social change. Collaboration is not a new idea; many organizations have utilized the idea of collaboration through sharing data, resources and sometimes funding (Kania & Kramer, 2011). Collaborations and partnerships across sectors can create a greater impact on a community than any one sole organization on their own (Prange, Allen & Reiter-Palmon, 2016). In a time when funding opportunities are very competitive, it is more important than ever to bring together resources and focus efforts across businesses, institutions and communities through collaboration initiatives (Chiara, 2017). However, an initiative's successful impact is dependent on the extent of the collaboration between the organizations. For example, Kania and Kramer (2011) categorized collaboration efforts into five types: funder collaboratives, public-private partnerships, multi-stakeholder initiatives, social sector networks, and collective impact initiatives. With the exception of collective impact initiatives, each listed collaboration type contains a missing component which can hinder the success of a cohesive effort to produce lasting change. Many grant funded STEM initiatives that advocate and encourage girls in STEM have frameworks that reflect one of the above collaboration types. Perhaps, if STEM stakeholders in a community or system are aware of the strengths and drawbacks of each collaboration type, they can analyse their collaboration efforts and adapt what they are doing to be more effective.

Collective Impact

Collective impact has emerged as a new framework for multiple stakeholders to partner together to address a social problem within a community (Christen & Inzeo, 2015). Too often when organizations work independently to one another they inadvertently duplicate efforts while exhausting resources without ever solving the problem they identified. Collective impact is a strategic coalition across sectors that can sustain a more lasting impact because the shared effort is coordinated to strive towards achieving a common goal. Integral for the success of a collective impact approach is that three preconditions must exist and five conditions must occur. The important pre-conditions before a collective impact initiative can begin are: leaders who are effective collaborators need to be present, the identified overarching problem must be important to all stakeholders and sufficient resources must be available (Weaver, 2014). The conditions which carefully guide and keep all the efforts focused include: a common agenda, shared measurement, mutually reinforcing activities, continuous communication and a backbone support organization (Kania & Kramer, 2011). Kania and Kramer (2013) describe the backbone support as, "Creating and managing collective impact requires a separate organization(s) with staff and a specific set of skills to serve as the backbone for the entire initiative and coordinate participating organizations and agencies."(p. 1). The role of the backbone support organization is key for moving stakeholders forward towards a shared vision.

Collective Impact and Collaboration in STEM

For the story of women in STEM to change, a systems approach is necessary. Many professional STEM organizations bring members together to strengthen capacity, provide professional development, and build networks. Networking opportunities can initiate collaboration between individuals but many organizations do not provide a mechanism or model for members to formally engage in sharing how they advocate for females in STEM. A number of organizations provide informal STEM learning opportunities within afterschool programs, camps or conferences to a wide age range of girls and young women. Collaboration across such organizations could identify potential areas of need and strengthen resources to strategically target those needs.

Unfortunately, competitive grant funding often prevents meaningful collaboration.

For a tipping point to occur with the representation of women in STEM, stakeholders would greatly benefit from engaging in meaningful collaboration with each other. The collective impact approach can be a useful framework for creating large scale social change in STEM within communities. However, it can be difficult to implement such an approach if all stakeholders involved are not in agreement. One can assume that any one approach is not successful in all cases. A backbone support organization is vital for the successful facilitation of collaboration (Turner, Merchant, Kania & Martin, 2012). Several organizations within STEM that support women and girls in STEM provide varying degrees of backbone support. For example, the National Alliance for Partner's in Equity (NAPE) and the National Girls Collaborative Project (NGCP) in the United States, exhibit characteristics of backbone support organizations despite not being directly identified with authentic collective impact initiatives. Through the STEM Equity Pipeline Project, NAPE assisted formal education communities to navigate through a 5-step institutional change model. NAPE directed institutions involved to analyse data, identify root causes, chose strategies then implement and evaluate strategies (Lufkin, 2008). The 5-step model kept teams on task and accountable for the root cause strategies implemented and outcomes evaluated. The grant funding of the STEM Equity Pipeline project had ended; however, the 5-step model could be replicated and utilized within a community or region. On the other hand, the large scale NGCP model initiates collaboration across a large network of organizations, both formal and informal, who are committed to advocating for girls in STEM. When such collaboration takes place within such a large-scale group, stakeholders can maximize their access to shared resources and strengthen the capacity of their projects (Marra, Peterson, & Britsch, 2008). In addition, with the aid of technology, collaboration is no longer bound within a community or region but can be more widespread offering support to rural and isolated areas.

Expected Impact

Gender equity initiatives in STEM share a vision to increase the number of females in STEM careers. It is advantageous for STEM organizations to collaborate using an agreed-upon framework. However, it may be necessary to modify or adapt existing frameworks to accommodate who is committed and who is willing to engage in genuine collaboration. If stakeholders are shown different types of collaboration and different models or frameworks for collaboration, they will be more equipped to collaborate successfully with other stakeholders within their region. Ideally, advocates for women in STEM would like to see a much stronger female presence throughout the STEM pipeline from elementary school into the workforce. In order for this to occur at a systemic level, STEM professionals must learn from each other and become catalysts of change.

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GONE GIRL: AN ARTS-BASED APPROACH TO ADDRESS THE ROOTS OF GENDER DISPARITY IN STEM DISCIPLINES AND FIELDS

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ABSTRACT

This forty-five-minute workshop will guide a maximum of twenty participants through the process of creating problem-based math and science teaching units geared toward increasing female engagement and participation in STEM subjects in high school. Ultimately, this workshop is designed to encourage more female secondary students to pursue STEM-related higher education and career options, thereby reducing the gender disparity in post-secondary STEM disciplines and industries. Workshop participants will explore the use of an interdisciplinary, project-based, arts-centred approach to teach STEM-based concepts. Participants will finish the workshop with complete teaching outlines for four math concepts and four cross-curricular, multi-concept STEAM design challenges, as well as the skills to create more. While the focus is on female participation, the strategy employed in the workshop can benefit any student, regardless of gender, whose interest in science and/or math is being impacted by the same factors as those identified in the Rationale. Facilitators will also share strategies for fostering interdisciplinarity and encouraging a cross-curricular STEAM-focused approach to learning within schools.

Keywords: *STEAM, gender, interdisciplinary, high school, cross-curricular, project-based learning*

RATIONALE

Why Female High School Students Opt Out of STEM

Canada's science, technology, engineering, and mathematics (STEM) disciplines and fields suffer from gender disparity, both at the post-secondary and industry levels (Meadows, 2016). This challenge is partly attributed by Ferguson (2016) to disproportionate levels of participation: far fewer women than men pursue STEM-related degrees and careers. In order for STEM disciplines and fields to approach gender parity, secondary school educators must encourage their female students to follow STEM pathways to post-secondary education and beyond. Teachers can increase the likelihood of female students pursuing careers in STEM fields by addressing the three most common factors that dissuade them in the first place: lack of motivation/interest; lack of selfconfidence; and lack of accurate knowledge regarding education and careers in STEM.

Lack of Motivation/Interest

Some students excel at math and science while others struggle; however, the majority of students fall somewhere in between. STEM disciplines and fields would benefit greatly by attracting more applicants from this group. Unfortunately, a significant proportion of these students will never even consider a STEM-based future due to a lack of intrinsic motivation or interest in following a STEM pathway. According to Dasgupta et al. (2015), these students' disengagement is based on negative experiences with math and science curriculum delivery: the classroom environment; the format of lessons and instruction; lack of self-identification in the curriculum materials; and lack of constructive feedback. To re-engage these students, secondary math and science teachers must adjust their methods of curriculum delivery: they need to change the way they tell their stories. This workshop will allow participants to develop and share a variety of such "storytelling" methods.

Lack of Self-Confidence

Ferguson (2016) found that students who are less confident in their mathematical abilities are less likely to pursue STEM-related educations and careers. Meadows (2016) attributed this lack of confidence to a number of factors, two of which are gender stereotypes, and learning environments that do not foster a sense of value and belonging. Cheryan et al. (2015) identified a misconception – the belief that math skills are intrinsic and require a natural brilliance – as another factor that affected female students' confidence in their mathematical abilities. A similar connection exists between confidence and the pursuit of higher learning and careers in the sciences. Research by Hutchinson-Anderson et al. (2015) revealed that students with poor lab practical skills and under-developed problem-solving skills were less likely to pursue a science pathway beyond secondary school. To build confidence in these students, secondary math and science teachers must provide opportunities for students to improve their math and science skills and thereby change their misconceptions. Essentially, students need to change the stories they tell themselves about their aptitude for math and science. This workshop will provide participants with exemplars and prompts to help teachers create more opportunities for their students to experience STEM success.

Lack of Accurate Knowledge Regarding Education and Careers in STEM

Some students claim they are uninterested in STEM education. A number of researchers have undertaken to discover the reasons for these students' disinterest. Hutchinson-Anderson et al. (2015) found that students were deterred by a perception that STEM disciplines lack creativity: that working in these fields would involve strict adherence to procedural methods. Meanwhile, Sun (2017) identified two different causes, both also related to perception, of student disinterest in STEM education: a seeming lack of empathy in STEM disciplines, and a lack of role models. Many students want to pursue work that will make a difference in the world, and they wrongly believe that following a clinical, unfeeling STEM pathway will not help them to achieve this goal. Others are dissuaded from pursuing STEM-centred careers because they feel they do not belong, based on the current representation within STEM industries. Changing these misconceptions requires that students re-examine the stories that form the basis of their false perceptions regarding STEM. This workshop will help teachers re-cast science and math courses in high school, not as obstacles to be overcome along students' journey through high school, but rather as building blocks for students' futures.

Using a Project-based Approach Grounded in the Arts

By developing arts-focused projects to teach STEM concepts, math and science teachers can address a number of the obstacles that female high school students perceive as barring them from a future in the STEM fields. The arts, in its wide variety of forms – music, dance, theatre, literature, history, fashion, film, and law are but a few – provide more opportunities for creativity and engagement; furthermore, the arts do not demand mastery as a pre-requisite for enjoyment, thus removing the issue of self-confidence from the equation. An arts-focused approach would also make available more role models for female students. Most importantly, the arts can imbue the sciences with that intangible, essentially human essence to which students allude when they claim that STEM disciplines lack empathy.

WORKSHOP DETAILS

Outline

Statement of Research Findings and Goals

In the first five minutes of the workshop, the facilitators will share with participants the research findings underpinning the session's activities. Participants will then review the short-term goals for the day: to design teaching approaches to mathematical and scientific concepts which will encourage female high school students to continue their studies in STEM-related disciplines. Finally, facilitators will advocate for the increased integration of the arts in STEM-centred education – an approach the workshop will showcase.

Small-group Work and Demonstrations

Participants will self-select into small groups, each with a maximum of four members; each group will then choose a mathematical concept on which to focus. For the next ten minutes, each group will select a real-world, arts-focused scenario that can be used to teach the group's chosen mathematical concept, as well as the delivery method that a teacher could employ. The challenge, which is also the key learning for participants, is to refrain from teaching the mathematical concepts at the beginning of the lesson. The next fifteen minutes will then be demonstration time: each group will attempt to teach the facilitators its mathematical concept using the scenario and method that the group developed. Group members should also attempt to connect their approach to the research findings shared at the beginning of the workshop. All participants will then work together for ten minutes to identify real-world scenarios that involve the application of multiple STEM concepts to settings most commonly associated with the arts.

Consolidation and Extension of Learning

The last five minutes of the workshop will provide participants and facilitators the opportunity to share ideas for fostering interdisciplinary connections with their colleagues in arts disciplines. This time will also be used to consolidate the day's work and upload it to the shared online folder. Finally, participants will be encouraged to consider how the day's learning might be used and/or adapted to serve the needs of students who are non-binary.

Resources and Requirements

Facilitators will need registrants' email contact information at least one week before the conference begins. All participants should have the necessary equipment to participate in a Zoom conference.

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POSTERS

A LONGITUDINAL STUDY: INVESTIGATING HOW ROBOTICS EDUCATION IMPROVE CHILDREN'S COMPUTATIONAL THINKING SKILLS

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ABSTRACT

The recent research has shown that robotics education (RE) may become a promising way to allow students to fully engage in all aspects of science, technology, engineering, and mathematics in the STEM education. Researchers also indicated that RE might help to increase girls' interests and develop their skills in STEM fields at an early age, which may help ameliorate the underrepresentation of women in STEM fields. However, there remains uncertainty about how RE will work for the Canadian student population. This study aims to investigate how RE helps to improve children's learning using computerized assessments. More specifically, we will address two research questions: (1) whether RE develops computational thinking skills, including number sense, visual memory, spatial understanding, and abstract thinking in children, and (2) whether there are gender differences in children's computational thinking skills over time. This study utilizes a repeated measures design, including a matched control group and an intervention group, with a total of 80 participants. Our findings will contribute to the existing STEM education literature by expanding researchers' and educators' understanding of how RE can benefit children in terms of their computation skills. This study will provide insights into gender differences in children's learning skills via robotics activities, which will examine some researchers' hypothesis about early exposure to robotics increasing girls' interests and abilities in studying STEM subjects.

Keywords: *STEM, robotics education, computational thinking skills, K-12 education, gender differences*

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EPIC BIOSCIENCE: AN ONLINE LEARNING ENVIRONMENT FOR BIODIVERSITY INVESTIGATIONS USING DIGITIZED SPECIMENS FROM SCIENTIFIC COLLECTIONS

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ABSTRACT

EPIC Bioscience is an online learning environment designed to engage students in authentic STEM research, using digitized specimens from scientific collections as the basis for collecting and analysing data relevant to scientific questions related to biodiversity. EPIC Bioscience draws upon theories of object-based and problem based learning, using digitized specimens to address scientific questions with the same specimens that domain scientists use for collections-based research. Investigations are designed for middle school classrooms and aligned to Next Generation Science Standards. Current investigations engage students in the study of interactions among organisms using digitized velvet ant specimens and understanding the effects of resource availability on organisms via analysis of digitized bat skulls and skins. Observations and measurements of digitized specimens allow students to collect concrete and meaningful data, providing students with a sense of ownership over data and giving them experience across the full range of scientific practices that researchers use in their work. Using digitized specimens in a scaffolded, online learning environment for science investigation increases the variety of scientific objects available for classroom STEM instruction. Notably, online investigations with digitized specimens also broaden access to scientific collections for populations that are underserved by traditional brick-and-mortar museums. Poster visitors can expect to be engaged in discussion about: Theoretical underpinnings of the EPIC Bioscience learning environment; Collections-based research with digitized specimens as the basis for highly engaging, authentic science investigation in classrooms; Challenges and opportunities to implementing online investigations using digitized collections objects, including ongoing research and development efforts surrounding EPIC Bioscience.

Keywords: *science investigations, museum specimens, object-based learning, 3D models, middle school*

ENTERING RESEARCH: THE IMPACT OF UNDERGRADUATE RESEARCH EXPERIENCES IN PRE-SERVICE SCIENCE TEACHERS

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ABSTRACT

Course-based undergraduate research experiences (URE) have been demonstrated to enrich the educational experience of university students in all disciplines by increasing student engagement and success. UREs aim to involve students in the investigation and research of challenging questions, thereby producing the sense of exhilaration stemming from uncovering answers to essential questions. This presentation reports on a pilot study conducted within a teacher education science course at a small Western Canada university. We examined how education science students are impacted by UREs? Can multiple, self-directed research projects be successfully supervised by a single instructor? How is the science classroom changed? Student-created artifacts (research questions, literature review, data, posters, etc.) became sources of data. Additionally, qualitative data from student interviews were collected. Data analysis revealed that while time constraints of a term-long URE resulted in a condensed timeline, the pre-service teacher-researchers became invested in their research and began to develop connections between their work and their future practices. Nevertheless, the students acknowledged that they devoted insufficient time to their projects in order to conduct in-depth research. Based on this pilot, recommendations are made regarding the incorporation of research activities in education science courses and the development of an independent course focused on undergraduate research in teacher education.

Keywords: *undergraduate research, science misconceptions, high impact educational practices, teacher education*

DIFFERENTIATED INSTRUCTION IN SCIENCE CLASSROOMS: A COMPREHENSIVE LITERATURE REVIEW

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ABSTRACT

This poster shows a comprehensive literature review about differentiated instruction (DI) with a focus on its applications in science, specifically Biology, secondary classes. It provides an overview about the following aspects related to DI: definition(s), background, rationale and purpose, methods to differentiate instruction, characteristics of effective DI, positive student outcomes, its applications in science classes, the integration of technology in DI, DI in science curricula, teachers' understandings of DI, teachers' implementation of DI, challenges faced by teachers in DI, and DI in teacher education programs. A total of around 100 peer-reviewed articles and books were included in this literature review. This research study analyses the literature, sheds the light on the gaps in the research, and thereby recommends areas for further exploration. Teachers, curriculum designers, school administrators, and educators can use this review as a summary of the aspects of DI, as it highlights the importance of this strategy and provides them with practical and diverse ways to differentiate instruction. Curriculum designers and policy makers can refer to the reported DI findings when writing and developing subjects' curricula and policies to help teachers differentiate their instruction. Also, teacher education programs can integrate and develop the reported strategies to enhance pre-service and in-service teachers' expertise in this domain. Correspondingly, researchers can explore the present gaps in the literature to plan future research programs.

Keywords: *differentiated instruction, science education, curriculum studies, teaching strategies, secondary classes*

TRAJECTORIES OF EARLY MATHEMATICS SKILL DEVELOPMENT FOR ENGLISH LEARNERS

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ABSTRACT

Using curriculum-based measures (CBMs) to identify students at-risk for not meeting mathematics competencies and enable early intervention support is one avenue to promote a path toward STEM fields in later academics (Clarke et al., 2011; Frye et al., 2013). Recent evidence suggests that CBMs designed as single-skill math probes are an efficient and promising approach to detect students who are at risk of experiencing difficulty in math (VanDerHeyden, 2017). Despite being historically underserved, there is a dearth of research on the applicability of standard early numeracy screening measures for use with English Learners (ELs; Alt et al., 2014). This study will use a multilevel modeling approach to analyze growth over time on singleskill CBMs that were part of a large-scale efficacy trial (n = 2,598) where primary students received a high quality, class-wide core curriculum. Outcome data will facilitate discussion on (a) the utility of the specific early mathematics skills that are worth assessing for ELs, (b) how this type of data acquisition in elementary school paves the way for an inclusive STEM trajectory in elementary school and beyond, and (c) the importance of diverse student characteristics in universal screening. STEM in K-12 education commonly focuses on building success from specialized programs in secondary school (e.g., Erdogan & Stuessy, 2016; Thibaut et al., 2018), and this study points to a universal screening approach with CBMs in Kindergarten. Identifying ELs with math difficulty at school entry increases opportunities to intervene early and provide a successful trajectory to future STEM education.

Keywords: *english learners, ELs, curriculum-based measures, CBM, prevention, early math intervention, at-risk learners, math trajectories*

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EXPLORING STEM EDUCATION IN THE JUNIOR SECONDARY IN TAIWAN

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ABSTRACT

Integrated STEM has become a prevailing trend influencing educational reforms globally. The success of quality integrated STEM in classrooms depends not only on teachers' knowledge and beliefs but contextual supports. Gaining deeper understanding of current STEM teaching practices can be useful for developing teacher supports as they move towards meaningful STEM integration. The purposes of the study were to explore Taiwanese science and technology teachers' conceptions of STEM, analyze contextual supports and barriers to the implementation of integrated STEM, and understand how the interplay of the factors shapes the current teaching practices in classrooms. The study adopted a qualitative approach to examine 20 in-service science and technology teachers' conceptions of STEM and their experiences in developing and implementing integrated curriculum. The interviews revealed that though the teachers defined STEM in various ways, their conceptions shared similar constructs: provide contexts for learning and applying disciplinary knowledge, cross disciplinary boundaries, hands-on experience, and link to everyday life. Teacher conceptions were closely related to the curricula developed. While problem-solving and engineering-design were the most used curriculum design models, some teachers adopted competition-driven projects or drew students' attention to the issues of local community. Most schools provided financial support, other supports like administrative support (flexible timetable) or professional leadership and community were rare. A rather trivial role science and mathematics play in the STEM curricula and a lack of team teaching in the cases in fact reflect implementation difficulties in the current settings where high stake examinations and disciplinary-based curriculum are dominant.

Keywords: *integrated STEM, junior secondary, teacher conceptions, curriculum*

SOFT SKILLS IN STEM MAKERSPACES LEARNING: A CASE OF A GRADE 3 CLASS BUILDING A MODEL OF THEIR VILLAGE

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ABSTRACT

School makerspaces is a novel context for learning STEM skills. From our CompeTI.CA research on digital competencies, we also identified the benefits of makerspaces for developing soft skills (Freiman et al, 2017; Freiman, 2020). Other studies (e.g., Falloon et al, 2020) report about soft skills like critical thinking, creativity, perseverance, and resilience in their students, but the nature of these skills and their role in STEM education is still not yet well understood. We will share new data from our case study on how soft skills unfold in Grade 3 students from a rural elementary school in the Western part of New Brunswick working on a STEM project in their makerspace. Supported by their classroom teacher and an ICT mentor, students built a miniature model of their village with an audio tour. Over several months, they collectively reproduced the most common locations of their village installed on a big, long table; each location was equipped with a button controlled by a computer program students wrote using Scratch and voice-recording. Data from interviews and video-observations reveal a variety of soft skills involved in tasks of measurement, 3D modelling, programming, electrical circuit building, and storytelling. Students particularly valued collaboration which seem to help the to deal with the complexity of the tasks and issues and were proud everyone's contribution to the success of their collective efforts. This poster presentation will also reflect on the holistic pedagogy that need to be in place to put upfront soft skills in STEM makerspaces learning.

Keywords*: STEM education, school makerspaces, primary grades, soft skills, collaboration*

SCI 192 THE SCIENCE AROUND US – AN INNOVATIVE, STUDENT-CENTRED, MULTIDISCIPLINARY APPROACH TO MEETING THE SCIENCE LAB REQUIREMENT FOR PRE-SERVICE TEACHERS

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ABSTRACT

Students intending to become K-8 teachers in British Columbia Canada require one introductory lab science course in any discipline. Eligible courses are not generally targeted to the teacher audience, and research suggests that they may not effectively prepare students to teach science in their future classrooms. To address this issue and better support these emerging teachers, a studio style, multidisciplinary science course "SCI 192: The Science Around Us" was developed at Simon Fraser University. The course incorporates a student-centred, inquiry-based approach reflecting the practice and nature of science. Topics in Physics, Chemistry, Biology and Earth Sciences are introduced through integrated activities, experiments, mini lectures, fieldwork and discussions. The goals are to provide an experience that fosters enthusiasm, interest, and knowledge of science and science processes, connects science to students' lives and empowers them to teach the science concepts and competencies in the BC Science curriculum. Climate change and energy, two societally relevant themes, are woven through the course. SCI 192 was developed and delivered by a multidisciplinary team comprising science and science education experts, a school district advisor, and an educational consultant. Piloted in Fall 2019, we document the approach, development process, evaluation and outcomes of this novel course. Course artefacts, quiz scores and student feedback suggest that participants are benefitting from this approach. Improvements to SCI 192 are informed by team debriefs, instructor reflections and results of student surveys, with the goal of having SCI 192 become the recommended lab science course for pre-service teachers at Simon Fraser University.

Keywords: *science education, teacher training, lab science requirement, multidisciplinary science, pre-service teachers*

WEB 2.0 TECHNOLOGIES: TEACHER PROFESSIONALISM AND SOCIAL MEDIA

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ABSTRACT

Developments in Web 2.0 technologies have heightened the level of scrutiny that teachers face. Teachers' digital identities and social media use can conflict with expected standards of professionalism, especially where these standards are ambiguous or absent. This creates tensions that may inhibit teachers from using internet technologies, both in the on- and off-duty contexts, which divorces them from the supports offered through professional learning networks as well as from inclusive platforms through which education in the STEM field can be delivered. This presentation is focused on the need for support and guidance for teachers to ensure that their use of Web 2.0 technologies, both on- and off-duty, does not cause them reputational harm or impact negatively on their professional identity. Specifically, the concerns of pre-service teachers regarding their use of social media are addressed which highlights the tensions that exist for teacher candidates around their use of SM as they transition into certified teachers. Participants will be presented with the concerns of pre-service teachers around their use of technology as they transition into their professional identity. It is hoped that this will highlight the additional challenges and dangers that Web 2.0 technologies can bring to teachers, given the higher standard to which they are held. It is expected that participants will gain a greater appreciation of the challenges teachers face in this regard, understand the tensions that these create, and see the urgent need for clear policy in the area of digital technology use for teachers.

Keywords: *Web 2.0 technologies, social media, teacher education, teacher regulation*

HOW TECHNOLOGY ASSISTS POST-SECONDARY STEM STUDENTS WITH MATHEMATICS LEARNING DISABILITIES

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ABSTRACT

STEM education is essential to meet the requirements of our complex and technologically advanced society; however, students with learning disabilities face enormous challenges and are underrepresented in STEM careers (Asghar, Sladeczek, Mercier, & Beaudoin, 2017; Fisher, 2017). Mathematics learning disabilities (MLD) affect some students' potential to study mathematics and be admitted to postsecondary STEM disciplines. We report the results of an exploratory study conducted on two post-secondary campuses in western Canada to identify how electronic devices and software technologies can assist students with MLD in their academic studies. We conducted in-depth semi-structured interviews with nine post-secondary degree/diploma students (of which eight were enrolled in STEM disciplines: including computer science, kinesiology, nursing, psychology and technology) who self-identified both as having an MLD and as being confident in their use of technology. We learned that specialized assistive (e.g., SmartPen) and mainstream (e.g., phones, online tutorials, search engines) devices and applications helped our participants by offering support with their work with numbers, symbols, problem solving, lack of focus and poor memory, as well as with their ability to access mathematics content and alternative presentations of the same topic, monitor work accuracy and reduce cognitive load. Additionally, our participants creatively adapted devices to their needs and offered design suggestions. This poster will present empirical evidence of how post-secondary students used technology to support their academic success in STEM disciplines, and the implications that our study brings to researchers, K-12 and post-secondary administrators and educators, and designers of technology.

Keywords: *mathematics learning disabilities, STEM post-secondary education, assistive technology*

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THE INFECTION GAME: DEVELOPMENT OF COMPUTATIONAL THINKING AMONG HIGH SCHOOL STUDENTS

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ABSTRACT

This poster prepares the groundwork for a project that focuses on high school students' construction of scientific knowledge through computer simulation. The activity "The infection game" simulates the diffusive dynamics of an infectious disease in close connection with the students (e. g. catching a cold). It is expected to characterize the actions of the participants in the comprehension of the dynamics and emergency processes in epidemics through the development of computational thinking practices (Weintrop et. al., 2016). The methodology considers two moments. The first, called "embodied", oriented to the internalization of the basic rules and the main variables (outside the computer); the second directed to the use of a computational simulation in Netlogo (Wilensky, 1999) focusing on the formulation of hypotheses and predictions about different levels of organization of the phenomenon studied. The contribution of this research is oriented to the discussion of STEM as a way to promote a scientific, transdisciplinary, participatory and innovative education, that contributes to a localized social development (Davis, Francis &, Friesen, 2019).

Keywords: *embodied modelling, Netlogo, high school, computational thinking*

USE OF LAB SIMULATION SOFTWARE DURING A 2-WEEK VIRTUAL SUMMER CAMP: A COVID-19 ADJUSTMENT

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ABSTRACT

The Drug Discovery and Biomedical Research Training program provides hands-on lab experience and mentoring to underserved minority high school students. With the inability to conduct an inperson summer camp, we transitioned to a virtual program in 2020. Thirty-three students and their teacher participated in live sessions using Blackboard Collaborate Ultra, which is the University's virtual learning platform. One highlight of the sessions was the use of interactive simulation software by program faculty e.g. science labs (Labster®), animal behavior experiments (Sniffy the Virtual Rat®), and aseptic compounding (Virtual Interactive Clean Room®). Graduate student mentors facilitated the simulation exercises by working with the students in small virtual breakout sessions (~6 student/group). A critical feature of all the software programs was the ability to monitor student engagement. Post-session survey data show that the majority of students (73% to 100%) felt comfortable participating in the simulation sessions. Students' responses indicate that they enjoyed the virtual labs and appreciated the effort to implement the game-like lab simulation exercises. Responses showed that, while the virtual program was not a direct substitute for the "hands-on" nature of the planned camp, the ability to do the simulations offered an engaging alternative experience that was still considered worth their time. In post-camp surveys, 96% of the participants indicated an interest in pursuing careers in pharmacy/other health professions. Student and teacher comments also indicated that the virtual experience of the camp prepared both students and their teacher for the coming fall semester at school.

Keywords: *lab simulation, STEM, virtual learning, biomedical training, underserved minority high school students*

TOY HACK: A STEM EDUCATION METHOD BY TOY MODIFICATION

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ABSTRACT

The subject of this research is a proposal and evaluation of an educational method named “Toy Hack”, in which children learn about STEM fields by modifying toys equipped with microcontrollers and other electronic devices. The author believes that modifying toys that have been played with in the past has the effect of maintaining interest and motivating learning for children and adults. This poster presentation shows which toys children want to develop, what kind of modification attracts the interest of children, and also gives examples of the Toy Hack method. The results of a survey revealed that railway toys were the most popular among a wide range of age groups. Therefore, teaching material on the modification of railway toys has been developed. The specific goals are to embed sensors in the rails for detecting trains, to automatically switch the route, and to automatically control departure and arrival. Toy Hack teaching materials have also been developed for other toys such as stuffed toys (puppets), cars, and blocks. The author also proposes a figure called a STEM map that shows which STEM fields can be studied from the developed teaching materials. This presentation covers three key points: (1) specific examples of Toy Hacking, (2) instructions for others to develop STEM educational materials, (3) a way to present STEM educational materials in an easy-to-understand manner. The author also discusses new modification methods.

Keywords: *Toy hacking, modification, embedded system, STEM map*

STUDY ON THE TRIGGERS FOR BRIDGING INQUIRY AND CREATIVE ACTIVITIES IN HIGHLYINTEGRATED STEM EDUCATION

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ABSTRACT

The most important aspect of STEM education that is expected in this fast-changing era is to develop human resources who can create new things, mechanisms and values. We are focusing on STEM education for developing human resources who can make innovations in such fast-changing era. It has been shown that there are various types of STEM education (Bybee, 2013). Among them, the one that suits our purpose is a highly-integrated type: classified as "Transdisciplinary". It is also shown that the problem solving and innovation activities we aim for are included in Engineering (Bybee, 2010). Therefore, the future goal of this study is to develop STEM education which integrates STEM fields by centering on Engineering. Though the importance of integrating fields in STEM education is recognized, there is no research yet on specific educational methods to realize it by centering on Engineering. With this in mind, we referred to Koldner's "Learning by Design" (Kolodner, 2002). It is a model make science inquiry learning as "authentic learning" by bridging the design process and the explorative process with "need to do" and "need to know". This is one of the educational models that integrate the creative activities of engineering and the inquiry activities of science, technology and mathematics. However, there is no specific knowledge of how those processes can be connected in highly-integrated STEM education. Thus, we tried to clarify what kind of "need to do" and "need to know" exist, what triggers make them appear, and how they can connect those processes.

Keywords: *Learning by Design, highly-integrated STEM education, transdisciplinary*

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STEM: CURRICULUM INTEGRATION IN PRIMARY SCHOOLS AND AMUZE PEDAGOGICAL PRACTICE IN CLASSROOM

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ABSTRACT

STEM education is paradigm shift from conventional education approach to a new interactive approach. STEM (Science, Technology, Engineering and Math) is very important aspect of this 21st century learning and teaching. The approaches to STEM opted by different countries varies in so many ways. The major problem I see in the south Asian region is the "STEM teaching methodologies and implementation of the curriculum in the run time". STEM is the philosophy and approach to teach the students about innovative solution to the real life complex problems. It is not a subject itself but it helps to foster the learning of science and mathematics with the help of engineering processes and technological tools. I will be proposing the right way of integration STEM in K-12 curriculum in school systems and innovative pedagogies by mixing up the flipping classroom approach with already existing pedagogies. This paper is about shifting the guided STEM learning to real life open end project based learning. The technique I developed is called Amuze its mixture of Pomodoro technique with flipped classroom approach. My major focus will be on STEM in real life, new and interactive technique in teaching methodology and will help in building interest towards STEM centred careers.

Keywords: *Project Based Learning, innovative pedagogies, STEM integration, flipped classroom, pomodoro technique, STEM k-12 education*

ANALYSIS ON KOREAN TEACHERS' STAGE OF CONCERNS ABOUT STEAM EDUCATION AND THE LEVEL OF STEAM IMPLEMENTATION

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ABSTRACT

This study was aimed to examine Korean teachers' stage of concerns about STEAM education based on Concerns-Based Adoption Model. For this, a CBAM questionnaire was administered to a total of 690 teachers. The original CBAM questionnaire has 7 stages from Unconcerned (Level 0) to Refocusing (Level 6). Of all the participating teachers, 31.9% was Level 0, 10.6% was Level 1, 15.4% was Level 2 and 20.1% was Level 3. One third of the participants were not interested in STEAM education. T-test and ANOVA showed that there were statistically significant differences found between teacher groups with different professional development experiences on STEAM education, previous experiences participating in STEAM programs, gender of teachers, and years of teaching experiences. Teachers' experiences of participating in STEAM projects and professional development affected their stage of concerns about this innovation. Teachers are often reluctant to any kinds of innovations. However, once they had participated in the innovation, i.e., STEAM projects, no matter it's voluntary or compulsory, their level of concerns seemed to be heightened. Also, male teachers were more concerned and interested in STEAM education compared to female teachers. This result calls for further research on underlying reasons for gender differences. Also, teachers with more than 16 years of teaching experiences were more concerned than teachers with less than 5 years of teaching experiences. This result illustrates that STEAM education requires complicated and complex teaching knowledge and competences in which novice teachers might have difficulties to try such challenging innovation.

Keywords: *stage of concerns, Concerns-Based Adoption Model (CBAM), teacher experience*

TEACHING BIODIVERSITY ONLINE AMID THE COVID-19 PANDEMIC: MUSEUM EDUCATOR'S NEW PRACTICES AND SELF-EFFICACY

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ABSTRACT

How does a natural history museum keep engaging the public online amid the COVID-19 pandemic? Based on a case study conducted at the Beaty Biodiversity Museum, Vancouver (www.beatymuseum.ubc.ca), this presentation focuses on museum educators' efforts to digitally transform their practice and their self-efficacy for digital communications with the public during the process. This presentation introduces the COVID-19 induced adaptations that the Beaty Museum has implemented for its educational programs. It highlights some of the museum's new online educational offerings, such as the Beaty@Home weekly tours and the Online Beaty Box Adaptation Exploration, that have helped to engage the public during and after the museum closure. This presentation also shares museum educators' stories and insights on their efforts to fulfill their educational missions and goals during the COVID-19 crisis, as well as the key lessons learned from Beaty's experience in supporting educators in building self-efficacy for teaching online. From this presentation, participants will grasp an overview of the challenges Beaty faced during the pandemic and the potentially transferrable teaching techniques and strategies their educators have used. Participants looking for safe, cost-efficient fieldtrip alternatives will find the online program offerings introduced in this presentation relevant. Regardless of their specialized fields and current affiliations, participants can receive an encouraging message that they and their fellow educators can exercise control during these uncertain times and continue to achieve educational missions with creativity and perseverance. Participants are welcomed to share their stories and comments in the anonymous guest book embedded in the poster.

Keywords: *museum education, distant learning, public program, school program, self-efficacy*

EMPOWERING THE GLOBAL COMPETENCE ABILITY OF STUDENTS THROUGH AUTOTUTOR

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ABSTRACT

Global Competence is one of the most essential abilities in 21st century citizens should acquire. The Organization for Economic Co-operation and Development has included the assessment of the Global Competence under the Programme for International Student Assessment in 2018. The assessment covers four assessment dimensions, which include four types of knowledge, Values, Attitudes, and Skills that are related to global competence. This study employs the dialogue-based intelligent tutoring system (Autotutor) as a teaching tool to develop teaching materials to investigate whether the intervention of the Autotutor will effectively improve students' global competence abilities. The one-group pretest-posttest design was used among eighth (8th) and ninth (9th) graders with a total of 73 participants. The teaching tools were eight sets of global competence materials developed with the Autotutor, and the online assessment system of global competence was used as a measurement tool to analyze students' learning outcomes. The results of the paired sample t-test showed that students' learning outcomes were significant differences ($p<0.05$), and the high-level group (top 27%) did not perform significantly better after the intervention; however, the overall performance of low-level-group (bottom 27%) did improve significantly ($p<0.05$). Furthermore, after the intervention, the two dimensions, engage in open appropriate and effective interactions across cultures (the third dimension), and take action for collective well-being and sustainable development (the fourth dimension) were significantly improved among all students. In conclusion, teaching students' Global Competence via Autotutor is effective, especially the students with less well, in this particular study. Further discussion is required.

Keywords: *global competence, intelligent tutoring system, autotutor, computerized assessment*

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ENHANCING STEM STUDENT ACADEMIC SUCCESS: THE VALUE OF A MULTI-FACETTED APPROACH IN AN AUSTRALIAN UNIVERSITY

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ABSTRACT

This poster presents the design and rationale of a multi-faceted approach to STEM support for learning used at an Australian university. Co-curricular STEM academic support has contributed to improvements in student engagement and outcomes. This university-wide program has received national and international acclaim for enhancing the learner experience and draws upon a strong theoretical basis in its design. The practices are presented so others can potentially adapt ideas to their own contexts. Student support at this university applies theories of student engagement, learning development approaches and learning communities to improve student outcomes. It uses a complementary suite of approaches, including online learning resources, dropin support in a social learning environment, group support and individual consultations, to suit the diverse needs of students. It is delivered by a team of specialist STEM Educators and over 100 volunteer student peer leaders, who offer STEM support across the university. The support has been particularly valuable for students entering higher education for the first time and it has helped to enhance student success and improve retention. The scaffolded transition into university develops academic skills; bridges gaps in knowledge, understanding and skills; and helps to build confidence. The program is data-informed, integrated with other student support services and coordinated centrally through a team of staff who are embedded within the faculties.

Keywords: *STEM, academic support, peer learning, support for learning, student success*

STEM STUDENT EXPERIMENTS: EXPERIENCES AND LEARNINGS IN THE COVID-19 PANDEMIC

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ABSTRACT

The COVID-19 pandemic has provided an opportunity out of necessity to develop and implement a multitude of learning models: hybrid, blended, hyflex, etc. Each of these models presents similar properties, wherein a portion of the students are tuning into the lesson online, while a smaller number of students attend lessons in-person. This change in learning environment has presented a particular challenge for STEM student experiments. Experiments are evidence-based and common activities that science teachers use to ensure that students are connecting conceptual understanding with practical application. The COVID-19 pandemic has highlighted an inequitable practical learning experience between remote and in-person students. This poster presentation is a summary of teaching activities and lesson plan structures that I have used in this challenging learning environment, to ensure that my students have a well-rounded, baseline understanding of experimental procedure, data analysis, and error analysis. Students are placed in "Peer Pods" that consist of one in-person student and two-three online students while the in-person student conducts the experiments. Using a quasi-experimental pre-post research model, I compared the effectiveness of Peer Pods through measurements of students' test scores, grade averages, and student engagement level. I identified that there is a positive correlation between individual Peer Pods and test scores and assessment averages which equals or succeeds that of pre-COVID in-person learning. Synthesizing my findings, I discuss the role of Peer Pods within the classroom environment.

Keywords: *STEM, education, remote learning, hybrid learning, experiments, practicals, science instruction, secondary school science, high school science, science instruction*

EXPLORING LEARNING PROCESSES IN YOUNG ROBOTICS EDUCATION STUDENTS THROUGH EYE-TRACKING

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ABSTRACT

Robotics education (RE) provides students with hands-on minds-on opportunities that improve computational thinking and foster interest in STEM as they design, construct, and program robots. Robotics activities have gained traction as an integrative approach for teaching STEM concepts and skills to young learners (Khine, 2017). In 2018, the Ministries of Education in BC and Saskatchewan announced that robotics activities would be introduced into K-12 curriculum (Kozar, 2018; Wadhwani, 2018). However, there is a lack of research to show how RE affects students' learning, especially for young children. The present study uses head-mounted eye-tracking to explore how children process information during robotics activities, and how their processes change over six months as they progress through a robotics program. Elementary school students (aged 6 to 8) enrolled in a local BC after-school program were recruited to wear eye-trackers during their learning activities. Metrics established in prior research, such as fixation duration, fixation count, and transitions between areas of interest, are used to measure processing time and cognitive load (Lai et al., 2013; Poole & Ball, 2006). Longitudinal changes in these indices can provide evidence for addressing if and how robotics activities improve children's learning processes (van Merriënboer, Kester, & Paas, 2006; Zu, Hutson, Loschky, & Rebello, 2018). Exploration of gender differences will also be presented. This study is the first to use eye-tracking to study the impact of RE, and our presentation will demonstrate how one can make use of eye-tracking gaze data in RE research. In addition to informing further research, our study may help educators and policymakers better understand how RE can benefit children's learning and its potential in early educational curriculum.

Keywords: *robotics education, STEM, eye-tracking, learning processes, cognitive development*

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THE INTERSECTION BETWEEN MATH AND SCIENCE REASONING IN ELEMENTARY EDUCATION: INITIAL FINDINGS OF A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Along with their STEM categorization, math and science education share many of the same pedagogical challenges. Reasoning, specifically logical thinking, is a critical component in the development of both math and science proficiency. Though they are often studied independently and under the guise of independent terminology, reasoning is a multidisciplinary competency. It has been theorized that reasoning may be a possible intersection point for math and science education (Pisesky, McFeetors & Kim, 2018). As such, a categorical literature review was deemed necessary to identify critical commonalities and key differences between math and science reasoning. A systematic search and screening process (Auslander et al., 2019; Campbell, Boyle & King, 2019) produced 42 literature articles pertaining to the empirical study of math and science reasoning. Articles are currently being read and analysed, but early indications have already revealed several topics for critical discourse. First, there is very little direct statement of reasoning or quotation from students themselves- it is most frequently measured indirectly through selfevaluation, achievement or using reasoning ability metrics. Second, we have noticed abundant differentiation between math and science in the terminology used to describe similar thought processes. Finally, we have noted science articles are more likely to reference mathematical reasoning than vice versa. As we move towards completion of our review, our findings will be more complex and concrete. Overall, we hope our review will jumpstart a conversation on how reasoning may be used as an interdisciplinary tool in elementary education.

Keywords: *logical reasoning, mathematical reasoning, scientific reasoning, systematic review, elementary education*

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TRANSFORMING PUBLIC LIBRARY PROGAMS INTO STEM-RELATED INITIATIVES: CREATE, ASSEMBLE AND PLAY

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ABSTRACT

This poster highlights the innovative roles of a new public library in facilitating STEM-based initiatives for young learners. This poster centers on successful STEM programs in a public library during the first twelve-month operation of the library. This poster seeks to share the planning and implementation process of STEM-based programs that made this public library into a main hub for nurturing STEM skills and developing lifelong learners. Additionally, this also aims to reveal how this library utilizes its resources to transform traditional programs into more engaging STEMrelated initiatives. What is hopeful to share is the experience of the library in organizing STEM-programs which will enable participants gain understanding and practical approach on how STEM could further complement the needs of young learners outside of the traditional classroom-based setting. Specifically, participants will witness several innovative STEM-activities implemented in a public library. Second, they will learn to determine useful and valuable resources to support the needs on STEM particularly how this can be integrated in K12 curriculum setting. Lastly, they will identify specific STEM-practices and collaboration that are beneficial to engage young learners in the STEM learning experience. Along with this, the poster reveals the latest survey results on young learners' expectation and recommendations in the future STEM programs in the library.

Keywords: *STEM, informal learning environments, public libraries*

RAISING THE ENGAGEMENT BAR IN THE TIMES OF COVID-19: PUSHING THE LIMITS OF SCIENCE EXPERIMENTS THROUGH TECHNOLOGY

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ABSTRACT

This poster demonstrates how a Deliberate Pedagogical Thinking with Technology Framework can guide educators in increasing student engagement in online and faceto-face STEM courses at both secondary and post-secondary levels. This framework has been especially useful during the COVID-19 pandemic when many STEM courses moved online and educators had to help students develop science experimentation skills remotely. We illustrate the power of this framework with three examples: (a) Smartphones as the tool for experimentation (e.g., Phyphox, Physics Toolbox, Video Analysis); (b) Slow-motion video experiments with the state-of-theart technology; and (c) Video Analysis with freely available Tracker software. We discuss the benefits, challenges, and technical details of these tools for designing and implementing in-class and online science experiments and demonstrations. We show how these technologies can turn traditional science demonstrations from mere entertainment to the effective means for science learning for both face-to-face and online courses. We also describe a novel and unique experimental set-up – a Slow Motion Chamber, which we have designed and used as a demonstration tool in large introductory physics lectures, and in online science methods courses for secondary students and future teachers. Finally, we discuss a more accessible version of these experiments – implemented with the slow-motion feature available in many contemporary smartphones already in use by the teachers and students. This poster challenges the common notion that online STEM education cannot engage students in hands-on experimentation and calls on educators to reconsider how smartphones already available to students can become instruments for scientific inquiry.

Keywords: *fast-speed camera, Phyphox, Physics Toolbox app, smartphone technologies, slow-motion videos, science experiments, science demonstrations, tracker video analysis*

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EFFECT OF KAMISHIBAI ON PEOPLE’S AWARENESS OF BIODIVERSIY CONSERVATION: AN EMPIRICAL STUDY OF THE TEACHING MATERIAL WITH A ZOO ANIMAL MOTIF

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ABSTRACT

In Japan, people’s awareness of biodiversity conservation is still low. Since the framework for biodiversity conservation is abstract and complex, the public is unclear about their role in it. The purpose of this study was to develop zoo animals’ kamishibai (a paper theatre) as teaching material, to increase awareness among people to easily understand biodiversity conservation issues. In this study, kamishibai was created for a polar bear, as a case animal, by three undergraduate students and demonstrated for visitors at the Tennoji Zoo in Osaka in 2018. The kamishibai was performed in front of the enclosure of a 4-year-old male polar bear named “Ichi-chan”, who is also the main character of the story. After the performance, the audience’s response (74 persons) to a questionnaire survey revealed the following visitor reactions: 1) It was good to watch the kamishibai (89.2%); 2) I felt a sense of affinity with the animal (89.2%); 3) I understood the effects of global warming and the threat to endangered species (67.6%); and 4) I need to practice environmentally-friendly behavior by (a) using things with good care for a long time (64.9%); (b) turning off electricity when not needed (68.9%); (c) reducing waste (63.5%); and (d) avoiding food loss (64.9%). Watching kamishibai at the zoo helped more than 60% of the audience understand biodiversity issues (global warming and endangered species) effectively, while others remained unresponsive. Although this kamishibai helped a majority of the zoo visitors understand biodiversity conservation, more ways are needed to motivate people to do their part in resolving global environmental problems.

Keywords: *biodiversity conservation, public awareness, kamishibai, zoo animal*

PREPARING TEACHERS FOR ROLES IN STEM PROJECT-BASED LEARNING

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ABSTRACT

The poster will provide information on a research project exploring teachers' role in secondary students' STEM projects. To prepare teachers to be successful in mentoring and supporting students in STEM project-based learning (PBL), it is important to understand their roles in the process. PBL and the problem solving and critical thinking it involves address a broadly recognized need for emphasizing higher order skills (Krajcik, McNeill, & Reiser, 2008; Lesh & Zawojewski, 2007). Students and teachers at a STEM PBL school were interviewed and observed working together on projects. These data informed our understanding about preparing teachers to teach in a PBL context, leading to recommendations such as providing preservice teachers with authentic experiences, celebrating failure as part of learning, explicitly teaching about PBL pedagogy, and stressing the importance of caring relationships, especially in secondary preparation programs. We focused on the learning environment in terms of teachers' challenges and supports as described by Shernoff et al. (2016) as the "challenges, tasks, activities, goals, structures, and expectations intended to guide student action or thinking" and "instrumental, social, and emotional resources made available to help students reach environmental challenges" (p. 52). The specific focus of the presentation is to communicate findings and recommendations regarding teachers' roles in STEM PBL learning. Participants will learn about findings regarding teachers' engagement in the STEM PBL projects and be engaged in conversation about best practices for preparing secondary teachers for a role in STEM PBL.

Keywords: *STEM teacher preparation, STEM learning, PBL*

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TEACHING SCIENCE BEYOND CONTENT: INTRODUCING THE CONTEXT DEPENDENCE OF SCIENCE TO FIRST-YEAR SCIENCE STUDENTS

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ABSTRACT

Context influences science. There is, however, little research on how to teach undergraduates about the context-dependence of science. This project examines how students' perceptions of science change after taking a course with activities examining how context impacts science (such as funding, nationality, gender, ethnicity and discipline) interspersed amongst other activities. The course opens with an in-class activity wherein students trade and discuss cards, each with a claim about science. Students then complete an at-home survey where they indicate their level of agreement with each claim. At the end of the course, students complete a post-survey and participate in a reflective activity to discuss the claims for which their perspective has changed. Data from the at-home survey and the in-class activities were analyzed for changes in student perceptions. The largest changes in student views were on topics related to the heterogeneity of the scientific community. For instance, 25% of students shifted from 'disagree' to 'agree' on "the growing number of women in science is changing the choice and definition of questions." Interestingly, during the reflective in-class activity, few students choose to discuss claims related to diversity and inclusivity, opting instead to focus on other less- sensitive claims. This project suggests that student engagement with material on the context- dependence of science alters their perception of the scientific community. In particular, students shift to view a heterogeneous research community as valuable, though are not comfortable openly discussing topics related to equity, diversity, and inclusivity in the classroom.

Keywords: *nature of science, diversity*

A CASE STUDY ON USING STEAM IN PHYSICAL EDUCATION FOR UNIVERSITY STUDENTS: THE LEARNING PROGRAM "TEACHING THROWING"

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ABSTRACT

This research aims to identify the changes in the university students' understandings of "throwing", which includes their knowledge and images based on a STEAM learning program which we constructed. For three decades, there has been a decline in children's abilities to throw, which is one of the several serious problems in Physical Education in Japan. Although the new Course of Study of Physical Education in elementary schools mentioned that they are creating opportunities to throw activities in Physical Education, young teachers tend to have not confidence to teach throwing to children. According to these trends, we developed a STEAM program for young female students (N=10) who want to be kindergarten teachers. The contents of the program were; self- and peer-evaluation of throwing motions using VTR (science/technology/mathematics), making objects to throw with considering the features of materials(engineering/art and design), observing human body structures using skeleton and muscle models(science), and activities of throwing using what they learned(STEAM). Before and after learning, students answered a questionnaire comprised of four categories about self-awareness of throwing and drew image maps about "throwing". The results showed that learning with this program, students' images of "throwing" became positive and the concept of "throwing" was understood in depth. Students gained more self-confidence to teach "throwing". From their final reports, it was shown that students did not know STEAM education before, but are now aware of the meaning of these cross-subjects learning. This research is supported by JSPS KAKENHI Grant Number JP 17H01982.

Keywords: *STEAM program for university students, teaching throwing, Physical Education*

TWO GOATS AND A NEW CAR: HOW STATISTICAL MISCONCEPTIONS ARE SPOKEN WITHOUT BEING HEARD

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ABSTRACT

This study sought to explore how student and instructor discourse in postsecondary statistics education embodies the complex boundary work students engage in at the intersection of their pre-existing and the normative statistical frameworks (Ackerman, & Bakker, 2011). Using a theoretical framework of Cultural Historical Action Theory (Akkerman & Bruining, 2016), this poster will present the results (forthcoming) of a discourse analysis (Gee, 2015; Ribeiro, 2006**)** of post-secondary students' talk in an introductory statistics course at the Southern Alberta Institute of Technology, a Polytechnic. The analysis identifies elements of student discourse which, as a result of lexical ambiguity (Kaplan, Fisher, & Rogges, 2009), conceal non-normative statistical conceptions (Huck, 2015). Introductory statistics is amongst the most often failed courses at this institution, with a D/W/F rate in excess of 30% during most years, and is an important gatekeeper to diploma completion. Data was collected in the form of transcripts and field notes of student (n=40) and instructor (n= 2) interactions, and will be used to explore differences in how students and instructors use statistical terminology, as a means of both conveying understanding and permitting students' agentive voice, thus facilitating transformative boundary work. This suggests an both an explanation why student intuitions about scenarios like the Monte Hall problem are so resistant to correction, as well as pedagogical techniques which may assist students in crossing the boundary between their pre-existing intuitions and normative statistical techniques.

Keywords: *misconceptions, discourse, aleatory, statistics education, boundary work, CHAT*

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INSERVICE TEACHERS' LEARNING TRAJECTORIES TOWARDS INTEGRATED STEM EDUCATION

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ABSTRACT

The Manitoba Science Curriculum includes *design process* activities where students must plan, design, build, and test prototypes and/or consumer products, through a process that incorporates aspects of science, mathematics, engineering and technology, with some consideration for environmental impact (Manitoba Education and Training, 2000). As part of a combined post-degree undergraduate and graduate course we have been co-teaching for the past three years, we attempt to guide K-12 in-service teachers to develop integrated, authentic STEM projects grounded on an eco-critical approach (Lupinacci & Happel-Parkins, 2017), which differs from market-driven approaches to STEM education in that strong environmental and social justice aspects are emphasized in all stages of the design process activities. This qualitative study explores students' learning trajectories in this course, through content analysis of students' final STEM projects, which they brought to class on day one and worked on daily until the end of the course, modifying it as needed to incorporate aspects of an integrated, authentic and ecocritical STEM project. We focus particularly on the challenges and achievements of students, as indicated in their final projects when compared to their original one, as well as their own rationale for the modifications they did to their projects. Results indicate students' self-perception of their pedagogical strengths influence their project revisions both qualitatively and quantitatively, and grade level has a major impact in the nature of the integration of the STEM disciplines in their projects.

Keywords: *integrated STEM, teacher preparation, eco-critical framework*

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PERCEPTIONS OF THE ROLE OF ADVANCED MATHEMATICS KNOWLEDGE IN THE DEVELOPMENT OF MATHEMATICAL KNOWLEDGE FOR TEACHING

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ABSTRACT

Advanced coursework in mathematics is pre-requisite for admission into most teacher education programs. This requirement does not exist without reason. Indeed, the secondary mathematics curriculum is deeply connected to many abstract concepts studied in post-secondary mathematics (Conference Board of the Mathematical Sciences, 2012). Unfortunately, the siloed structure of future teachers' mathematical knowledge for teaching may not allow for such connections to be developed (Zazkis & Leikin, 2010). Indeed, mathematicians are responsible for the mathematical content knowledge of future teachers, while teacher educators are responsible for situating mathematics content knowledge in the context of teaching. Using a case study methodology and semi-structured interviews (Merriam, 1988), we explore the perceptions of five secondary mathematics teacher candidates in response to the role advanced mathematics knowledge plays in their development as teachers. Results revealed that participants viewed their advanced mathematical knowledge as valuable in shaping their beliefs around mathematics, but expressed little value towards post-secondary mathematics content in teaching the secondary curriculum. This study provides important information on how a post-secondary degree in mathematics impacts the ways prospective secondary teachers perceive and understand secondary school concepts and how connections between these two bodies of knowledge influence their pedagogy. Moreover, this study has implications for ways mathematics teacher educators might explicitly support future teachers' understanding of secondary and post-secondary mathematics, so that this new integrated knowledge might better inform their pedagogy. Results suggest that teacher educators might want to consider the ways in which they draw upon teacher candidates' advanced content knowledge during teacher education.

Keywords: *mathematical knowledge for teaching, pedagogical content knowledge, advanced content knowledge, teacher education*

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ENVIRONMENTAL EDUTAINMENT: HOW TO DESIGN FOR 'FUN'

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ABSTRACT

Education and fun are not often synonymous. Yet, the term edutainment is often used to describe this exact situation. Grounded in Vygotsky's role of play and the zone of proximal development, this paper expands upon Malone's initial inquiry of designing fun in computer games (1980, 1984) and includes modern inputs from industry and designers of entertainment media (Koster, 2014). By exploring how to 'design for fun', we can further discourse how to apply design thinking for effective learning. In particular, this poster will present the methods used by graduate students designing an 'edutational' game. During a 13-week graduate study course, a small group of 6 graduate students explored the processes of designing an edutainment game. They were presented with an open creative task to 'design for fun' but also to create learning opportunities for players focused on environmental education. The results of several weeks of research, through the design thinking process and rapid prototyping *Princess Pretty Tum Tum* game was created. During this time, the students played games and developed several interactive experiences, while framing their design around environment education. This poster explores the design process of graduate students creating a prototypical 'edutational' game. Edutainment can have a significant role beyond 'just educational' or 'just entertainment' if proper attention is given to the design. Focusing on designing for fun and play is important as "fun is just another word for learning".

Keywords: *design process, agile methodologies, Vygotsky, environmental education, game, fun*

MIIGO: DESIGNING AN INTERACTIVE COMPANION TOY FOR CHILDREN WITH AUTISM

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ABSTRACT

Graduate school is not typically known for collaborative real-world prototyping projects. Often graduate school students work independently on their own project. However, in a graduate school of digital media, students work in teams on real-world client briefs attempting to solve a problem. For this case study, six graduate students were identified with a challenge to design an interactive companion toy (Miigo) for children with autism that not only incorporated physical features (huggable) but also digital features (emotion recognition from YouTube, visual schedules and reminders, and educational games/apps). The client wanted to help children on the autism spectrum by creating this companion toy to improve communication skills, encourage creativity and playfulness, and increase social skills. This presentation will explain features of their design process over 13 weeks and the ability to rapidly prototype using agile spring methodologies for a physical and digital toy. By sharing the student process of ideation to development, this project not only demonstrates the possibility for real-world projects using project-based learning methods in graduate school, but also interdisciplinary abilities of STEM in graduate school. Also, this presentation will demonstrate the effective use of agile methodologies and how it can be used in STEM and graduate education.

Keywords: *Project-Based Learning, design process, agile methodologies*

THE EFFECT OF A SCIENCE AND TECHNOLOGY HUMAN RESOURCE DEVELOPMENT PROGRAM ON HIGH SCHOOL STUDENTS' MOTIVATION IN SCIENCE LEARNING

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ABSTRACT

Developing excellent human resources for science and technology is a required issue in every country. Students in talented education programs sometimes must solve difficult tasks, so it is important to maintain and improve their motivation. However, many previous studies only analyzed average motivation changes, failing to consider the interaction between initial motivation and educational effects. This study aimed to examine the influence of the "Oita Super Science Consortium's program (OSS program)" on participants' motivation in science learning, focusing on the interaction between preparticipation motivation and the educational effect of the program. The OSS program is a science and technology human resource development program developed in Japan. Participants in the OSS program are highly motivated high school students. We used pre-participation and postparticipation two-wave panel (two-times) data of 208 students. Firstly, we confirmed that the OSS program enhanced participants' positive emotions towards science observation and experiments. Secondly, based on the cross-lagged effect model, we found that students with initially 'deep interest' in science (thought deepening-based orientation factor) tended to have reduced 'surface interest' in science (experience-based orientation factor) subsequently. While students with initially 'surface interest' in science showed decreased 'deep interest' in science after program participation. The results implied that students' high-quality preparticipation motivation could be an important condition to benefit from talented education programs. We considered the results from the viewpoint of the "Matthew effect" and discussed the mechanism. We also discussed educational methods for students who did not have high initial motivation before program participation.

Keywords: *human resources for science and technology, interest, motivation*

EXPLORING INTEGRATED STEM: CROSS-CUTTING THEMES IN SCIENCE, ENGINEERING, AND MATHEMATICS PRACTICES AND EPISTEMOLOGIES

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ABSTRACT

In society today, educating young people in the disciplines of science, technology, engineering and mathematics (STEM) is seen as important for maintaining technological progress and economic growth. One possible avenue to improving education in these fields is teaching them in an integrated manner. Teaching integrated STEM (iSTEM) has the potential to improve students' understanding of the connections between these disciplines and enhance student outcomes through engaging in authentic contexts. One proposed approach toward iSTEM in K-12 education has been through the integration of disciplinary practices. In this work we conducted a document analysis of the Next Generation Science Standards (NGSS), Common Core State Standards for Mathematics (CCSSM), and the American Society of Engineering Education (ASEE) standards for K-12 education to identify cross-cutting themes among the practices. The themes identified included: communicating, investigating, modeling, using tools, working with data, making sense of problems or phenomena, solving problems, and evaluating ideas or solutions. After identifying these themes, we used disciplinary epistemologies to critically examine how these themes may arise in an iSTEM context and identified potential promises and perils of teaching iSTEM. Promises include reducing learning standards, improving diversity and inclusion, and challenging siloed disciplinary knowledge. However, perils exists in the potential for conflating or neglecting important disciplinary practices. This presentation will engage participants in a critical examination and discussion about the affordances and limitations of iSTEM. We will solicit feedback from participants about the cross-cutting themes identified and their potential role in K-12 classrooms.

Keywords: *integrated STEM, practices, science education, mathematics education, engineering education, epistemology*

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UNCONVENTIONAL SCIENCE PROGRAMMING IN A TREATMENT FACILITY IN CANADA: SUCCESSES, CHALLENGES, AND OPPORTUNITIES

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ABSTRACT

Learning STEM outdoors can be a powerful tool for mitigating some of the stress associated with understanding STEM subjects, while promoting academic achievement for marginalized youth. Specifically, high school science subjects are notorious for being challenging, stressful, and requiring additional resources (González et al., 2017; Mallow & Greenburg, 1983). In addition, marginalized youth (e.g. those with low-socioeconomic status or those racialized as Black) face several barriers to passing high school science, including: little cultural relevance (Gay, 2010; Ladson-Billings, 1995); minimal exposure to science fields; minimal representation; and a lack of resources (Emdin, 2010). These barriers are also present when it comes to access to quality STEM education in Canada (Duodu et al., 2017). Consequently, numerous research initiatives explore fostering STEM engagement with at-risk youth. Yet, little research exists on STEM programming for youth who are recovering from addictions and are in schools in treatment facilities. I address this gap with a case study on the unconventional STEM programming offered–through a school in Canada–to youth in a treatment facility. The program takes an interdisciplinary approach to learning and uses outdoor experiences to reap therapeutic benefits. Documents were analyzed, staff members were interviewed, and the site was observed in a field study. Based on preliminary findings, being in the natural world helped students to learn STEM.

Keywords: *science education, STEM, alternative school, marginalized youth, outdoor education*

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STEM LEARNING ECOSYSTEMS: MEANINGFUL COLLABORATIONS THAT SUPPORT STEM EDUCATION GOALS

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ABSTRACT

STEM Learning Ecosystems provide the architecture for cross-sector learning, offering all young learners access to STEM-rich, hands-on and engaging learning environments and activities so they can develop important 21st Century skills and engagement in science, technology, engineering and math throughout preK-16. Strong STEM Learning Ecosystems feature dynamic collaborations among formal education institutions including out-of-school time programs, STEM expert institutions (such as museums, science centers, institutions of higher education and STEM professional associations), business and the private sector, community-based organizations, youth and families. Successful initiatives include tech camps and programs, career networking events, community science festivals, professional development workshops for teachers, early childhood educators, STEM professionals and Science Communicators and STEM programs specifically for girls, indigenous and under-served audiences. This poster will feature the international STEM Learning Ecosystems Community of Practice led by the Teaching Institute for Excellence in STEM (TIES) and will highlight two very different Communities of Practice: Symbiosis in British Columbia, Canada and North Country in New York State, USA. Included will be each Ecosystem's successful initiatives and stakeholder collaborations, collective impact statistics, governance models, and communication strategies and links. Information will be provided on how a school, museum, business or other entity could initiate a Community of Practice as well as contact information for the presenters. The goal is to strengthen and improve access to STEM education opportunities worldwide through the growth of Communities of Practice and international collaborations.

Keywords: *cross-sector learning, 21st century skills, back-bone organisation, collective impact initiatives, multi-organisation governance models*

Relevant online resources https://stemecosystems.org/

https://www.symbiosis.ca/about-us.html

http://www.northcountrystem.org/

PARENT-CHILD ENGAGEMENT WITH MATHEMATICS AND SCIENCE IN INFORMAL ENVIRONMENTS

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ABSTRACT

This study investigated parent-child interactions in scientific and mathematical reasoning in the context of a family math and science day event. The study employed an interpretive case-study approach, in which 30 Parent-Child dyads were invited to engage in a variety of interactive tasks that challenged children in manipulating materials to pose and solve mathematical or scientific problems. Parent and child interactions and follow-up discussions were video recorded and children were asked to explain their reasoning in think-aloud protocols. Following the activity, parents participated in a short interview about their experiences as parents, including what they noticed about their child's learning during the activity and the strategies they used to support their child's learning. Data were analysed inductively to understand the emergent themes of parent-child interactions, what parents say and do, in supporting scientific and mathematical reasoning. Our results highlight three forms of parent-child interactions as children engaged in hands-on problem solving. These include: 1) verbal interactions such as silent interactions, task explanations, and instruction translations to a home language; 2) dispositional or mindset interactions offered to encourage and keep children on task and engaged; and 3) parental actions that include parallel play (parent and child independently solve tasks) and annotated play (parents announce play-by-play next steps). Our study provides valuable insights about how parents interact with children in facilitator-led informal activities and what parents view as their role in regards to supporting their child's math and science learning, particularly at events such as a family math and science day.

Keywords: *parent-child interactions, informal learning environments, interactive activities, mathematics, science*

CO-DEVELOPING STEM LITERACY AND 21st CENTURY COMMUNICATIVE SKILLS THROUGH "CONCEPT AND LANGUAGE MAPPING" AND PREMISE-REASONING OUTCOME (PRO) COGNITIVE SCAFFOLDING

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ABSTRACT

This design-based research study demonstrates how international students' language and cultural knowledge can be integrated into their learning of STEM literacies in a higher education where English is dominant. This is important for the international students as the curriculum innovation enhances their STEM related knowledge and equips them to engage in the contentious social scientific issues democratically. According to Statistics Canada (2017), the number of international students in higher education has increased at a higher rate than that of Canadian students. These international students come to a Canadian university with a wealth of knowledge and experience that is oftentimes overlooked. Drawing on Lemke's (1990) "thematic patterns" theory, we piloted "Concept + Language Mapping" (CLM) (He & Lin 2019) and Premise-Reasoning-Outcome (PRO) cognitive scaffolding (Tang, 2015) in a first-year university biology classroom which recognize and extend students' prior knowledge. The study undertook two stages: first, using a naturalistic observation, we identified the lessons where language and content could be further integrated. In the quasi-experiment stage, we designed and delivered content-language integrated lessons that enabled students to apply their science knowledge to generate well-reasoned arguments. Specifically, we measured how students used scientific concepts in order to discuss contentious social scientific issues (e.g., genome editing). Through our analysis, we argue that integrating content and language in STEM education are critical for the international students as it not only enhance their STEM related knowledge but also facilitate them to become a responsible global citizen on contentious social scientific issues in the 21st century.

Keywords: *STEM literacy, Concept + Language Mapping" (CLM), Content and Language Integrated Learning (CLIL)*

DEVELOPMENT AND VALIDATION OF A SELF-EFFICACY QUESTIONNAIRE FOR YOUNG CHILDREN IN ROBOTICS EDUCATION

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ABSTRACT

Robotics education (RE) has become an emerging subject field because it involves all aspects of STEM and also can be fun for Children. Some researchers have hypothesized that RE at a young age can be particularly beneficial for girls by decreasing the gender stereotypes in STEM. One important aspect of the gender gap is lower self-efficacy in STEM for female students. Currently, there is a lack of RE self-efficacy measure for young children, particularly 6-8 years old, which prevents measuring the benefits of RE. The primary purpose of this study is to develop and validate the "Self-Efficacy Questionnaire for Robotics Education" for children aged 6-8. This questionnaire is developed based on Bandura's *Guide for Constructing Selfefficacy scales* (2006) and is designed to assess how children feel about their competence in robotics activities. Our secondary purpose is to compare children's self-efficacy between girls and boys. The psychometric properties of the measure will be evaluated through internal consistency reliability, content validity, and factor structure. The measure will be a useful tool for STEM researchers to assess the development of RE self-efficacy in young students. The findings obtained from this study will provide insights into whether girls are equivalent to boys in their RE self-efficacy if they are exposed to RE at an early age. Additionally, our findings may be useful for educators and policy makers to consider the integration of RE in K-12 curriculum.

Keywords: *robotics education, self-efficacy, gender difference, young children, test development and validation*

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TEACHER-MADE VIDEOS AS PROFESSIONAL DEVELOPMENT FOR STEM TEACHERS

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ABSTRACT

Research in education contains ample literature on the use of videos as a form of professional development for teachers (Borko et al., 2011; Brouwer, 2011; Gaudin & Chalies, 2015; Karsenty & Sherin, 2017; Tekkumru-Kisa & Stein, 2017; Tembrevilla & Milner-Bolotin, 2019). There are video clubs, where teacher-participants analyse videotaped classroom instruction in the context of teaching-learning process (van Es & Sherin, 2008, 2010). Videos are used for specific STEM subjects like simulations and animations to make abstract concepts visible (Wieman et al., 2008; Wieman et al., 2010). Less frequent in the literature are teacher-made videos used as a form of professional development. As the trend of integrating technology in STEM education expands with the emergence of newer digital tools, there is an immense challenge for STEM teachers to deliberately use technology to further instruction. In this presentation, we will first present the reasons behind science teachers-designed educational science videos using the perspective of funds of knowledge (González et al., 2005). Second, we will provide initial evidence showing that science teachers who make videos using the perspective of funds of knowledge of their students and students' immediate community improve their technological, pedagogical, and content knowledge (TPACK) (Koehler et al., 2013). Third, we will discuss supporting evidence pointing that practiced-based type professional development, like science teachers making their own videos, has potentials to be an effective professional development not only in science but also in other STEM-related subjects.

Keywords: *teacher-made videos, professional development, funds of knowledge, STEM, TPACK*

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DESIGNING AN INTEGRATED STEM SEMESTER FOR PRE-SERVICE ELEMENTARY TEACHERS

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ABSTRACT

Teacher educators in an undergraduate elementary teacher certification program at a large university in the United States redesigned the program to integrate STEM learning across multiple courses. During this Integrated STEM Semester, typically taken during the fifth semester of college, pre-service teachers (PSTs) enrolled in mathematics content, mathematics methods, science methods, instructional technology, and practicum courses. Three cohorts of PSTs participated in the Integrated STEM Semester during each of two semesters (*n=67 in* Semester 1; *n=66* in Semester 2). Instructors from each of the courses collaborated to design integrated learning experiences and projects that spanned multiple courses. The design process was documented in meeting notes, reflections, and artefacts of teacher educators' work. Additional data sources focused on student impacts (artefacts of PST work, reflections, observations, surveys) and informed the iterative design of the Integrated STEM Semester. During the first iteration, coding and robotics were incorporated as a cross-cutting STEM theme and engineering design was added in the science methods, mathematics methods, and instructional technology courses. In the second iteration, a cross-cutting STEM module focused on sustainability and flood mitigation was added. The Integrated STEM Semester design also included four projects spanning multiple courses, with opportunities for PSTs to work both collaboratively and individually, and connect work in the university classroom with elementary practicum experiences. This poster presentation will share this programmatic approach for preparing elementary teachers to teach integrated STEM and will highlight design challenges and opportunities that might benefit other programs interested in integrating STEM experiences for elementary PSTs.

Keywords: *elementary, integrated STEM, preservice, teacher education*

CONCERNING CURRICULUM: TEACHERS' PERSPECTIVES ON A NEW SENIOR PHYSICS CURRICULUM DOCUMENT IN CANADA

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ABSTRACT

Provincial governments often develop Canadian science curricula for teachers with the assumption they will cover material as intended. However, teachers are not robots, programmed to deliver curriculum, they have stories. In education, these stories have been often studied through teacher concerns, which has been part of the educational research since the work of Frances Fuller (1969). Teachers' concerns regarding curriculum have been studied in the context of science education (Albadi et al., 2019; Boergerding et al., 2013; Fischer et al., 2019; Oguoma et al., 2019; Ryder & Banner, 2013; Vocht et al., 2017) but such concerns from a Western-Canadian, secondary science context are severely understudied. This poster reports on a study investigating teachers' concerns regarding a new, provincially-developed, grade 12 physics curriculum document in one Canadian province. Semi-structured interviews with 16 teachers from across the province were analyzed using the stages of concern (SoC) framework (Hall & Hord, 1987, 2014). Findings indicate that teachers were primarily concerned with their abilities to teach this document, management and a lack of accompanying resources, and the absence of a cohesive physics education community in their province. Teachers also struggled with the amount of freedom the new curriculum document gave them in deciding what to teach. In this presentation, participants will have the opportunity to engage with these stories through teacher quotations and discuss the role of the teacher in the conception, writing, and interpretation of a new curriculum document mandated by a governing body.

Keywords: *teacher concerns, curriculum documents, science curriculum, physics education, physics teachers*

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LET'S TALK INNOVATION: DEVELOPING NEW APPROACHES TO STEM OUTREACH FOR YOUTH OF ALL AGES

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Let's Talk Science Outreach at the University of British Columbia

ABSTRACT

Science, technology, engineering, and math (STEM) fields are growing rapidly. Despite this, the majority of Canadian high school students still graduate without a senior level math or science credit. Let's Talk Science Outreach at the University of British Columbia (LTS-UBC) is a local chapter of a national, charitable STEM outreach organization. Our mission is to make science engaging and accessible for youth by delivering free, hands-on activities to schools and communities across Greater Vancouver and BC, engaging students from Kindergarten to Grade 12. LTS-UBC consistently reaches more than 20,000 youth annually, through over 30,000 interactions. This is made possible through the implementation of a diverse portfolio of programs reaching youth both inside and outside of a traditional classroom setting, with many programs designed to reach under-represented communities, including Indigenous youth and girls. After 23 years of successful outreach we have many examples of how programs can be initiated, adapted, and evolved over the years to meet the changing needs of youth today. Here we will discuss approaches to STEM outreach (including community events, symposia, rural trips, classroom activities, and mentorship programs), and the challenges we have overcome in the process. Our experience in STEM outreach will help educators to implement similar programming by discussing how to initiate collaborations with community partners, how to develop new STEM programs from the ground up, how to manage volunteers, how to form and maintain educator relationships, and how to promote professional development in STEM for educators.

Keywords: *outreach, hands-on, accessible, classroom, community, success, failure, elementary, secondary*

HONORING YOUNG CHILDREN'S THINKING AND GIVING MINIMAL PROMPTS

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ABSTRACT

The mathematics intuition and comprehension of early learners are generally underestimated (Gervasoni & Perry, 2015). Criticizing their 'wrong' solutions tends to limit their creativity and curtail their willingness to explore the unknown. Yet, discourse surrounding STEM education points to the value of both creativity and exploration in mathematics education. This presentation will illustrate how (1) retracing children's reasoning is meaningful in analyzing their thoughts and bridging the gap between what they know and what they are coming to know, and 2) giving minimal prompts provides room for children to make their own connections. I will report on one child's (age 5 years) creative mathematical thinking and our interactions, during 4 task-based interviews using WECHAT. I will detail his mathematical reasoning when provided minimal adult guidance with manipulating geometric shapes (4 triangles), number combinations (cookie problem), building patterns (tower problem), and partitioning (cutting cake) (Sakshaug, Olson, & Olson, 2002). Educators attending STEM 2020 are invited to reflect on how they might change the story in math education by (i) viewing early learners as 'math beginners' with substantive original ideas and the ability to show a range of thinking, and (ii) considering how to encourage children to elaborate their reasoning and generate significant mathematical ideas (Jung, Kloosterman, & McMullen, 2007). This presentation demonstrates what may occur if teachers remain open to understanding their students' logic and reasoning, and argues for developing STEM education in ways that values young children's authentic ideas and guides them to communicate mathematically.

Keywords: *early learners, creative thinking, mathematical reasoning*

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PANELS

COULD PRIMARY TEACHERS' SCIENCE CAPITAL HAVE AN IMPACT ON THAT OF THEIR STUDENTS?

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ABSTRACT

The ASPIRES/Science Capital project (2009-2017, Years 6-13) was a longitudinal study set up with the aim of addressing the issue of STEM career aspirations and the low uptake of science subjects by students at 16+. To-date, it has focused on Secondary/High school students, Archer (2013, 2015, 2017), and developed a 'Science Capital Teaching Approach', Godec (2017), specifically for secondary science teachers. One of their recommendations was to boost family science capital. They also reported how students lacking STEM-related aspirations at Year 5 are unlikely to develop them by Year 9 when students make their first subject choices, Archer (2013:3, 5). This research, instead, focusses upon upper primary and lower secondary (Years 5-8) to study: teachers' science capital & attitudes (rather than that from students' homes); the changes in students' science capital & attitudes as they move through the primary-secondary transition; and with the aim of linking the two, student to his/her teacher. So far, some of England's few remaining Middle Schools (Years 5-8, without phase-transition) have been surveyed (June 2019): 1. 658 students using the ASPIRES 'Dimensions of Science Capital' questionnaire and 2. their teachers' (N=18) using van Aldren-Smeets (2012, 2013)'s 'Dimensions of Attitude towards Science' instrument. Early findings, which indicate a significant dip in student science capital between Middle School Years 5 and 7 (p-value=0.002), were presented at BERA (2019). This presentation will report on-going analysis on this Middle School data but also on data to be collected (May/June 2020) from clusters of English primary schools and link-secondary schools.

Keywords: *science capital, attitudes, teachers, students, primary-secondary transitions*

THEY LEARN, WE LEARN. BUILDING A MULTIDISCIPLINARY STEM LEARNING COMMUNITY TO PREPARE PRE-SERVICE TEACHERS FOR SCIENCE TEACHING

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2. *Coquitlam School District (SD43)*

ABSTRACT

In 2017, ten faculty members from five departments in the Faculty of Science, a faculty member from the Faculty of Education and a science educational consultant at Simon Fraser University, as well as a science curriculum coordinator from the Coquitlam school district came together to address a pressing need: to improve the interdisciplinary science literacy, competency and confidence of future K-8 teachers as they teach the new inquiry-based BC curriculum. This process produced SCI 192: The Science Around Us, which was first offered in the fall of 2019 and is set to become the only science prerequisite for future students in the elementary teacher professional development program (PDP) at SFU. Although the target audience of these efforts was pre-service teachers, the various meetings, workshops, and teamwork that ensued also fostered a robust and inspiring learning community that provided unparalleled professional development for all involved. What did it take to bring this community together? How did the community foster professional growth for its members? What were the expected and unexpected roadblocks and successes? Bring your own questions and join us for a panel discussion with the developers, pedagogical consultants and course evaluator from the SCI 192 collaboration.

Keywords: *STEM education, learning community, multidisciplinary science, interdisciplinary science, preservice teachers, professional development*

HOW CAN OUTREACH FOSTER FURTHER INTEREST IN STEM AND EVENTUALLY LEAD TO CAREERS IN STEM?

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1. *Stewart Blusson Quantum Matter Institute, Programs and Careers*
2. *i-Radical, Strategic Unit*
3. *STEM Aces, Academic department*
4. *Geering Up Engineering Outreach*
5. *The University of British Columbia, Department of Physics and Astronomy*
6. *Science World, Community Outreach*
7. *University of British Columbia, Faculty of Science*

ABSTRACT

Numerous universities, colleges, and STEM-focused organizations co-create outreach activities with secondary education institutions by connecting the work-context with school-science, with the aim to inspire students and motivate them to consider a career in STEM. Although many such activities are being offered, little is known about their actual influence and outcomes. The panel speakers, with backgrounds ranging from not-for-profit science centers, through industry, research institutes, and universities, will address their approach to measuring what impact their STEM outreach programs had on program participants. At the same time, the panel will focus on what role equity, diversity and inclusion plays in their programs, how they achieve diversity of participants and in what ways it influences quality of experience for the program participants. The goal of this panel discussion is to engage the audience in a lively discussion about what meaningful and effective outreach programs can do to foster interest in science and encourage careers in science. The panel is open to elementary, secondary, college and university teachers as well as STEM educators and practitioners are interested in STEM and equity and diversity. The panel will increase awareness of the impact that STEM programs may have on their participants and discuss with the audience the importance of equity, diversity and inclusion. This will be a unique opportunity to bring together scientists, industry experts and programs leaders to discuss how outreach can motivate students to pursue careers in science.

Keywords: *STEM Outreach, Equity, Diversity and Inclusion, education, industry, not for profit, careers*

BRIDIGING THE GAP IN STEM WITH EDUCATION, INDUSTRY AND GOVERNMENTAL PARTNERS DURING A GLOBAL PANDEMIC

Lindsey Keith-Vincent[1], Don Schillinger[2], Tireka Cobb[3], Nathan Lippe[4] Susanne Thompson[5] and David LaFargue[6]

1.Louisiana Tech University
2.Louisiana Tech University
3.Louisiana Board of Regents- LOSFA
4.Coursera
5.Discovery Education
6.Louisiana Board of Regents- LASTEM

ABSTRACT

This exciting panel session will showcase innovative virtual science, technology, engineering and mathematics (STEM) education efforts led by Louisiana Tech University's College of Education with stakeholders from industry, education, and government focused on improving STEM, PK-workforce and life-long learning. Specific examples of unique, customized, and targeted opportunities designed around the federally-funded LA GEAR UP program and including Coursera, LASTEM, and Discovery Education will be highlighted. Experts from respective institutions and organizations will share unique learning models, innovative initiatives, and world-class resources to help students continue learning even as schools close or pivot to hybrid schedules during pandemics and natural disasters. Specifically, participants and attendees of the session will 1.) learn about current efforts and virtual pilot projects designed to meet the STEM education needs of learners from pre-k to adulthood, 2.) discuss with leaders from organizations including Louisiana Tech University, Coursera, Discovery Education, and the Louisiana Board of Regents the challenges and opportunities related to STEM associated with the 2020 year, and 3.) engage with panelist using a planning template to help design custom experiences to meet the needs of their STEM learners and stakeholders including accessing free digital resources and learning platforms available through presenting partner organizations.

Keywords: *STEM, Virtual Learning, E-resources, innovative education, collaboration, partnerships, workforce development*

STEAM EDUCATION ACROSS CONTEXTS: HOW INFORMAL LEARNING ORGANIZATIONS SUPPORT LIFELONG LEARNING

Trish Pattison[1], Yukiko Stranger-Galey[2], Jaclyn Baxter[3], Karen Lee[4]

1. *H.R. MacMillan Space Centre*
2. *Beaty Biodiversity Museum*
3. *The Exploration Place*
4. *Science World BC*

ABSTRACT

This panel presentation brings together a group of informal educators to share ideas about how we might more effectively work together to support STEAM (science, technology, engineering, art & design, and math) learning in schools as well as outside the classroom. In this lively discussion about leading STEAM education workshops, we will examine the importance of supporting lifelong learners. Using STEAM as a teaching tool, we will share different ways each organization engages diverse learners in workshops, lectures, and hands-on activities. We will also examine how each organization collaborates with external partners to support STEAM learning. The panel discussion will address the challenges of STEAM outreach and strategies to support remote communities. We will end the session by sharing some key activities that have resonated with our learners. The sociocultural theory of learning informs our understanding of learning in informal settings. Accordingly, leveraging learners' backgrounds and learning contexts can improve Science, Technology, Engineering, Art & Design, and Math (STEAM) learning experiences and render STEAM more inclusive of diverse learners.

Keywords: *informal education, outreach, community partnerships, lifelong learning, collaboration*

Innovative Learning Environments (ILEs) in the Periphery – Moving from Theory to Practice in distance learning to strengthen STEM approach

Luggasi Maya[1], Sa'adon Chetrit Shani[1], Rauch Orly[2], Guy Beigel[2], Baratz Oren[3], Margolin Tirzah[4]

1. *Beit Yatziv, Israel*
2. *Social Finance Israel (SFI)*
3. *Jewish Federation of Cleveland*
4. *Rashi Foundation, Israel*

ABSTRACT

Developing an independent student with 21st century skills, relate to both soft and cognitive skills, are prominent in the periphery, especially in the STEM professions. Due to insufficient exposure to technological means, driven by long-standing changes in pedagogic, Innovative Learning Environments (ILEs) has established. ILEs are joint initiative based on cooperation between the Jewish Federation of Cleveland, Social Finance Israel (SFI), Beit Yatziv and the Ministry of Education, which aims to tangible difference and reduce gaps among specific demographic groups (Bedouin, Ultraorthodox communities etc.). The design process of learning environments is part of a dialogue and collaboration with a leading team of teachers, according to the needs and vision of each school. That includes also a professional training model and professional community for schoolteachers that aims to create an optimal use of the ILEs. The activities in the ILE spaces are modular, flexible and enables an interactive and experiential learning, which exposes to contemporary multidisciplinary challenges. The educational objectives are developing cognitive, SEL skills for learners through significant technological tools by the STEM approach. Due to COVID-19, the ILEs operates as a hybrid format enabling emotional and differential teaching-learning strategies for teachers and students without a supportive environment and online limited accessibility. SFI is conducting research evaluating the ILEs activities. The evaluation tools developed with a broad consultation with professionals. This study allows to evaluate needs and to promote systemic changes for continuous improvement of the quality of ILEs. The results of this evaluation research are yet to come.

Keywords: *Innovative Learning Environments (ILEs), STEM approach, evaluation tools*

STEM TEACHER EDUCATION AND PROFESSIONAL DEVELOPMENT: EXAMINING POSSIBILITIES FOR COLLABORATION

Dragana Martinovic[1], Yifat Ben-David Kolikant[2], Marina Milner-Bolotin[3], David Anderson[3], Laura Gorjao Stringer[4] and Mike Hengeveld[5]

1. University of Windsor
2. Hebrew University of Jerusalem
3. University of British Columbia
4. Gleneagle Secondary School
5. Templeton Secondary School

ABSTRACT

This 40min long panel with educators from Canada and Israel is organized around the professional development (PD) of STEM teachers. We will discuss ideas and experiences from facilitating collaboration and PD of teachers from different STEM areas. The goal is to present and examine some effective STEM curricular and pedagogical practices across a variety of education settings (e.g., K-16, Israel, and Canada), as well as describe some challenges we have encountered in organizing STEM PD. As educators, we see value in the professional growth that happens when teachers from different STEM areas collaborate with other stakeholders. Providing venues and opportunities for such collaboration and dialogue is a challenge in the era when professional learning of in-service teachers consists of few annual PD sessions run by the district facilitators. Also, the new and pre-service teachers need to be mentored by the practicing teachers in their discipline in far more effective ways that those that are presently available. The first three panellists (Ben-David Kolikant, Martinovic, & Milner-Bolotin, 2020) have co-edited a book in which they investigated different models of PD for mathematics and science educators. This book has a theoretical and practical significance for improving teacher education and PD opportunities in schools, and for answering some critical questions about the uses of research for policy and practice. In addition, we have a science education professor and two grade 8-12 teachers as panellists. First, each presenter will respond to the posed question, which will be followed by questions and feedback from the audience.

Keywords: *STEM, teacher education, professional development, international perspectives*

SCIENTIFIC LEADERSHIP - A STEM YOUTH MOVEMENT

Ronin Igor[1], Lugassi Maya[1], and Margolin Tirzah[2]

1. Beit Yatziv
2. *Rashi Foundation*

ABSTRACT

The educational system in the Israeli periphery provides limited opportunities for upward social mobility for children and young adults, mostly in STEM studies. The Youth movement Scientific Leadership (SL) strives to develop STEM knowledge and motivation, as well as socio-emotional skills amongst Israelis from the geographic periphery. SL is a comprehensive leadership training program implemented by MoE, Beit Yatziv, and the Rashi Foundation. The program trains high school students from Israel's periphery to become youth leaders through STEM studies. The young leaders join a summer camp where they are exposed to leadership workshops and science education training. Following successful completion of the camp, they start a year-long program guiding elementary school students. SL fosters a deep relationship between leaders and their students, who are exposed to positive role models and STEM studies through science experiments. The young leaders strengthen their own passion for science while they develop leadership and social skills. Evaluation based on quantitative and qualitative research showed impact on the participants' scholastic achievements and 21st-century skills. Their experiences and skill building lead them to academic achievements, high-school matriculation, and in many cases university studies. Evaluation outcomes pointed out the program's influence on the participants' self-efficiency and confidence as well. Moreover, those who graduated as young leaders in SL reported that the program influenced their future orientation by increasing self-confidence and having aspirations for STEM careers. SL aspires others who wish to create an opportunity to excel and explore science and to influence underprivileged communities and strengthen social mobility.

Keywords: *informal education, social mobility, youth movement*

VIRTUAL WORLDS, SCIENCE, AND ART: THE ART OF EDUCATION

Jiyoung Shim[1], Hojung Choi[1], Huijun Li[1], Hsiao-Cheng (Sandrine) Han[1]
1. University of British Columbia

ABSTRACT

The panel of this discussion are science and health educators who have designed and created virtual worlds to teach science to different age-level students. Through the designing and creating process, we discovered that when thinking about teaching STEM education in a limitless virtual environment, the way in which we see and think about education is totally different. In the virtual learning environment, students are going on field trips, receiving quests, and solving problems. Education is no longer linear, and learning becomes fun and flexible. In this panel discussion, the panel will share their experiences in designing and creating the virtual learning environment for K–12 and adult students. The questions for discussion will include but are not limited to the following: How can virtual learning environments enhance STEM education? What are the potential limitations and weaknesses? Have you seen arts in a virtual STEM learning environment? What have you learned through the designing and creating process? The presentation will be an open forum in which the chair will provide several questions for the panel to discuss, and the audience is welcome and invited to participate in the discussions.

Keywords: *virtual worlds, virtual learning environment, STEM, STEAM, science*

DIGITAL STORYTELLING: STEAM IN EDUCATION

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1. *University of British Columbia*
2. *Simon Fraser University*

ABSTRACT

Can we teach STEAM through digital storytelling? Maybe we should first ask if arts should be included in STEM. If so, why? What is the value of including arts in STEM education? Furthermore, how can arts be included in STEM? Through arts, STEM education is no longer only about facts, but also about humanity. The panel participants include a visual artist, designer, writer, musician, and art educator, all of whom engage digital storytelling to create, perform, and educate in one or more aspects of STEAM education. In this panel discussion, the panel will share their experiences of utilizing digital storytelling to enhance students' STEAM learning experiences. The questions for discussion will include but are not limited to the following: Why STEAM? How STEAM? Why digital storytelling? What kind of experiences can digital storytelling provide? The presentation will be an open forum in which the chair will provide several questions for the panel to discuss, and the audience is welcome and invited to participate in the discussions.

Keywords: *digital storytelling, STEAM, arts, humanity*

BUILDING RELATIONAL CONNECTIONS IN STEM EDUCATION THROUGH INDIGENOUS EPISTEMOLOGY AND IMMERSIVE EXPERIENCES

Poh Tan[1], Paula MacDowell[2], Quincy Wang[1], and Josh Gillingham[1,3]

1. *Simon Fraser University*
2. *University of Saskatchewan*
3. *Aspengrove School*

ABSTRACT

A scientifically literate person is traditionally attributed to one who: 1) has a breadth of scientific knowledge and understanding, 2) develops an ability to apply that knowledge and understanding towards oneself and society, and more importantly, 3) innovates solutions to solve current global challenges. These attributes develop core scientific knowledge in the field of science, however, many paradigms of scientific research stem from a dualistic view of the world where there is a divide between object and subject. Objective interpretations of the world perpetuate human/nonhuman, nature/culture, and indigenous/non-indigenous perspectives that reinforce a human-centric view of the world. Our panel will discuss how post-humanist theories and Indigenous understandings paired with virtual reality (VR) experiences can enable holistic awareness and nurture a relational connection between object and subject. Participants will learn how educational VR applications can initiate emotions and stories that build accountable and respectful relationships between humans and non-humans/nature. Imagine a curriculum that places equal importance on the relational connection between the scientist and what she is learning about; will she see her subject material differently? Will she take action in the world in more empathetic and connected ways? Through a panel discussion, we will share our working theoretical framework and preliminary findings that explore the advancement of STEM education through immersive experiences designed to transform how we view and relate to the world from a scientific perspective. We will facilitate audience discussion and generate knowledge exchange around expanding the definition of a scientifically literate person to include a relational lens.

Keywords: *scientific literacy, post-humanist, virtual reality, indigenous epistemology, immersive learning*

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DESIGNING THE "STEAM + "LEARNING PROJECTS TO BRIDGE COMPULSORY EDUCATION SCHOOLS AND MUSEUMS IN CHINA

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ABSTRACT

Considering that curriculum-link and pedagogical models are two vital challenges for collaboration between compulsory education schools and museums in China, STEAM, as a meta-discipline that constitutes the entire spectrum of five disciplines (science, technology, engineering, art, and mathematics), appropriately provides curricular structures and philosophies for the collaboration. Project-based Learning (PBL), simultaneously, featured on questions-oriented, teamwork-reliance and inquiries-centered, perfectly matches the pedagogical requirements with museums' informal learning context. In the view of above-mentioned reasons, "STEAM+" Learning Projects， referring to a Project-based Learning designed with the pedagogy and philosophy of STEAM, will bridge schools and museums in an ideal way of feasibility and validity. The "STEAM+" Learning Projects should be designed from three aspects, including standards, requirements and procedures, all of which will be discussed in detail in order to prove its feasibility and validity. From the Panel, participants will know the status quo of collaboration between schools and museums in China and a method to bridge them better, in which critical analysis and creative idea sharing will be welcomed. Then, the topic and discuss might open a window for others to think about what STEAM can do in bridging informal education and formal education.

Keywords: *STEM, Project-Based Learning, museum, school*

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REVISIONING EDUCATION THROUGH TECHNOLOGY

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ABSTRACT

Technology is changing our world. From mobile devices to virtual reality, from augmented reality to artificial intelligence, everything is moving forward speedily, and education is quickly catching up. This presentation invites education specialists from the fields of education technology, math education, music education, art education, and adult education to envision education through changing technology. We will discuss how each field of education is changing because of changes in technology, how VR will be broadly implemented into education, how AI will assist technological changes, influence the role of teachers, and change the way we think about education, and how the future of education technology will improve the teaching and learning of STEM education. Through the panel discussion, participants will envision the future of education together. The presentation will be an open forum in which the chair will provide several questions for the panel to discuss, and the audience is welcome and invited to participate in the discussions.

Keywords: *education technology, STEM, STEAM*