DEVELOPING INTEGRATED SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) PROJECTS IN EDUCATION

Isha DeCoito
Western University, Canada
idecoito@uwo.ca

Abstract: Science, technology, engineering, and mathematics (STEM) is an emphasis which stresses a multidisciplinary approach for better preparing all students in STEM subjects, and increasing the number of postsecondary graduates who are prepared for STEM occupations. The ability to understand and use STEM facts, principles, and techniques are highly transferable skills that enhance an individual's ability to succeed in school and beyond, across a wide array of disciplines. This study focuses on STEM project-based learning which integrates engineering design principles, mathematics, science, and technology concepts with the K-12 curriculum. The infusion of design principles enhances real-world applicability and helps prepare students for post-secondary education, with an emphasis on making connections to what STEM professionals actually do in their jobs. This study adopts an integrated approach to teaching STEM education and is grounded in situated cognition theory which highlights the fact that understanding how knowledge and skills can be applied is as important as learning the knowledge and skills itself, as well as recognizing that the contexts are critical to the learning process. This study is unique as it examines the attributes of STEM education using an organic approach to curriculum development and a unique focus on STEM concepts borne of the motivation to reinforce and integrate engineering, math, and science concepts. To be effective, teachers need content knowledge and expertise in teaching that content, but research suggests that science and mathematics teachers are underprepared for these demands; weak initial teacher preparation heightens the importance of continuing professional development. This mixed-methods study explored teacher candidates' development of 15 digital STEM projects focusing on various topics, including the environment and sustainability, health and well-being, energy efficiency, and climate change. Through the development of STEM projects, findings reveal that teacher candidates' interest and engagement in STEM increased, and their understanding of STEM education and learning of STEM concepts were positively impacted as they designed curricula addressing STEM education.

1 INTRODUCTION

The science, technology, engineering and mathematics (STEM) paradox of having too many open positions that require STEM skills, but not enough graduates and qualified professionals who are applying to fill those positions remains a concern in both Canada and the United States (Ford, 2012). STEM jobs will grow almost twice as fast as any other profession, with over 1 million jobs by 2018 in STEM fields, but only 16% of Canadian degrees awarded will be in STEM specializations. Research indicates that the low number of graduates in STEM areas can be attributed to students' attitudes and interest in science and mathematics, combined with a 'negative image' in the early years. Achieving greater STEM proficiency begins in the K–12 educational system, where in many countries including Canada, students have demonstrated poor progress in math and science from 2003-2013 (Richards, 2014). In 2007 Canada's participation in STEM education at the postsecondary level was awarded a "C" grade, based on the relatively low proportion of graduates in these fields (Conference Board of Canada, 2013; Orpwood, Schmidt, & Jun, 2012). Statistics Canada (2013) indicates that at the post-secondary level, STEM fields represent 18.6% of all fields of study. Globally, Canada ranks 10th out of 16 peer countries in terms of

STEM graduates. In 2010, Canada's proportion of overall graduates emerging from STEM disciplines was 21.2%, the third year of decline. These trends have ramifications in terms of satisfying labor demand and promoting business innovation. The Conference Board concluded that Canada needs more graduates with advanced qualifications and more graduates in STEM fields as these graduates are necessary to enhance innovation and productivity growth, and ultimately to ensure a high and sustainable quality of life for all Canadians (Conference Board of Canada, 2013).

1.1 Teacher Education and STEM

STEM has long been an area of confusion for some educators. While they can see many of the conceptual links between the various domains of knowledge, they often struggle to meaningfully integrate and simultaneously teach the content and methodologies of each of these areas in a unified and effective way for their students (Duschl, Schweingruber, & Shouse, 2007; Thomasian, 2011). Essentially the questions are: How can the content and processes of four disparate and yet integrated learning areas be taught at the same time? How can the integrity of each of the areas be maintained and yet be learnt in a way that is complementary? How does teacher confidence or knowledge of STEM translate to students' interest in STEM careers? These are ongoing challenges faced by educators, especially in the early grades. For example, failure to motivate student interest in math and science is prevalent in most K–12 systems, as math and science subjects are disconnected from other subject matter and the real world, and students often fail to see the connections between what they are studying and both their everyday world and STEM career options (Alexander, Johnson, & Kelley, 2012). Briefly, effective instruction capitalizes on students' early interest and experiences, identifies and builds on what they know, and provides them with experiences to engage them in the practices of science and sustain their interest. Ultimately, understanding how to provide students with the support and skills they need to succeed, how students become aware of STEM career options, and how educators can help students translate awareness into pursuit of STEM careers, are crucial elements in ensuring the future of a STEM workforce (Subotnik, Tai, Rickoff, & Almarode, 2010). Currently, learning strategies in initial teacher education programs do not prepare teachers to promote STEM careers. Teacher education could play a role in establishing these norms, imparting best pedagogical strategies and providing opportunities for teachers to experience science workplaces. This study has the potential to impact STEM education, especially areas related to teacher professional development, teacher education, to name a few.

1.2 Integrated STEM and Social Learning

Integrating STEM subjects can be engaging for students, can promote problem-solving and critical thinking skills and can help build real-world connections. Hence, preparing students with global workforce skills to ensure successful careers in STEM fields will require new approaches to teaching STEM topics in K-12 classrooms. Developing a conceptual framework for STEM education requires a deep understanding of the complexities surrounding how people learn, specifically learning STEM content. The emphasis on social learning as the locus for creating a more sustainable and desirable world is especially meaningful. Instead of teaching content and skills and hoping students will see the connections to real-life application, integrated STEM education sees to locate connections or intersections between science, technology, engineering and mathematics and provide a context for learning the content. Social learning reflects the idea that the shared learning of interdependent stakeholders is a key mechanism for arriving at more desirable futures. Social learning advocate an interactive or participatory style of problem solving, whereby outside intervention takes the form of facilitation (Leeuwis & Pyburn, 2002, p. 11). Thus this research is informed by Bandura's social learning theory (1977) situated in the context of integrated STEM project based learning. This theory explains human behavior in terms of continuous interactions among cognitive, behavioral, and environmental influences. Specifically the focus is on active social learning that is non-hierarchical and promotes co-learning (Glasser, 2009).

1.3 Project-based Learning

STEM project-based learning integrates engineering design principles with the K-12 curriculum. Integrated STEM project-based learning builds on engineering design as the cornerstone and as the foundation on which students bring their compartmentalized knowledge of science, technology, and mathematics to bear on solving meaningful real-world problems. The infusion of design principles enhances real world applicability and helps prepare students for post-secondary education, with an emphasis on making connections to STEM professionals and careers. Project-based learning provides the contextualized, authentic experiences necessary for students to scaffold learning and build meaningful connections across science, technology, engineering, and mathematics concepts, while challenging and motivating students at the same time. Studies comparing learning outcomes for students taught via project-based learning versus traditional instruction show that when implemented well, project-based learning increases long-term retention of content, helps students perform as well as or better than traditional learners in high-stakes tests, improves problem-solving and collaboration skills, and improves students' attitudes towards learning (Strobel & van Barneveld, 2009). In addition, project-based learning enhances 21st century skills by fostering critical and analytical thinking, enhancing higher-order thinking skills, promoting collaboration, peer communication, problem-solving, and self-directed learning (DeCoito, 2014). Barron and Darling (2008) have identified several components that are critical to successful project-base learning: i) identifying a realistic problem or project, ii) structured group work; iii) multi-faceted assessment; and iv) participation in a professional learning network.

1.4 Curriculum Development, STSE and STEM Projects

In Ontario, science and technology curricula for grades 1-12 require students to analyze socioscientific issues (SSI) through curriculum expectations in which they “relate science and technology to society and the environment” (STSE Expectations) (Ontario Ministry of Education, 2008). Many teachers avoid the integration of socioscientific issues (Forbes & Davis, 2008) into the science classroom because they possess limited content knowledge and skills to deal with complex issues, lack teaching strategies for dealing with these issues, and tend to place more worth in teaching the value-free concepts and skills of science than messy socioscientific concerns (Lee & Witz, 2009). Proponents of STSE education advocate literacy grounded in the context of ethical, individual and social responsibility (Krug, 2014; Kumar & Chubin, 2000). Gray and Bryce (2006) concede that this new focus on complex, value-laden science requires a careful consideration of the professional updating of teachers’ knowledge and skills. One way to address the professional updating of teachers’ knowledge and skills is supporting them in learning to effectively use curriculum materials. Forbes and Davis (2008) suggest that with support, educators can learn to make effective adaptive decisions regarding existing curriculum materials. One way to support educators’ work with curricula is through the development of educative curriculum materials, or those that are designed to promote teacher learning as well as student learning. This study examines the attributes of STEM education using an organic approach to curriculum development and a unique focus on STEM concepts borne of the motivation to reinforce and integrate engineering, math, and science concepts.

2 METHODOLOGY

A mixed-methods design (Mills, Durepos, & Wiebe, 2010) was utilized for the study to help meet the overall aim of the project and answer specific research questions related to STEM project development in teacher education. The data collecting methods consisted of T-STEM surveys (Erkut & Marx, 2005), student reflections, interviews, and student work. Participants include teacher candidates (TCs) enrolled in two science education courses (Science/ Biology, and Physics/Chemistry at the grades 9-12 levels) at a Canadian university. In total, thirty-one science education students (19 females, 12 males), ranging from ages 20-47 participated in this study. A total of 15 digital STEM projects focusing on various topics, including the environment and sustainability, health and well-being, energy efficiency, and climate change were completed by TCs. Analysis of qualitative data constituted an interpretational analysis framework, executed through the process of thematic coding and constant comparative method (Stake, 2000). STEM projects were analyzed using content analysis with specific emphasis on i) STEM disciplines, ii) STEM content, and iii) STEM integration. This paper reports on one STEM project focusing on the environment and sustainability, through the exploration of mountaintop mining and alternative sources of energy.

3 ANALYSIS OF STEM PROJECT

3.1 Goals and Curricular Focus

The project, *Energy Systems – A STEM Integrated Approach*, strives to draw attention to energy production, consumption, and engineering practices, while exploring renewable and non-renewable energy resources. Students research advantages and disadvantages of various methods of generating power and calculate efficiencies. Class discussion include the environmental impacts, comparisons between personal usage, as well as Ontario and Canada's usage, to other provinces and other countries, and the economic costs of mining. This pedagogical approach in employed in the hope that students will gain a deeper understanding of their own energy consumption and come to the realization that their actions impact not only the environment but their own future. Table 1 illustrates a suggested timeline for the project, including a sequence of lessons along with corresponding STEM topics and content.

Table 1: Sequence of Topics and STEM Content

Lesson Sequence	STEM Topics and Content
Lesson 1	Renewable and non-renewable sources of energy
	Research and Discussion
	Uses of electricity, generation source, energy consumption, how to reduce energy consumption
Lesson 2	Energy efficiency and environmental impact
	Data analysis, terminology, symbols, calculations
Lesson 3	Economics and environmental impacts of mining
	Environmental Assessment and Reclamation Plan for mine site
	STEM Project - Blade design proposal (blueprints)
Lesson 4	Testing initial blade designs
Lesson 5	STEM Project concludes
	Compile data, class discussion, submit new proposal
Lesson 6	Class debate on pros and cons of wind power
	Personal reflection on STEM project and debate

Table 2 is the assessment developed for the STEM project, according the categories of Ontario's Ministry of Education achievement chart.

Table 2: Assessment of STEM Project

Knowledge and Understanding	Thinking and Investigation	Communication	Application
Efficiency Calculations	Blade design	Class Debate	Final blade design proposal
Terminology and Symbols	Building blades	Personal Reflection	
Mining Activity	Class Discussions	Environmental Assessment	
	Mine Reclamation Plan		

3.2 The Engineering Design Process

This STEM project is an exploration into the engineering design process, as illustrated in Figure 1. Most engineering designs can be classified as inventions created by human effort and are the result of bringing together technologies to meet human needs or to solve problems. Design activity occurs over a period of time and requires a step-by-step methodology (Khandani, 2005).The process aims to be an authentic learning experience, in which students "learn by doing", as well as gain insight into project management. The wind turbine blade design project is structured as mini tasks at the end of each lesson. Thus, students have direct experience with project management, design and the importance of the successful and timely completion of subtasks to the overall success of the final project. This structure also affords an opportunity for formative feedback to assure success across diverse learning needs of the individual.

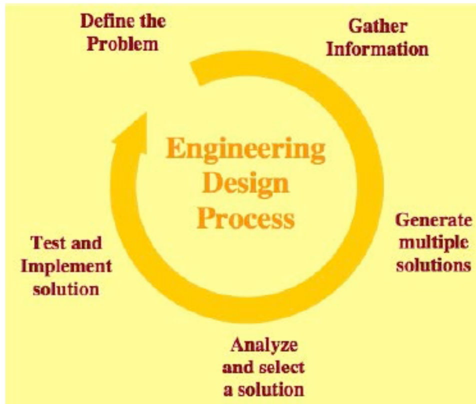

Figure 1: Engineering Design Process (Khandani, 2005)

The STEM project utilizes a STSE (Science, Technology, Society and Environment) framework which is issues-based in nature and explores mountaintop mining practices on Coal River Mountain in Appalachia. Students are confronted with a challenge of designing a profitable mining simulation, but are thrust into internal conflict (Socha et al., 2003) between making a profit and trying to restore the environment. Figure 2 illustrates a mountaintop removal mining site and reflects permanent changes to the landscape.

Figure 2: Mountain Top Mining

The citizens of Coal River Mountain have proposed a wind power generation installation as an alternative to the planned mountaintop removal mine. In this STEM project, the class takes on the role of design engineers - they design, test and refine their initial design as a class and write a proposal for the wind turbine blade design. There are costs associated with energy that generally go unaccounted within the individual's mind, especially in countries where power is produced cheaply and is freely available. The goal is for students to reflect on their relationship to energy consumption, environmental sustainability, and issues surrounding both renewable and non-renewable energy, including costs related to mining and restoring the environment. The sequence of lessons cover renewable and non-renewable sources of energy, specifically energy production methods. Through research and class discussion, students are exposed to different methods of energy generation and categorize the different sources into renewable and non-renewable energy. These topics cover methods of power generation, including advantages and disadvantages, and explore in depth power distribution showing the path from source to point of use. Students are introduced to the Wind Turbine project – in groups, the first task is to construct the wind turbine base and stand. The base and stand can be made of wood, but PVC tubing, T's and elbows are useful for other projects and store easily (assembled in Figure 3). Students are introduced to terminology, symbols, and definitions and are provided opportunities to practice energy efficiency calculations. Class discussion focus on addressing energy efficiencies and advantages and disadvantages of each energy generation resource. Students continue to work on the design of the wind turbine and in the next step, they set up the circuit needed to collect data and familiarize themselves with using a multi-meter for measuring voltage and current (Figure 4).

Figure 3: Wind turbine base and stand

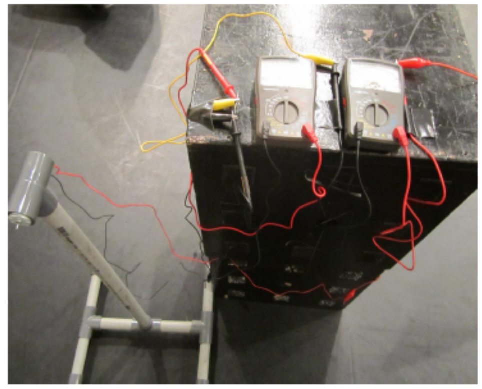

Figure 4: Building testing circuit

The Mountain Top Coal mining simulation focuses on environmental assessment and a reclamation plan. The class explores the topic of mountaintop coal mining through a simulated mining operation. In groups, students assume the role of a mining company wishing to develop a mountaintop coal mine. They are introduced the social, economic and environmental impacts via a video produced by local residents that proposes an alternative, more environmentally friendly renewable energy wind farm. The corresponding task toward the final project is to design and produce a draft of the wind turbine blade. This blueprint is to be submitted before any testing can commence. Students also prepare a pitch angle protractor (Figure 5) for use to set the various pitches to be tested. Figure 6 illustrates the testing of a 2-blade configuration.

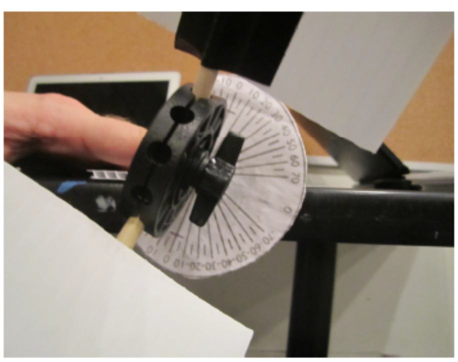

Figure 5: Preparing pitch protractor

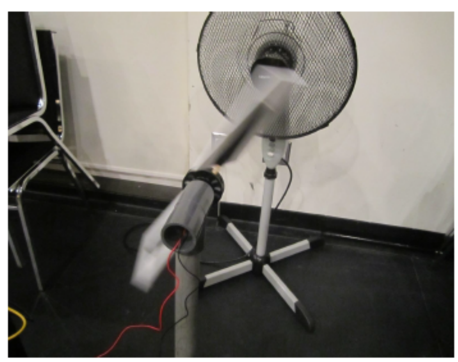

Figure 6: Testing 2-blade configuration

The need to collaborate continues in the final proposal and class analysis of the design data. After testing and class analysis of the data is complete, individuals compile their initial design, testing data and generate a proposal based on class recommendations derived from analysis of the class data set. Students must describe their reasoning and provide a rationale as to why the class design is an improvement compared to their tested design. As a final activity, the class reflects on the completed STEM project and debate the pros and cons of wind power generation. This allows student to amalgamate their learnings and experiences within the project to formulate their own informed stance on the issue of wind power generation.

4 DISCUSSION

The integrated STEM project, *Renewable and Non-renewable Resources: Wind Turbine Blade Design,* focusing on power generation technologies; the environmental, economic and societal costs of coal mining; wind turbine blade design and optimization was successful in terms of addressing the goals of STEM education, specifically the implementation of an engineering design process. The sequence of topics introduced students to various components and STEM content that was essential in order for students to complete the project. It was necessary to divide the turbine blade design into small achievable subtasks as this allowed for timely feedback and raised the overall success of the project. More importantly, this approach provided opportunities for students to gather information through research, learn mathematical calculations, and investigate the economic costs of mining by managing a fictional Mountaintop coal mine (they were required to purchase a hypothetical coal mining site with limited start-up funds), alongside designing the wind turbine blade. Hence, these steps reflect the beginning phases of the engineering design process.

Prior to mining activities, students submitted an environmental assessment detailing the environment. They were provided with a Mountaintop Mining Fact Book as a resource for developing a mine reclamation plan, which stated how they would restore the environment to its original condition. This particular activity provides students with a hands-on simulation and demonstrates the importance of environmental sustainability and making responsible decisions that will reduce business' negative impact on the environment. This is reflective of social learning which advocates an interactive or participatory style of problem solving. Furthermore, the process of developing the wind turbine blade afforded students the opportunity to assume the role of engineers as they designed, tested, and calculated the power generation potential of their wind turbine blade designs by varying the blade angle. Students participated in knowledge construction as they amalgamated their findings in the form of a proposal to a fictional engineering firm, including the blueprint of their group's initial blade design and the class' conclusions about the optimum blade design, and scientific reasoning as to why the class design was an improvement over their initial design. These steps are imperative to the STEM project design process as they enhance problem-solving and critical thinking skills, creativity and innovation, and collaboration and can help build real-world connections as students integrate their compartmentalized knowledge of science, technology, and mathematics to bear on solving meaningful real-world problems. The infusion of design principles enhances real world applicability and helps prepare students for post-secondary education, with an emphasis on making connections to STEM professionals and careers, such as environmental engineering in this project.

Participants reported success and challenges during the development of the STEM projects. Challenges included integrating engineering and mathematics content, and tensions related to self-efficacy and confidence in teaching these content areas. Successes included collaboration, engagement, self-realization, heightened self-efficacy, enhanced critical thinking skills, multi-literacy, agency, environmental stewardship and awareness, fostering 21st century agents, and innovation. In this STEM research, project-based learning provided contextualized, authentic experiences necessary for students to scaffold learning and build meaningful connections across science, technology, engineering, and mathematics concepts, while challenging and motivating them at the same time. The expected impact of this research include direct benefits in terms of i) developing awareness of learning styles related to STEM initiatives; ii) identifying and employing instructional and targeted learning strategies designed to enhance learning in STEM; iii) developing and incorporating meaningful STEM perspectives and activities when planning instruction; and iv) implementing strategies and STEM activities for developing 21st century skills in students and teachers. This research can inform educators, researchers, policy makers, and curriculum developers as to benefits, drawbacks, and challenges of implementing STEM initiatives.

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