STEM OUTREACH FACILITATION AS A CATALYST FOR 21st CENTURY TEACHER EDUCATION

by

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M.A. TESOL, University of London, 2003

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Science Education)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

July 2018

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the thesis entitled

STEM outreach facilitation as a catalyst for 21st century education submitted by Carlos Cesar Fumagalli Marotto in partial fulfillment of the requirements for the degree of Master of Arts Science Education

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Abstract

This study provides an in-depth description of teacher candidates (TCs)' experiences of their participation in a family-oriented science, technology, engineering, and mathematics (STEM) outreach event organized at a Canadian university. In the event, TCs facilitated mentally-engaging hands-on activities to the public as part of a *General Science Secondary Methods* course. The aim of the study is to further knowledge of the possible role of STEM outreach in teacher education programs, and to learn how this outreach experience impacts TCs': a) pedagogical content knowledge (PCK); b) communication skills; c) motivation to teach STEM; and d) understanding of how STEM can be taught and learned effectively. This study is situated within a social-constructivist theoretical framework and employed an intrinsic case study methodology with a Partially Mixed Concurrent Dominant Status Design. Although the quantitative facet of the study was given less weight, it informed the analysis of the qualitative data. The data from the pre-event survey (n=29) revealed TCs' passion for STEM as their greatest self-reported strength, whereas their lack of PCK was self-reported as their greatest limitation. Moreover, the participants predicted that activity facilitation at the event would enhance their teaching skills by allowing them to put their content knowledge into practice to facilitate visitors' learning experiences. Furthermore, the findings from post-event focus group discussions (n=46) and individual interviews (n=9) indicated that this outreach experience enabled TCs to: a) expand pedagogical content knowledge; b) increase awareness of the role of effective communication on STEM teaching and learning; c) increase or reinforce appreciation of STEM hands-on activities for cognitive and affective reasons; d) enhance or strengthen understanding of the importance of parental engagement with children's STEM education; and e)

put in practice some of the theories learned in the teacher education program. Evidence of the above emerged through TCs' engagement in the event preparation, activity facilitation at the event, and post-event reflections.

Lay Summary

This intrinsic case study describes teacher candidates (TCs)' experiences of their participation in a family-oriented STEM outreach event organized at a Canadian university. In the event, TCs facilitated hands-on activities to the public as part of their teacher education program. Situated within a social-constructivist theoretical framework, the study aims to further knowledge of the role that STEM outreach plays on pre-service teacher education programs. The data from post-event focus group discussions (n=46) and individual interviews (n=9) indicated that teacher candidates benefitted from the outreach experience in multiple ways. Among other things TCs' participation at the event enabled them to: a) expand pedagogical content knowledge; b) gain awareness of the importance of effective communication in STEM teaching and learning; c) increase or reinforce appreciation of STEM hands-on activities for cognitive and affective reasons; d) enhance or strengthen understanding of the importance of parental engagement with their children's STEM education; and e) employ some of the theories learned in the teacher education program.

Preface

This thesis is part of a 30-credit research program, Master of Arts in Science Education, organized by the University of British Columbia's Faculty of Education (Vancouver campus). It was produced by Carlos C. F. Marotto (Primary Investigator) with direct supervision of Dr. Marina Milner-Bolotin and Dr. David Anderson. The study was supported by UBC Teaching and Learning Enhancement Fund and approved by UBC Research Ethics Board (UBC BREB number: H16-02469). It is part of the Science Outreach Research Program led by Dr. Marina Milner-Bolotin.

The current study provides an in-depth description of teacher candidates (TCs)' experiences about their participation in the 2017 *"Family Math and Science Day"*, a family-oriented outreach event organized by UBC Faculty Education. In the event, TCs from a *Secondary Science Methods Course* facilitated mentally engaging science, technology, engineering and mathematics (STEM) hands-on activities to the public as part of their teacher education program.

A previous phase of the Science Outreach Research Program, conducted in the context of the 2016 *Family Math and Science Day*, encompassed a study that investigated the role of parental engagement with their children's STEM education. As a result of that investigation, two papers were published: one encompasses the meta-analysis of the literature on parental engagement with children's formal and informal STEM education and the other focusses on how parents responded to the 2016 *Family Math and Science Day* event. Under Dr. Milner-Bolotin's guidance, I was actively involved in its literature review, data collection, data analysis, and manuscript production. The papers were subsequently published in LUMAT International

Journal on Math, Science and Technology Education, the University of Helsinki, Finland. Below are full details of these papers:

Milner-Bolotin, M. & Marotto, C. (2018) Parental engagement in children's STEM education. Part I: Meta-analysis of the literature. LUMAT: International Journal on Math, Science and Technology Education, *6*(1), 41–59.

Marotto, C. & Milner-Bolotin, M. (2018). Parental engagement in children's STEM education (Part II): Parental views on promoting children's STEM education. LUMAT: International Journal on Math, Science and Technology Education, 6(1), 60-86.

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List of Abbreviations

Content Knowledge (CK)

Communication Skills (CS)

European Centre for the Development of Vocational Training (CEDEFOP)

Family Mathematics and Science Day (FMSD)

Inadequate Personality Traits (IPT)

Inquiry-Based Demonstration Classroom (IBDC)

Inquiry in Motion (IM)

Lack of Content Knowledge (LCK)

Lack of Pedagogical Content Knowledge (LPCK)

Passion for STEM (PS)

Personality Traits (PT)

Pedagogical Content Knowledge (PCK)

Poor Communication Skills (PCS)

Science, Technology, Engineering and Mathematics (STEM)

Science Writing Heuristic (SWH)

Search, Solve, Create, and Share (SSCS)

Teacher Candidates (TCs)

United Nations Educational, Scientific and Cultural Organization (UNESCO)

University of British Columbia (UBC)

Wind Turbine Blade Design (WTBD)

Zone of Proximal Development (ZPD)

Acknowledgements

I offer my enduring gratitude to the faculty, especially Dr. Marina Milner-Bolotin, Dr. David Anderson, Dr. Sandra Scott, Dr. Michelle Tan, Dr. Douglas Adler, Dr. Peter Cole, and Dr. Wayne Ross. In their own ways, they have inspired and supported me in this great academic adventure. Moreover, I would like to thank the staff, particularly Alan Jay and Fred Brown, and my fellow students at UBC.

I owe particular thanks to Dr. Marina Milner-Bolotin who, apart from being my program supervisor, was my thesis supervisor. Her dedication, professionalism and competence cannot be put into words. Also, I would like to thank Dr. David Anderson for sharing with me some of his enormous research expertise.

Furthermore, I am grateful to UBC Teaching and Learning Enhancement Fund for the financial support.

Lastly, I owe special thanks to my family, including my deceased parents, who have supported me morally, financially, and spiritually.

Dedication

To Daniela, Angelo and Enrico.

To Osvaldo and Maria Dailze (*in memoriam*).

To all the friends and family members whose caring wishes cheered my heart.

Chapter 1: Introduction

Despite the great support and attention devoted to STEM education in recent years, there is still a widespread phenomenon of student disengagement from STEM-related subjects (Let's Talk Science, 2013, 2017). To address this problem in a rapidly-changing world, teachers need to be educated in ways that equip them to adopt more engaging and interesting ways to teach such subjects both in and out-of-school (DeCoito, 2016). In so doing, they can inspire their students to develop a greater interest in STEM (Zan, 2016).

This chapter is divided into four sections (1.1-1.4). Section 1.1 presents the problem the study aims to address. Section 1.2 lists the research questions that will be answered in the study. Section 1.3 describes the study. It is divided in six sub-sections (1.3.1-1.3.6). Sub-section 1.3.1 describes the outreach model on which the study focuses. Sub-section 1.3.2 explains the researcher's personal motivation to conduct the study. Sub-section 1.3.3 elucidates the significance of the study. Sub-section 1.3.4 provides information about the study's methodology, design, and methods. Sub-section 1.3.5 describes the study's sampling technique. Sub-section 1.3.6 outlines the study's data analysis. Finally, Sub-section 1.4 gives an overview of Chapter 1.

1.1 The Problem

Over the past years, STEM (science, technology, engineering and mathematics) education has received worldwide attention for economic, social and political reasons (DeCoito, 2016; The Royal Society Science Policy Centre, 2014; USA National Research Council, 2013). Concurrently, there has been a general concern about student disengagement from STEM disciplines (Let's Talk Science, 2013, 2017; O'Grady, Deussing, Scerbina, Fung & Muhe, 2016; The National STEM Learning Network, 2017).

Four factors, including, 1) students' early exposure to STEM-related subjects; 2) parental support to enhance students' engagement with and achievement in STEM-related subjects; 3) STEM outreach initiatives aimed at families; and 4) teacher education programs that provide TCs with opportunities to engage with learners in out-of-school contents, have the potential to stop, or at least curb, this trend of student disengagement from STEM. The first highlights the importance of students' early exposure to STEM-related subjects. Perera (2014) claims that student attitudes towards STEM are set prior to grade 9. In line with this, Zan (2016) argues that the earlier students are exposed to STEM subjects, the greater their interests in and motivation towards them are.

The second factor refers to the role of parents. Research evidence shows that parental engagement with their children´s STEM education positively influences children engagement with and achievement in STEM (Chachashvili-Bolotin, Milner-Bolotin, & Lissitsa, 2016; Ing, 2014; Yaro, 2015). One way to engage parents and/or families with their children's STEM education is through informal, out-of-school activities.

In line with the above, the third factor refers to STEM outreach initiatives aimed at families. In a comprehensive literature review, Milner-Bolotin & Marotto (2018) provide examples of international opportunities of informal STEM education for families. These include: extra-curricular projects and workshops (Let's Talk Science, 2017b), courses aimed at parents with limited STEM knowledge (Leach, 2017), websites with videos with experiments and demonstrations that can be done at home (The National STEM Learning Network, 2017), bilingual science guide for Spanish-speaking families living in the USA (AAAS, 2013), among others. Furthermore, research evidence shows that family visits to science centres, such as science museums and aquariums, are beneficial as they offer opportunities that facilitate

emotional learning as well as the acquisition of scientific knowledge (Briseno-Garzon & Anderson, 2012; Dierking & Falk, 1994).

The fourth factor concerns effective teacher education programs. Bearing in mind the importance of the first three factors described above (students' early exposure to STEM, parental engagement with children's education, and out-of-school STEM initiatives), one possible step to enhance teacher education is by providing TCs, with opportunities to engage with learners in informal, out-of-school settings during their education program.

In recent years, University of British Columbia (UBC)'s Faculty of Education has made changes to its teacher education program to give TCs some out-of-school experience. For example, on one occasion, a three-week internship in the Vancouver Aquarium was added to the existing classroom-based practicum of a secondary science teacher education program in the province of British Columbia, Canada. In evaluating this initiative, Anderson, Lawson & Mayer-Smith (2006) concluded that the experience was positive in ways that included teacher candidates development of a broader understanding of teaching theories and of teaching skills, which could be applicable to teaching K-12 students in formal settings.

Another similar initiative relates to a STEM outreach event called *Family Math and Science Day* (FMSD) (http://blogs.ubc.ca/mmilner/outreach/family-math-science-day-at-ubc-faculty-of-education/). The event was founded by Dr. Marina Milner-Bolotin in 2010 (Milner-Bolotin & Milner, 2017) and consists of almost a hundred independent, self-contained hands-on interactive activities, where TCs act as "STEM experts" whose role is to facilitate interactive hands-on activities to the visitors. As FMSD is open to the community, it enables TCs to communicate science to hundreds of young learners and their families (Milner-Bolotin, 2017a).

When combined, these four factors have the potential to address the problem of student STEM disengagement. To some extent, each one of these factors is addressed by TCs' participation in FMSD, which forms the experiential context of this study.

However, as most existing studies have focused on students and/or families, there remains a gap in the research looking at the impact of activity facilitation at STEM outreach events on TCs during their teacher education program. Hence, the purpose of this study is to further knowledge of the role that STEM outreach plays on pre-service education programs. Specifically, it investigated how this outreach experience impacted TCs': a) pedagogical content knowledge, b) communication skills, c) motivation to teach STEM, and d) understanding of how STEM is effectively taught and learned. It is relevant to emphasize that this study aims to further knowledge of the role that STEM outreach plays on pre-service education programs, and not to generate statistically generalizable findings.

Moreover, the study aims at making the outcomes of the FMSD experiences for TCs publicly available as this issue seems to have been overlooked by the current literature. While there exist many STEM outreach models, this study evaluated only one, which will be described in detail in Sub-section 3.2.3.

1.2 Research Questions

The goal of this study is to investigate how the engagement of mathematics and science TCs in outreach activities during their teacher education program can support them in becoming effective educators and reflective practitioners. Therefore, this study aims to answer the following research questions (RQs):

- RQ1: *How does participation in a public STEM outreach experience impact teacher candidates' pedagogical content knowledge, communication skills, motivation to teach STEM-*

related subjects, and understandings of how STEM is effectively taught and learned?

- RQ2: *What do teacher candidates perceive their own strengths and weaknesses as STEM teachers to be?*

- RQ3: *How do teacher candidates perceive what it means to be an effective STEM teacher?*

1.3 The Study

1.3.1 Context: Study outreach model

There are various approaches to science outreach (Vitale, Romance & Dolan, 2006). However, this study focuses on *Family Math and Science Day (FMSD)*, an outreach event organized by UBC's Faculty of Education to provide its TCs the opportunity to facilitate hands-on STEM activities to the public. The event takes place on a fall weekend at the Faculty´s science laboratories and consists of about 100 independent, self-contained interactive stations facilitated by TCs, faculty members and other university staff (Milner-Bolotin & Milner, 2017). The 2017 event was open to visitors for two and a half hours and attended by hundreds of guests coming from the Greater Vancouver area, Vancouver Island and other communities. To engage visitors of different ages and backgrounds, FMSD has a flexible structure, which allows the visitors the opportunity to choose stations according to their interests.

Figure 1. An event volunteer engages visitors at FMSD. (Courtesy of Marina Milner-Bolotin)

Figure 2. A TC engages visitors at FMSD. (Courtesy of Marina Milner-Bolotin)

1.3.2 Researcher's motivation

Several factors motivated me to conduct this study. The first one relates to my experiences as a STEM teacher in my home country, Brazil. For over a decade I have actively participated in science fairs and other school-related events open to the school community and the community at large. In those instances, the benefits of the enterprise were obvious to everyone involved, i.e., learners, facilitators, teachers, parents, the community, and the community.

The second one is connected to my perspective as a STEM teacher. Engaging learners with hands-on activities is beneficial for reasons that include: a) fostering higher-order cognitive skills in learners, b) raising learners' interest in STEM, and c) the integration of different STEM-related subjects, a key factor in STEM education (Akkus, Gunel, and Hand, 2007; Zan, 2016).

The third factor is associated with my experience as a graduate student in the MA in Science Education Program at UBC Faculty of Education. At the beginning of my program I was fortunate enough to be invited to work as a research assistant to Dr. Marina Milner-Bolotin, who, among many contributions to STEM education, is a main figure behind the foundation of FMSD. Together we did a study in the context of the 2016 edition of the FMSD event in which we learned what motivates parents to engage with their children´s STEM education. At that time, I became so impressed by the magnitude of the event that I decided to conduct my own research on the 2017 FMSD. Finally, some of the courses I have taken in my graduate program reinforced the importance of STEM learning and teaching in informal, out-of-school settings.

1.3.3 Significance of the study

Research evidence demonstrates the importance of outreach events to motivate and inspire students to engage with science (Koehler, Park, & Kaplan, 1999; Laursen, Liston, Thiry,

& Graf, 2007; Milner-Bolotin & Marotto, 2018). However, as most studies have focused on students and/or families, there remains a gap in the research looking at the impact of activity facilitation at STEM outreach events on TCs during their education program. Considering the current student STEM disengagement, equipping teachers with the skills of working in STEM outreach events may be a crucial move to stop or reverse this trend. After all, establishing connections between experiences from formal (in-school) and informal (out-of-school) settings is shown to enhance science education (Anderson et al., 2006; Metz, 2005) as these linkages are beneficial learners and teachers (Anderson, Storksdieck & Spock, 2007; Yager & Falk, 2008).

1.3.4 Methodology, study design and research methods

This study adopted an intrinsic case study methodology with a Partially Mixed Concurrent Dominant Status Design mix-method (Merriam, 1998; Stake, 1995). As it aims to describe and understand TCs' experiences during their preparation to facilitate activities and their reflections about their performances at the 2017 FMSD, this methodology seems appropriate as it enabled a detailed description of the entire process. Consistent with the method of case study, it encompassed data collection through multiple methods and from multiple sources (Merriam, 1998).

To describe and understand the impact of the outreach experience on TCs and generate sufficient data to answer the RQs, this study adopted a three-stage approach to data collection. This comprises on-line surveys, focus group discussions and follow-up individual interviews. Table 1 gives an overview of each instrument, their corresponding procedures, dates, and aims.

Table 1

Study's instruments, procedures, timing, and aims

Instrument	Procedures/Timing	Aims
Online Survey	Participants answered questions with pre-selected answers and open-ended questions. This was done in early-October, a few weeks before their activity facilitation at the event.	To ascertain participants' demographics, perceived strengths and limitations as educators, views about science teaching and learning, the importance of informal education, and expectations about their participation in the FMSD.
Focus group discussion	A set of open-ended questions was shared with TCs in early-November, two days after they had facilitated their activities at the 2017 FMSD. The discussions were audio-recorded.	To ascertain how TCs experienced the event as well as their engagement with the visitors. This opportunity allowed TCs to build on each other's comments and answers.
Follow-up individual interviews	A set of open-ended questions was posed to each interviewee in early-November, 2-5 days after they had facilitated their activities at the 2017 FMSD. The interviews were audio-recorded.	To allow TCs to freely express their ideas without the constraints of the group.

1.3.5 Sampling

A convenience sampling method was used due to the substantial number of TCs who were enrolled in the *General Secondary Science Methods* course as part of their teacher education program at UBC Faculty of Education. All TCs who participated in the course were invited to participate in the study. Their participation was voluntary and entailed doing at the least one of the following: a) responding to an online survey in early-October, about three weeks before facilitating at the 2017 FMSD; b) participating in a focus group discussion in early-November, two days after the FMSD; and c) participating in individual follow-up interviews in early-November, a few days after TCs' participation at the FMSD.

1.3.6 Data analysis

As is the case with mixed-method studies, data were quantitatively and qualitatively analyzed. However, this study sought to provide an in-depth description of TCs' experiences, not generate statistically generalizable findings – accordingly, descriptive statistics adds depth to the portrait of TC's as participants in the study and informed the analysis of the qualitative data. This was done with the support of NVivo 11 (QSR International, 2016). Furthermore, all data were triangulated to address the issues of credibility and validity (Mathison, 1988). Detailed descriptions of the methods of data collection and analysis are provided in Chapter 3, Sections 3.3 and 3.4, respectively. In turn, information about the emerging themes is provided in Chapter 4 (Sections 4.1 and 4.2).

1.4 Organization of the Chapters

There are six chapters in this study. The first three chapters lay out the foundation on which the study was based. They are: Introduction (Chapter One), Literature Review (Chapter Two), and Methodology (Chapter Three). Chapter Four provides the results for the online survey (Section 4.1) and for the focus group discussions and individual interviews (Section 4.2). Chapter Five discusses the outcomes of the data analysis in light of the research questions this study aims to answer. Lastly, Chapter Six presents the conclusions and recommendations of this study to improve teacher practice, curriculum and further research.

Chapter 2: Literature Review

This chapter is divided into five main sections. Section 2.1 provides the theoretical framework for the study. Section 2.2 gives an overview of STEM education, starting with its definition and goals (Sub-section 2.2.1), the need for scientifically literate citizens and STEM workforce (Sub-section 2.2.2), and the current challenges of STEM education (Sub-section 2.2.3).

Section 2.3 addresses some of the challenges that prevent STEM education from fulfilling its full potential. Sub-section 2.3.1 offers some effective models of STEM education. Section 2.3.2 shows the benefits of science centre-university partnerships to teacher education. Sub-section 2.3.3 provides examples of other forms of university-based outreach used in STEM pre- and in-service teacher professional development.

Section 2.4 highlights that outreach has an enormous potential to engage parents/families to motivate learners to engage with STEM-related subjects, benefitting all parts involved in STEM education. Sub-section 2.4.1 focusses on courses for parents who have limited STEM knowledge. Sub-section 2.4.2 brings initiatives where STEM materials are designed to encourage minority groups to engage with STEM.

Section 2.5 summarizes the main points addressed in Sections 2.1-2.4. In this literature review, science outreach entails STEM-related extra-curricular activities in or out-of-school settings. These include STEM clubs, workshops, events such as the FMSD, visits to science centres and to websites that encourage educators, students and their families to engage with STEM in a variety of ways.

2.1 Theoretical Framework

This study aims at examining the impact that facilitating activities at an outreach event has on TCs' teaching knowledge, communication skills, motivation to teach STEM-related subjects, and understandings of how STEM is effectively taught and learned. To this end, it will use a social-constructivist theoretical framework (Vygotsky, 1978).

This framework seems adequate because all study participants are TCs attending a *General Science Secondary Methods* course where they are expected to work collaboratively to learn with and from each other. Thus, the meaningful interactions TCs have with the course instructor, course materials, peers, technology, and event visitors at FMSD will provide them with opportunities to notice new concepts and practices, reflect on them, and subsequently incorporate them into their teaching repertoire (Milner-Bolotin, 2017b, Savec, 2016; Vygotsky, 1978).

Moreover, the study data was gathered through three methods (on-line survey, focus group discussion, and individual interviews), the protocols of which encompassed some open-ended questions. The answers to such questions were coded according to themes created based on Shulman's definition of teacher knowledge. For Shulman (1986), teacher knowledge encompasses content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK), where the last overlaps the first two. In line with that, Milner-Bolotin (2016) states that a sound teaching knowledge is a significant gauge of elementary and secondary students' learning.

Furthermore, in the *General Science Secondary Methods* course, TCs will learn how to effectively adopt the new British Columbia (BC) curriculum (https://curriculum.gov.bc.ca/), which has inquiry-based education in its core. To do that, TCs are expected to learn and put into

practice strategies that will allow their future pupils to master subject-specific CK while, at the same time, developing skills such as questioning, predicting, hypotheses raising, and summarizing. For this reason, having TCs facilitate activities at FMSD before they participate in the school-based practicum should contribute to broadening their teaching skills, while making them more confident and motivated to engage with learners.

2.2 STEM Education: Definition, Goals, and Challenges

2.2.1 Definition and goals of STEM education

This study is positioned in the views of DeCoito (2014) who states that STEM education encompasses the teaching and learning of science, technology, engineering and mathematics in an integrated manner. Along these lines, Zan (2016) argues that one reason which justifies why this integration works is because the four subjects in STEM can be exploited through problem-solving. It is the integration of these subjects that differentiates STEM education from the teaching of each of these four subjects in a more traditional, isolated way. Another aspect that deserves attention regards the manner through which student knowledge is built. Emphasis is placed on the process, which entails observation of a phenomenon, the identification of a problem, hypotheses raising and testing, data collection and analysis, and conclusions, which might trigger other questions. To accomplish the whole enterprise, several skills are needed such as planning, problem-solving, action, reflection, effective reading, interpretation, and communication (DeCoito, 2016).

The examples used in this sub-section demonstrate that Canada, the USA and the UK, despite some variations, share similar goals for STEM education. Broadly speaking, these countries are aiming to increase the level of STEM literacy of their citizens, while at the same

time, producing competent STEM-related professionals to maintain these countries in the forefront of technological and economic advancement.

In Canada, according to DeCoito (2016), a major goal of STEM education is to improve students' STEM proficiency regardless of their intentions of pursuing STEM-related careers. This is grounded in the belief that STEM education lends itself to fostering important 21st century skills in students, and these include critical thinking, problem solving, creativity, and collaboration. Such skills are regarded as key to personal, social and economic success. In addition, there is the need to increase the number of STEM graduates to meet the demands of the job market as there are currently not enough qualified professionals to fill in those positions (Conference Board of Canada, 2013; DeCoito, 2016; Let's Talk Science, 2017).

A similar situation takes place in the USA. According to the National Research Council (2011), the broad, long-term goals of STEM education are to increase: a) advanced training in STEM-related areas; b) the quality and the size of STEM-capable workforce; c) the level of scientific literacy of the average citizen; and d) the participation of women and minority groups in STEM-related professions. More immediate goals, however, focus on: a) expanding the number of students who pursue advanced STEM-related careers; b) increasing the number of well-equipped professionals for STEM-related careers; c) increasing the number of female students who enrol in STEM-related subjects at high-school level; and d) increasing the level of STEM-related knowledge and understanding of individuals who do not follow careers within STEM areas, which will ultimately prepare individuals to make well-informed decisions about a wide range of issues that affect their personal lives, communities, and the society at large (National Research Council, 2011).

Likewise, in the UK, to ensure that 21st century science and mathematics education keeps pace with a rapidly changing world, The Royal Society Science Policy Centre states in its 2014 report (The Royal Society Science Policy Centre, 2014) that equipping people to think scientifically and mathematically is paramount as it enables them to use knowledge from the classroom to make informed judgements about personal, social, political, and global issues. Moreover, the 2014 report emphasizes that STEM education needs to be strengthened even further if the UK is to remain an economic power and keep its leading position in STEM-related areas. Apart from these broad goals, there are more specific ones which include: a) an increase in STEM educational-based research linking it to teacher professional development of both pre-service and in-service teachers; b) to improve communication among scientists, policy-makers, educators, students, and the general public; c) to motivate minority group students such as those of black Caribbean descent to engage with STEM; and d) to increase the number of students in STEM-related areas in higher education (The Royal Society Science Policy Centre, 2014).

2.2.2 The demand for STEM professionals

In line with the goals described above, The United Nations Educational, Scientific and Cultural Organization (UNESCO) emphasizes the importance of STEM as a contributing factor to equip young people for the job market. UNESCO "Current Challenges in Basic Science Education" document states that *"[a]ll schools and schooling systems accept that part of their role is to prepare children for the world of work, sometimes implicitly and, more and more, explicitly. To achieve this aim, school systems and their stakeholders will see that affective and motivational aspects of science learning are important not only in the classroom, but also in the wider societies"(UNESCO, 2012, p. 12).*

As shown below, the shortage of STEM workers is a common problem in many parts of the world. According to BQ Portal, supported by the German Federal Ministry for Economic Affairs and Energy (2013), countries such as Germany, the USA, Japan and Brazil were trying to attract foreign STEM workers. To do this, they reformed their immigration policies.

Similarly, in Canada, the 2012 HUMA Committee Report by the House of Commons states that some companies are working on making STEM-related jobs appealing to foreign workers. Moreover, the report emphasizes that without a steady number of students graduating in STEM-related professions, the science and technological industries will be negatively impacted. The mining industries, for example, are expected to hire an additional 1,370 geologists, geochemists and geophysicists and 665 mining engineers by 2021. Petroleum producing companies are expected to need engineers, geologists and technicians. Other types of engineers, architects, biotechnology and environmental workers are also in demand. The report concludes that STEM-related careers need to be promoted to students, parents and teachers (HUMA Committee Report, 2012).

The European Centre for the Development of Vocational Training (CEDEFOP) states that professionals in STEM-related areas are among the top five skill shortage occupations across the European Union (EU) (CEDEFOP, 2017). The EU Skills Panorama 2014 report (ICF and CEDEFOP, 2014) emphasized that there was consistent numerical and percentage growth in STEM jobs in Europe from 2003 to 2013. This growth is expected to continue from 2013 to 2025. "*Over one million additional science and engineering jobs are expected to be created from 2013 to 2025; meaning that, by 2025, science and engineering professionals will comprise 3% of the total EU-28 workforce (7.7 million workers)*" (ICF and CEDEFOP, 2014, p. 2).

The following statistics come from the USA. According to “Strengthening High School Chemistry Education Through Teacher Outreach: A Workshop Summary to the Chemical Sciences Roundtable” published by The National Academic Press in 2009, the Wright-Patterson Air Force Base in Dayton needed 7,000 scientists and engineers to replace retiring workers in the subsequent five years. According to a Miami University professor, recruiting professionals of such qualification may prove challenging (Olson, 2009).

Furthermore, the US Department of Commerce Executive Summary published in 2011 emphasized that STEM workers play a key role in the sustained growth and stability of the US economy (Langdon, McKittrick, Beede, Khan, & Doms, 2011). In addition, the report provides meaningful statistics: a) growth in STEM jobs was three times greater than non-STEM jobs between 1997 and 2007; b) STEM workers are less likely to lose their jobs than their non-STEM counterparts; c) STEM occupations are expected to grow twice as much than non-STEM ones between 2008-2018; d) STEM workers earn on average 26% more than their non-STEM counterparts; and e) workers who are STEM degree holders have greater financial rewards than their non-STEM counterparts even when they work in non-STEM fields (Langdon, McKittrick, Beede, Khan, & Doms, 2011). Apart from a sustained demand for STEM workers, the sources above show that STEM education has the potential to offer professional stability and financial reward. In addition, STEM knowledge and skills are appreciated not only in STEM-related areas but also because they can be transferable to other fields.

This sub-section highlights that professionals in STEM-related fields are appreciated for their knowledge and skills, because they are effective contributors to a country’s society and economy. However, STEM education still faces some challenges, and those will be described in the next sub-section.

2.2.3 The challenges and the potential contributions of STEM education

There is a consensus among educators that quality K-12 education is paramount to achieving greater STEM proficiency in the general population (DeCoito, 2016; Katehi, Pearson and Feder, 2009; Marshall & Alston, 2014; The Royal Society Science Policy Centre, 2014; Zan, 2016). However, it is well accepted that despite efforts from educators and policy makers, there is a current student disengagement from STEM-related disciplines (Hathaway & Kallerman, 2012; Let's Talk Science, 2013, 2017; O'Grady, Deussing, Scerbina, Fung, & Muhe, 2016; The National STEM Learning Network, 2017). This dichotomy leads us to believe that STEM education has not been able to fulfill its potential. According to the studies below, inadequate teaching practices is part of the problem. In addition, engineering education (the "E" in STEM) is particularly affected by the lack of space in the curriculum, adequate standards, and failure to attract women and minority groups.

For example, Zan (2016) states that engaging children in early education with well-designed STEM projects led by well-prepared teachers has the potential to foster skills, knowledge, and positive attitudes towards STEM in them. In addition, based on the evidence from her work on ramps and pathways with young children, she argues that *"by engaging in STEM experiences, children have opportunities to develop habits and behaviors that will serve them well in academic achievement in all domains"* (p.7). However, according to Zan (2016) not all teachers are fully-equipped to provide students with STEM activities that nurture creativity, problem-solving, and the ability to make intentional plans. In her opinion, *"opportunities to introduce young children to important STEM concepts and processes are being missed every day because teachers do not provide activities that challenge children to think about and engage with STEM contents beyond memorizing isolated facts"* (Zan, 2016, p.7). Along these lines, DeCoito

(2015) emphasizes that inadequate pre-service teacher education programs hinder the development of effective STEM education.

In a survey administered to 1,222 US K-12 elementary, secondary and high-school mathematics and science teachers to measure their beliefs about and use of inquiry-based pedagogy in the classroom, participants reported devoting about 20% less class time to such practice than they judge adequate. The study also shows that there was no correlation between teachers' seniority level and the amount of inquiry time in their classes. In addition, the authors hope this study will motivate teacher professional development programs to adopt practices aimed at nurturing inquiry-based practices in teachers (Marshall, Horton, Igo & Switzer, 2009). In tandem with this, Marshall and Alston (2014) state that traditional, teacher-centred pedagogies are still widely used in the US mathematics and science classrooms despite research evidence that demonstrates the educational value of inquiry-based learning on students.

Katehi, Pearson and Feder (2009) analyzed the current state of engineering in US K-12 schools. For them, despite its potential to efficiently integrate mathematics, science and technology, and the increase in the number of schools that have incorporated engineering in their curricula, engineering education is not as widespread and structured as the other three STEM-related subjects. The authors state that challenges of K-12 engineering education include the lack of: a) clarity and understanding of the most important ideas in engineering; b) consensus regarding the type of knowledge and skills that should be addressed; c) content standards; and d) enough teacher professional development programs (Katehi, Pearson and Feder 2009).

According to Custer and Daugherty (2009), there has been a growing interest in K-12 engineering in recent years, not least because of *"serious concerns about the declining number of students entering the engineering pipeline"* (p.18). However, they list several issues that need

addressing before engineering education becomes a fundamental part of school programs. These include: a) deciding on a set of contents that should be taught; b) convincing stakeholders about the importance of engineering; and c) preparing teachers. Regarding teacher education, teachers will have to be better equipped in terms of content knowledge and pedagogical practices to integrate subject contents and to facilitate hands-on inquiry-based activities (Custer and Daugherty, 2009).

This sub-section presented several issues that prevent STEM education from fulfilling its potential of producing scientifically-literate societies and qualified professionals. The next one will indicate some ways to address some of the above-mentioned issues.

2.3 Addressing the Challenges in STEM Education

2.3.1 Some effective inquiry-based models to STEM education

This sub-section provides some models to STEM education that are based on the premise that inquiry plays a key role in addressing the challenges mentioned earlier. Their proposition is in line with the contemporary educational reforms advocated by the new K-12 school curriculum in British Columbia (BC), Canada (British Columbia Ministry of Education, 2015). It is important to highlight, however, that these models should not be regarded as recipes, but rather as examples of effective practices.

Luft (2001), for example, explored how Inquiry-Based Demonstration Classroom (IBDC) impacted the instruction of in-service secondary science teachers. This program, aimed at enabling teachers to incorporate extended inquiry lessons into their practices, was developed according to the Search, Solve, Create, and Share (SSCS) problem-solving model described in Pizzini, Shepardson and Abell (1989). It is consistent with the recommendations for inquiry-based science education from the National Science Education Standards (NRC,1996). Findings

from the study revealed that participants showed improvements in their extended inquiry practices, including the way they assess inquiry-based instruction. Their students, in turn, showed improvement in developing researchable questions, designing and conducting investigations, and communication skills (Luft, 2001).

For Akkus, Gunel, and Hand (2007), one of the challenges faced by STEM education is changing the more traditional ways generally adopted by teachers into inquiry-based learning. For them, Science Writing Heuristic (SWH) enables learners to develop a firm grasp of the "big ideas" within science contents by adopting a template. This encompasses "*constructing and testing questions, justifying their claims with evidence, comparing their ideas with those of others, and considering how their ideas have changed through this process*" (p.1746). In addition, learners engage in collaborative writing tasks that emphasizes scientific argumentation. In other words, SWH can be viewed as an improved format of laboratory reports. Evidence from a mixed-method study in which the authors compared SWH's effectiveness with a more traditional teaching approach indicates the benefit of SWH. The authors further argue that *"the SWH approach provides both teacher and students with a common discourse pattern where they can jointly contribute to the construction of scientific knowledge produced within their classroom"* (Akkus, Gunel, and Hand, 2007, p 1763).

In a five-year study aimed at analyzing a teacher professional development program called Inquiry in Motion (IM), Marshall and Alston (2014) concluded that quality inquiry-based instruction improved student performance and achievement. The program included 11 schools, 74 middle school teachers, and 9,981 students. Students whose teachers participated in IM performed significantly better on the Measure of Academic Progress science tests than those whose teachers did not participate in it. However, despite the positive results, students have not

yet achieved the new benchmark by *Next Generation Science Standards*. For Marshall & Alston (2014), teachers who go through professional development programs such as Inquiry and Motion are more effective in providing students with the opportunity of asking questions, raising hypotheses, testing hypotheses, and justifying their reasoning. Thus, through quality inquiry-based instruction teachers can help students gain STEM proficiency (Marshall & Alston, 2014).

Besides, DeCoito (2015) concluded that through the Wind Turbine Blade Design (WTBD) students and TCs could attain the goals of STEM education, especially regarding the implementation of an engineering design process. The WTBD approach is based on Khandani (2005)'s "Engineering Design Process", which encompasses defining a problem, gathering information, generating multiple solutions, analyzing workable solutions, selecting a solution, and testing and implementing a solution. For the author, when students work to achieve the mini-tasks of the process, they acquire experiences in project management and design, thus recognizing the importance of each step of the process for the project's overall success. For the TCs who participated in the study, this inquiry-based approach was successful in terms of: "*collaboration, engagement, self-realization, heightened self-efficacy, enhanced critical thinking skills, multi-literacy, agency, environmental stewardship and awareness, fostering 21st century agents, and innovation"* (DeCoito, 2015, p.7).

Moreover, Zan (2016) proposed the Inquiry Teaching Model (ITM), which is a framework to help teachers to support learners' inquiry learning. The model follows the format of a cycle of three interconnected sections: "engage learners", "provide opportunities", and "make informed decisions". "Engage learners" involves identifying their interests, while activating their prior knowledge and stimulating their interests. "Provide opportunities" facilitates learners' active exploration, and this entails posing and solving problems. In

scaffolding learners to develop problem-solving and experimentation skills, resourceful teachers have opportunities to nurture communication and linguistic development in learners. Lastly, "make informed decisions" encompasses teachers making appropriate interventions to promote deeper thinking, check for understanding, integrate activity contents with other school subjects, and document learning (Zan, 2016).

In "Implementing Ramps and Pathways in the Classroom", Geiken, Uhlenberg and Yoshizawa (2016) argue that making comments and asking productive questions are some important strategies through which teachers can effectively apply the ITM described above. For them, teachers' comments should give learners specific indication of why they are correct or incorrect. Thus, phrases such as "*good job*" should be avoided for being too generic. As for questions, Geiken et al. (2016) provide examples that allow students to move along a continuum, from a more concrete to a more abstract reasoning. For example: *"Where did the marble stop when it went up the ramp? What would happen if you added another block under the ramp? What could you do to make the marble turn two corners?*" (p.48). For Geiken et al. (2016), quality teacher-learner interaction is the foundation of effective inquiry-based instruction.

The models presented in this sub-section emphasize the educational value of quality inquiry-based instruction. They are in line with Howard-Brown & Martinez (2012) for whom inquiry-based instruction is becoming increasingly accepted as the way to move forward in STEM education. As demonstrated, both student and teacher effective communication is an integral part of the process. The next sub-section will show that providing pre- and in-service teachers with opportunities to practice their teachings in environments other than school classrooms is beneficial to their professional development.

2.3.2 Improving teacher knowledge through outreach

The studies presented in this sub-section demonstrate that out-of-school experiences allow pre- and in-service teachers to broaden and adjust their teaching techniques to cater for different audiences and contexts. These out-of-school experience should help STEM education to fulfill its potential and attain its main goals.

2.3.2.1 Partnerships between science centres and university-based teacher education programs

The studies below illustrate that university–science centre partnerships are valid initiatives for teacher education. Such linkages are shown to have the potential to prepare TCs for their future teaching jobs for reasons that include: a) opportunities to teach the same contents multiple times; b) experience in utilising constructivist educational approaches; c) appreciation for the affective nature of pedagogical relationships; and d) increased motivation and confidence to teach science.

For example, Middlebrook (1999) concluded that science museum educators as well as college faculty members regarded the experience in which TCs spend some practicum time in a science museum beneficial to both TCs and museum staff. According to senior educators involved in the initiative, the museum experience enabled TCs to: a) enhance their teaching practice by engaging with learners of different age-groups and backgrounds; and b) learn by observing other educators' teaching styles.

In an ethnographic study, Jung and Tonso (2006) examined the effects of two experiences in which TCs spend some time during their practicum as interns in science centres. Study outcomes indicate that participants acquired experience with hands-on and inquiry-based science

teaching practices. Furthermore, TCs' affective domain was positively impacted as they gained confidence in their abilities to teach.

Moreover, UBC Faculty of Education added a three-week internship in the Vancouver Aquarium to the existing classroom-based practicum of a teacher education program leading to certification as secondary science teachers in the province of British Columbia, Canada. In evaluating this initiative, Anderson *et. al* (2006) concluded that the experience was positive as participants developed a broader understanding of teaching theories and of teaching skills that could be applicable to teaching K-12 students in school settings.

Subsequently, UBC Faculty of Education raised the Vancouver Aquarium experience to another level by adding two additional sites (a science museum and an art gallery) to the practicum. At that time, TCs, who had majors either in biology, chemistry, physics, or art, were divided in three groups and assigned to a 3-week internship in one of those three institutions. Thus, once their 10-week classroom placement was over, TCs went to their respective institutions where they had to attain the following aims: a) to establish effective communication with K-12 students; b) to broaden their teaching skills to accommodate students' needs; and c) to facilitate learning in those informal environments. According to Jenkins (2010), this study's findings indicated that the partnership was beneficial to the development of novice teachers in several ways. First, participants gained a better understanding of different pedagogical approaches either by observing other educators apply them or by experimenting with such pedagogies themselves. Second, they developed awareness of and appreciation for the affective nature of pedagogical relationships. Third, the absence of the pressure they had experienced in the classroom-based placement regarding lesson planning and their own evaluation allowed

participants to be more attentive to student involvement and learning. Fourth, participants developed a better understanding of constructivist pedagogies.

Furthermore, Gupta and Adams (2012) evaluated two studies that encompass similar partnerships between universities and what they refer to as “informal science institutions” (ISIs). One study was done in Jerusalem and the other in New York. In the Israeli one by Brezner (2008), female undergraduates pursuing qualification to become science teachers in elementary and/or secondary schools attended 60 hours of training at Bloomfield Science Museum Jerusalem. In the US study, undergraduate students pursuing qualification in secondary science at City College spent at least seven hours per week at the New York Hall of Science during the third and fourth years of their teacher education program. For Gupta and Adams, *“overwhelmingly, preservice teachers mentioned that working in an ISI helped them to practice and refine their teaching, especially in using constructivist pedagogy, as this is the guiding philosophy of many ISI program designs and enactments”* (2012, p.1154).

Gupta and Adams (2012) further concluded that by explaining the same contents multiple times to a variety of visitors made TCs more aware of the type of interventions they would make depending on how visitors asked questions and/or responded to them. As each interaction was unique and enacted differently, the ISI experience helped TCs to develop essential skills, which could then be applied in classrooms as well as in informal educational settings.

This sub-section showed some successful examples of partnerships between science-centres and university-based teacher education programs. The next sub-section will provide evidence of the benefits of other forms of university-science centre partnerships to both pre- and in-service teachers.

2.3.2.2 **Influence of other outreach initiatives on STEM teacher professional development**

The previous sub-section provided an analysis of some studies that focused on science centre-university partnerships during teacher education programs. This sub-section brings some research evidence of how pre- and in-service teachers benefit from other forms of university-based outreach.

Myszkal (2016), for example, explored the potential of Outreach Workshops in STEM (OWS) to affect in-service teachers' content knowledge, self-efficacy, pedagogical approaches, and its viability as a potential form of professional development. In a mixed-method study, which was part of a larger longitudinal study looking at the potential of OWS to influence middle school students' and teachers' attitudes and beliefs in STEM, the author found that 64% of the in-service teachers from the three different Ontario schools, felt they acquired new teaching ideas and strategies after participating in the OWS workshops. Moreover, although only 18% of teachers reported having gained STEM content knowledge, 45% of them acknowledged the educational value of their OWS participation. Furthermore, 27% of the participants considered that the OWS experience reaffirmed the need for hands-on inquiry-based STEM activities. In addition, 36% of teachers felt encouraged to do more hands-on inquiry-based STEM activities (Myszkal, 2016).

The other example comes from Louisiana, in the USA. In a quantitative study funded by Shell Oil Company Foundation and carried out by McCarthy (2015) to raise interest in STEM-related activities, 20 TCs from an integrated science/language arts/social studies methods course at Southeastern Louisiana University were asked to mentor fourth graders and eight graders from two different Louisiana schools. The students were being prepared to enter a Science Fair

contest. The objective of the study was to assess TCs' knowledge of designing and conducting appropriate inquiry-based scientific practices. First, TCs divided students into groups. Then they provided students with ideas and websites to help them identify a theme of their interest. After, TCs helped students to carry out the many steps required by robust scientific investigations. Evidence shows that 56% of the 41 eighth graders and 83% of the 43 fourth graders in the partnership entered their school science fairs. Furthermore, pre- and post-test revealed a significant increase in TCs' knowledge of scientific practices and investigations. Apart from the quantitative findings above, McCarthy (2015) states that TCs' reflections revealed that

> "*this was a valuable experience beyond strengthening understanding. Lessons in improving science pedagogy were also learned. The teacher candidates adapted science teaching materials to fit ability and age, learned to be "animated" about the task, use "visual examples" use "visual examples," those "personal to the students' lives." They recognized the effectiveness of "small group settings" and "one-on-one time."* (p. 40).

In addition, National Research Council (US) Chemical Sciences Roundtable published in 2009 "Strengthening High School Chemistry Education through Teacher Outreach: A Workshop Summary to the Chemical Sciences Roundtable". Chapter 5 of this document focuses on evaluating the impacts of some successful outreach initiatives on teachers. For example, The AirUCI Summer Workshop for Teachers has been running a two-week workshop attended by 20 teachers every year since 2005. As each of those teachers interacts with approximately 150 students in any given year, it is estimated that the program has the potential to reach 3,000 students each year. Participants are middle or high school teachers specialized in chemistry, physics, environmental science or integrated science from schools located near the University of California, Irvine (UCI). The workshop features activities done with cutting-edge equipment

adapted to match school curricula. In a recent evaluation, when asked whether they had been able to incorporate information from the workshop into their school course syllabi, 84% of the participants answered "*yes, to a certain extent*" (p. 26). Moreover, 13% answered "*My syllabi have changed significantly as a result of taking this course*" (p. 27). Additionally, 97% of the participants reported that their content knowledge had improved (Olson, 2009).

Another example from the workshop summary mentioned above concerns an outreach program run by Miami University, in Ohio called "Terrific Science: Empowering Teachers through Innovations". More than 22,000 teachers have participated in it since its creation in the eighties. Participants learn how to set up and run hands-on activities and are encouraged to adapt these activities to their school contexts. Assessments of the program revealed that the students whose teachers attended the program: a) spent more time in laboratories testing their own hypotheses; and b) had better results in physical science tests (Olson, 2009).

The studies above provided various examples of how quality outreach programs can be viable options for pre- and in-service teacher professional development. All in all, the cited programs have had a positive impact on the participants' teaching practices, which ultimately produced a positive effect on their students. The next section will demonstrate that outreach can also be beneficial to parents and families as well as learners.

2.4 Benefits of STEM Outreach to Parents and Learners

Research evidence shows that parental engagement is key to children's education (Green, Walker, Hoover-Dempsey & Sandler, 2007; Hango, 2007; Let's Talk Science, 2015). It is also well accepted that parents play a crucial role in their children's STEM education (Chachashvili-Bolotin et al., 2016; Ing, 2014; Yaro, 2015). In line with this, Let's Talk Science runs a project called "Canada 2067 – The Science of a Successful Tomorrow". Its website informs parents

about how and why they should exert a greater influence on their children's STEM education (Let's Talk Science, 2017a).

Moreover, in a mixed-method case study done in the context of 2016 UBC FMSD, Marotto and Milner-Bolotin (2018) learned the following about parental motivation to engage with their children's STEM education. For parents, STEM *"has many applications in everyday life (93.1%); provides interesting ways to learn about the natural world (89.7%); is at the core of technological innovations (82.8%); and helps students develop critical thinking (86.2%)"* (p.23). Moreover, 100% of the parents approved of the 2016 FMSD, considering it either *"very interesting"* (79.3%) or *"interesting"* (21.7%). Furthermore, 89.6% of the participants reported that accompanying their children to science centres such as science museums, aquaria, botanical gardens, and STEM-related events are effective ways to motivate children to engage with STEM.

In line with that, Briseno-Garzon and Anderson (2012) and Dierking and Falk (1994) concluded that family visits to science centres are appreciated as they offer opportunities that facilitate emotional learning as well as the acquisition of scientific knowledge. Moreover, science centre visitors place a high value on the social dimension of the visit (Briseno-Garzon, Anderson & Anderson, 2007).

Milner and Marotto (2018) provide a comprehensive list of international outreach initiatives aim at encouraging parents to support their children's STEM education. These will be described in the sub-sections below.

2.4.1.1 **Courses that help engage parents and children with STEM**

Evidence from the international studies below shows that parents and learners benefit from courses and other similar initiatives which motivate families to engage with science. The University of York in the UK, for example, created a set of courses for parents called "Science is

for Parents Too" (Leach, 2017). The courses are structured to teach parents science-related contents their children are learning at school. The 2014-2015 course final assessment report indicates an increase in parental knowledge of and confidence about science. It also shows that *"[a] greater proportion of children whose parents attended the courses would like to be a scientist after the course compared to the control group"* (West, 2015, p. 1).

The second example comes from the University of Helsinki in Finland, where "S*cience Clubs"* were created for children aged 3-6 years old. According to Vartiainen and Aksela (2013), parents whose children attended the science club reported that discussions about the club's activities were recurrent in the family. Moreover, these parents reported that their children's interest towards science was raised as a result.

The third example comes from the US where The Franklin Institute (TFI), a major US Science Museum, developed and implemented Parent Partners in School Science (PPSS) (Luke & Foutz, 2007). This project, funded by the National Science Foundation, provided teachers, parents and children from three Philadelphia elementary schools with opportunities for engaging in STEM-related activities at school, at home, and in the community. According to McCreedy, and Luke (2006), parents reported that the PPSS initiative helped to: a) raise their children's interest in science; and b) improve their relationship with their children's teachers.

2.4.1.2 **STEM materials for minority groups**

These initiatives focus on parents for whom the lack of proficiency in the language of school instruction might become a barrier for supporting their children's STEM education: Family Science (Foundation for Family Science, 2017); Techbridge Girls (Techbridge, 2017); and Equals and Family Math (Lawrence Hall of Science, 2017). Besides, they are in tandem with

some of the overarching goals of STEM education that aim to motivate minority groups to engage with STEM.

This sub-section presented some studies that provide evidence of the benefits of outreach to educators. Moreover, outreach provides valuable educational experiences for parents/families and learners. Benefits include conceptual and social learning as well as an increase in excitement, motivation and interest to engage with STEM-related activities. The next sub-section will bring a summary of the literature analyzed in Sections 2.1-2.4.

2.5 Summary of Literature Review

Section 2.1 provided the theoretical framework for this study before presenting the literature review to contextualize the literature presented in the subsequent sections. Section 2.2 presented an overview of STEM education, including a definition, some of its goals, potential contributions, and the demands for STEM professionals in several parts of the world such as Canada, the USA and Europe. These studies demonstrated that, despite its potential to contribute to the creation of scientifically-literate societies and qualified workforces, STEM education still faces several key challenges. As shown in Section 2.2.3, these include: a) student disengagement from STEM; b) inadequate teaching practices; and c) the lack of a solid foundation for engineering education is schools.

Furthermore, Section 2.3, offered some ways to address the aforementioned challenges. Research evidence shows that inquiry is a major component in STEM education, and some inquiry-based models are effective for improving teaching practices and student learning. Finally, Section 2.4 demonstrated that outreach experiences and initiatives play an important role in STEM education for reasons that include: a) promoting parental engagement with their

children's education; b) increasing motivation of teachers and learners towards STEM; c) improving pre-service and in-service teachers' practices; and d) increasing student learning.

In summary, the studies described in this chapter reinforced the relevance of further investigating how the engagement of STEM TCs in STEM outreach activities during their teacher education program can support them in becoming effective educators and reflective practitioners. This led to the main question of this study: *How does participation in a public STEM outreach experience impact teacher candidates' pedagogical content knowledge, communication skills, motivation to teach STEM-related subjects, and understandings of how STEM is effectively taught and learned?*

The next chapter will describe the study's methodology and design, its context, participants, and methods of data collection.

Chapter 3: Discussion Methodology and Design, Context and Methods

This chapter is divided into six sections. Section 3.1 presents the study's methodology and design. Section 3.2 presents the study's context, which includes *Secondary Science Teacher Education* program at the University of British Columbia (Sub-section 3.2.1); the *General Science Methods* course (Sub-section 3.2.2); *Family Math and Science Day* (Sub-section 3.2.3); and the study's participants (Sub-section 3.2.4).

Then, Section 3.3 presents the methods used for data collection: online survey (Sub-section 3.3.1); focus group (Sub-section 3.2.2); and individual interviews (Sub-section 3.2.3). Section 3.4 presents information about data analysis, and that is followed by the study's ethical considerations (Section 3.5). Finally, Section 3.6 presents the limitations of the study design.

3.1 Methodology and Design

This study aims to further the knowledge of the role that STEM outreach plays on teacher education programs. Moreover, it seeks to learn how this outreach experience impacts TCs' pedagogical content knowledge, communication skills, motivation towards STEM, and understanding of how STEM is effectively taught and learned. To achieve that and answer the research questions accordingly, this study adopted an interpretative case study methodology (Merriam, 1998; Stake 1995; Yin, 2002). This approach enabled a detailed description of the whole process, including participants' experiences of the: a) preparations for the event; b) activity facilitation at the event; and c) reflections about activity facilitation at the event. Consistent with case studies, data collection comprised multiple methods and multiple sources (Merriam, 1998).

The research design employed a *Partially Mixed Concurrent Dominant Status Design* (PMCDSD; Leech & Onwuegbuzie, 2009), where both quantitative and qualitative data were

collected. The descriptive statistics informed the analysis of qualitative data, as well as the emergent descriptive themes that impacted TCs.

3.2 Context

3.2.1 Secondary Science Teacher Education at UBC

The University of British Columbia hosts one of the largest teacher education programs in Canada. Teacher candidates must have a bachelor's degree in a science-related area to enroll in it. Obtaining the 60 credits required by this 11-month program encompasses taking a subject-specific methods course (e.g., a three-credit chemistry methods course), one general methods course (e.g., a three-credit science methods course), and a 10-week extended school practicum (http://teach.educ.ubc.ca/bachelor-of-education-program/practicum/) . The remaining credits come from the general education courses aimed at developing TCs' general pedagogical knowledge (Milner-Bolotin, 2016b).

3.2.2 General Science Secondary Methods course

The *General Science Secondary Methods* is a required course for all secondary science UBC TCs. It encourages future secondary science teachers to reflect on curriculum, pedagogy and assessment in the context of secondary science education. Because of the large number of attendees in the program in 2017 (almost 80 TCs), three sections of it ran in parallel. This study comprised TCs from two of these three sections (N=46): one of the sections had 26 and the other 20 TCs, respectively. The *General Science Secondary Methods* course (http://teach-educ.sites.olt.ubc.ca/files/2016/08/EDCP-352A.pdf) run for a 12-week period and had 24 meetings of 1.5 hours each.

One of the course's mandatory assignments required TCs to facilitate a hands-on station during FMSD. This experience of facilitating a STEM-related activity to the public at the event

aimed at giving TCs the opportunity to become active, productive, and confident at an early stage of their teaching career. In 2017, the course instructor presented this assignment to TCs at the beginning of the course to allow them enough time to decide on and prepare for the activity to be facilitated at FMSD. The TCs had the freedom to decide on the activity's content and procedures, which could be done individually or in small groups.

3.2.3 Family Math and Science Day

Family Math and Science Day (FMSD) is a free annual family-oriented outreach event that takes place on a fall weekend at UBC Faculty of Education. It consists of 60+ independent, self-contained interactive stations, facilitated by TCs. The event is attended by hundreds of guests coming from the Greater Vancouver Area. To engage visitors of different ages and backgrounds, FMSD has a flexible structure, which allows its public the opportunity to choose stations according to their interests. In 2017, the event was open to visitors for two and a half hours.

Figure 3. A TC engages visitors at FMSD. (Courtesy of Marina Milner-Bolotin)

Figure 4. A TC engages visitors at FMSD. (Courtesy of Marina Milner-Bolotin)

3.2.4 Study Participants

All 46 TCs who attended two of the three sections of the *General Science Secondary Methods* course were invited to participate in the study. The TCs who attended the third section of the course were not invited because that section was run by a different professor, who did not require his students to facilitate activities at FMSD.

The researcher audited the two sections of the aforementioned course as part of his UBC graduate program and, consequently, was acquainted with the course attendees. This familiarity seems to have encouraged the TCs to participate in the study. All 46 of them agreed to take part in at least one of the three data collection methods: online survey, focus group, and individual interview. Thus, a convenience sampling method was used and the TCs' participation was

voluntary and unpaid. Specific information about each of the methods and about the participants is provided in Sections 3.3 and 4.1, respectively.

3.3 Methods

To answer the RQs, it was paramount to describe and understand the impact of the FMSD experience on the TCs. Therefore, a three-stage approach was employed. This comprised: a) on-line survey; b) focus group discussions; and c) follow-up individual interviews. Figure 6 shows the study's data collection methods, their corresponding dates, and number of participants.

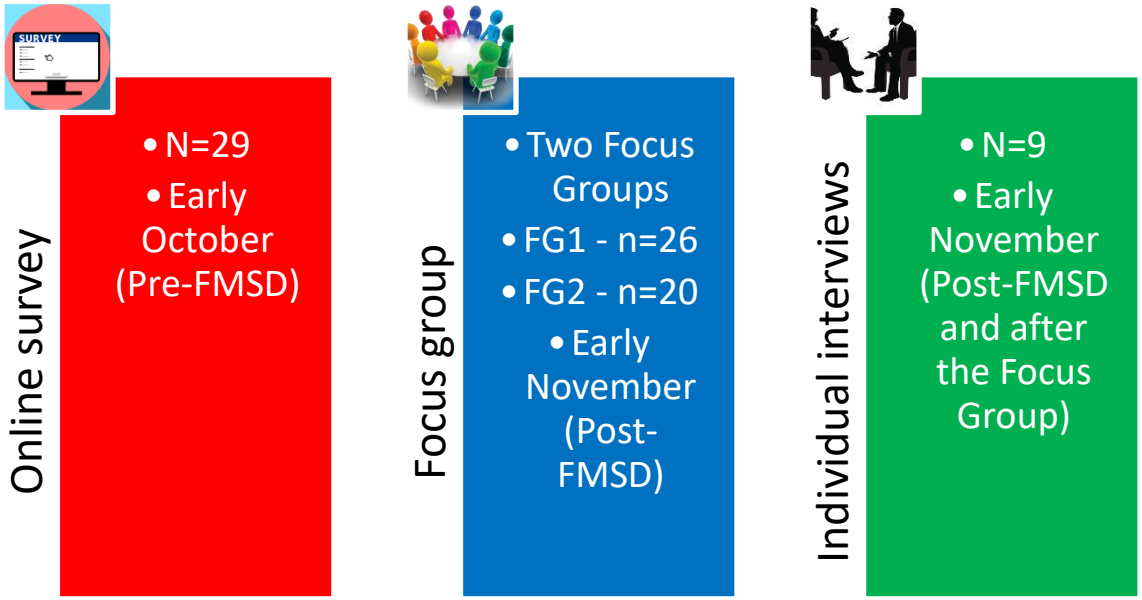

Figure 5. Data collection methods, dates, and number of participants.

The on-line survey enabled a large amount of data to be collected before the TCs' facilitation at the event. Moreover, it was useful to learn TC's expectations about FMSD. The focus group discussions, held after the event, encouraged TCs to share their views and experiences about their facilitation and build on each other's responses. Lastly, the individual

interviews gave TCs the opportunity to deepen their views about their experiences without the constraints of the group.

3.3.1 Online Survey

The first data collection method was a specially developed on-line survey (Appendix A). That decision was based on the following reasons. First, an on-line administration mode allowed TCs to do it at their own convenience, eliciting a high response rate. Second, the on-line format enabled a large amount of data to be collected, organized, and partially analyzed in a short space of time. Third, the survey allowed the researcher to gain specific knowledge of the participants' demographics, personal relationships with STEM education, and previous teaching experiences. Finally, it asked participants about: a) their strengths and limitations as STEM teachers; b) the potential benefits of the outreach experience to their education; and c) effective ways to prepare for the facilitation at the event. This method generated relevant data to answer RQs 2 and 3.

The survey was piloted in advance and was produced based on a previous study done together with UBC professor Dr. Marina Milner-Bolotin in the context of the 2016 FMSD. On that occasion, our aim was to learn what motivated parents to engage with their children's STEM education.

Twenty-nine (63%) of the 46 TCs who attended the two sections of the *General Science Secondary Methods* course described in Section 3.2 completed the survey. An e-mail message with the link to the survey questions was sent to TCs. The respondents did it within one week after receiving the invitation. Table 2 gives an overview of the 16 questions that comprise the survey.

Table 2

Overview of the study's survey questions

Item/question focus	# of items/questions
Demographics: TCs' age, bachelor's degree, teaching experiences in formal and informal settings.	7
TCs' reasons to be STEM-related teachers.	2
TCs' views of what makes effective STEM teachers.	1
TCs' strengths and limitations as STEM teachers.	2
TCs' views of what they would need to be effective activity facilitators at FMSD.	1
TCs' views of how their participation at FMSD would contribute to their teacher education.	1
Invitation to participate in a follow-up individual interview	2

3.3.2 Focus Group

The second data collection method comprised two focus group discussions. This method was useful to answer RQs 1 and 3 as it gathered information about TCs': a) preparation for FMSD; b) experiences about their facilitation at the event; b) impressions about the event organization; c) views about parental engagement with their children's STEM education; d) ideas of the importance of STEM outreach; e) and suggestions for future FMSD editions.

All 46 TCs from two of the three sections of the *General Science Secondary Method*s course participated in the focus group discussions. Ideally, focus groups should contain no more than eight participants to allow each one of them enough speaking time. However, due to the

constraints of the context, only two group discussions were conducted. They respected the groupings of the *General Science Secondary Method*s course, and so, one group had 26 participants and the other 20.

While this decision may have had an impact on the quality of the data that emerged from the discussions, the realities of the context had to be dealt with. The main justifications behind the decision were: a) it was logistically easier to conduct the discussions according to the course groupings because they were done in the same room as the course, immediately before the class started; b) the TCs already knew their peers and were comfortable with each other as they had been attending the same course; and c) some TCs had common experiences to share as they had worked together during activity preparation and facilitation. Both group discussions were conducted two days after FMSD to make it easier for TCs to retrieve the facts, feelings and emotions related to the event. The discussions lasted approximately 30 minutes each and were audio-recorded.

One of the advantages of focus group discussions is that they allow participants to build on each other's ideas, and this may lead to a deeper, more reflective thinking. However, one of its limitations regards participants feeling uncomfortable to express their views in front of their peers. To address this, subsequent individual follow-up interviews were conducted. Another focus group limitation refers to the potential of "group thinking" to occur. To mitigate this, a semi-structured interview protocol was used (Fontana & Frei, 1994).

The protocol used in the focus group discussions (Appendix B) was very similar to the one used in the individual interviews. The questions, which had been piloted in advance, were informed by the participants' responses to the on-line survey and by the discussions between the

principal investigator and the thesis supervisor. Table 3 gives an overview of the 16 questions that comprise the focus group discussion protocol.

Table 3

Overview of the protocol used for the focus group discussions

Item/question focus	**# of items/questions**
TCs' impressions about the event.	1
TCs' previous outreach experiences.	1
TCs' views of the stakeholders in STEM education.	1
TCs' views of the importance of outreach to STEM education.	1
TCs' views of the importance of parental engagement with their children's STEM education.	1
TCs' description of the activity facilitated at the event.	1
TCs' preparation for the event.	3
TC's views of their activity facilitation at the event.	4
TCs' strategies for a hypothetical future participation at FMSD.	1
TCs' views about the importance of FMSD to their education.	1

TCs' suggestions for future FMSD editions.	1

3.3.3 Individual Interviews

Of the 46 TCs who had participated in the focus group discussions, nine (19.5%) were subsequently interviewed: eight face-to-face and one in written format via email correspondence. This third method of data collection allowed participants to freely express their ideas without the constraints of the group. The interview protocol (Appendix C) was similar to the one used for the group discussions. Minor changes were made to allow the interviewees to deepen their views on topics that had not been fully exploited during the group discussions. This included customized questions about how they: a) prepared for the event; b) facilitated their activity; c) refined their activity facilitation as the event unfolded; d) interacted with visitors; and e) evaluated the impact of the event on their education. Learning about TCs' individual experiences was one of the advantages of conducting the individual interviews after the group discussions.

The interviews were set at TCs' convenience and conducted between 2-5 days after their facilitation at FMSD. They were audio-recorded and lasted approximately 20 minutes each. The main purpose of both person-to-person interview and group discussions is to obtain specific information or when the researcher *"cannot observe behavior, feelings, or how people interpret the world around them"* (Merriam, 1998, p. 72).

3.4 Data Analysis

3.4.1 On-line survey

The answers to the first five questions of the on-line survey involved descriptive statistics, and so were quantitatively analysed by means of frequency counts. The answers to the

remaining survey questions were open-ended, and so, were qualitatively analyzed according to emerging themes. These were subsequently tabulated along with the response frequencies. Specific information about the data analysis from the on-line survey is given in Sub-section 4.1.

3.4.2 Focus group discussions and individual interviews

The data from focus group discussions and individual interviews were analysed together because the protocols used in both methods had similar open-ended questions. The two focus group discussions and eight of the nine individual interviews were audio recorded (the remaining interview was done in written via e-mail message). Once the audio-recordings were made, their contents were transcribed.

As the study aimed at investigating how this outreach experience impacted TCs' pedagogical content knowledge, communication skills, motivation towards STEM, and understanding of how STEM is effectively taught and learned, emergent themes were identified within these parameters. In total, 11 emerging themes were identified, and this was done with the support of NVivo 11 (QSR International, 2016). Subsequently, the participants' comments were carefully re-examined and coded according to the 11 pre-identified themes. The number of comments coded for any given theme was relevant to data analysis because it indicated how recurrent the themes were.

Furthermore, the data analysis was also informed by two NVivo queries. The first, *Themes Clustered by Word Similarity,* indicates how connected the 11 emergent themes are according to the wording of their respective coded comments. The second, *Pearson Correlation Coefficient,* indicates the correlation between two variables or, in the case of this study, two themes. *Pearson Correlation Coefficient* values range from 0-1. Thus, the higher the value, the greater the correlation between the themes. Specific information about the data analysis from the

group discussions and interviews is given in Sub-section 4.2. Finally, all the data from were triangulated to address the issues of credibility and validity (Mathison, 1988).

3.5 Ethical Considerations

This study was approved by UBC Behavioural Ethics Review (BREB) Board. Initially, all TCs from the *General Science Methods Course* were orally informed that I would be carrying out this study. All participants agreed to share their email address with me so that I could send them the link to the online survey. Prior to their participation and in accordance with BREB procedures, all participants received and signed a consent letter for each data collection method of the study (online survey, focus group and interview). These documents outlined the principal investigator, the goals, and the conditions for participating and withdrawal from the study.

To ensure anonymity and to maintain privacy and confidentiality, no names or any other personal information were included. Participants were numbered and referred to by their corresponding numbers. Only the participants who wished to be contacted by the researcher to be interviewed provided their first name and a contact number or email address. Those data, however, were not used for the data analysis.

Moreover, as the participants were all attendees of a secondary science methods course instructed by my thesis supervisor, the data collected during for the study was not shared with her before the course was over and all the course grades had already been decided upon. This was done to avoid any conflict of interest, discomfort or embarrassment.

3.6 Limitations of the Design

This study has several limitations. First, its participants are TCs who are attendees of a *General Science Secondary Methods* course instructed by one of the main figures behind the creation and organization of the *Family Math and Science Day* event. Therefore, TCs may feel

inclined to express appreciation for the event as they might think an eventual criticism would be taken amiss. This response bias could have an impact on the study outcomes. Second, the study focuses on a specific type of outreach model, which limits generalizability of results. Furthermore, there are my own limitations as researcher, my gender, age and socioeconomic background. Despite all this, to the best of my ability, this study tried to remain neutral to the findings and open to any and all possible outcomes.

Chapter 4: Results

The data from the closed-ended questions of the online survey involved numbers, and so were quantitatively analysed. On the other hand, open-ended questions from survey, focus group discussions, and individual follow-up interviews were qualitative analysed. The number of comments coded for a specific theme was also relevant as it informed how important the theme was for the participants. Section 4.1 will present the results from the online survey, while Section 4.2 will present the results from the focus group discussions and interviews. The results from Sections 4.1 and 4.2 were subsequently triangulated to enable a better understanding of the study's findings.

4.1 Online Survey

4.1.1 TCs' age groups

Table 4 provides the demographic description of the 29 respondents (63%) to the online survey. As the respondents were from a teacher education program in Canada, it does not come as a surprise that the clear majority were in their early 20s.

Table 4

Respondents' age groups

Respondents' age group	Number of respondents (percent)
20-24 years-old	21 (72%)
25- 29 years-old	5 (17%)
30+ years-old	3 (10%)

4.1.2 TCs' bachelor's degrees

Table 5 shows the fields of participants' bachelor's degrees. All participants (n=29) in this study were from the *General Science Secondary Methods* course. Therefore, all except one had their bachelor's degree in science-related areas. The results suggest that some participants had more than one bachelor's degree.

Table 5

Respondents' bachelor's degrees

Bachelor's degrees	Number of participants	Relative percentage (%)
Biology	17	58.6
Physics	8	27.5
Chemistry	6	20.6
Science	5	17.2
Mathematics	2	6.9
Other	3	10.3

4.1.3 TCs' teaching experiences in formal educational settings

Table 6 shows respondents' (n=29) teaching experiences in formal educational settings. The results suggest that some participants had their teaching experiences in more than one type of formal setting.

Table 6

Respondents' teaching experiences in formal educational settings

Type of formal teaching experience	Number of participants (percent)

Elementary school level (K - Grade 8)	7 (24.1%)
Secondary school level (Grade 9-12)	15 (51.7%)
University/college level	7 (24.1%)
Graduate level	1 (3.4%)
Pre-school level (ages 3-4)	1 (3.4%)
No teaching experience in formal educational settings	9 (31.0%)

4.1.4 TCs' teaching experiences in informal (out-of-school) settings

Table 7 shows respondents' (n=29) teaching experiences in informal (out-of-school) settings. There were multiple responses from a single participant, which account for a response rate greater than n=29. The results suggest that some participants had their teaching experiences in more than one type of informal setting.

Table 7

Respondents' teaching experiences in informal settings

Type of informal setting	Number of participants (percent)
After-school programs	16 (55.2%)
Science museums	6 (20.7%)
Aquaria	2 (6.9%)
In-company programs	1 (3.4%)
Art gallery	1 (3.4%)
Other teaching experiences	8 (27.6%)
No teaching experience in formal settings	9 (3.1%)

4.1.5 TCs' most important reasons to become a STEM educator

Table 8 shows respondents' (n=29) most important reasons for becoming a STEM educator. The survey question asked participants to select the three reasons that best reflected their own case. An analysis of this data reveals the top four reasons included; 1) *I have a passion for teaching*; 2) *I like to work with children/adolescents*; 3) T*o contribute to the production of a scientifically-literate community*; and 4) *STEM-related subjects are instrumental in fostering problem-solving and critical thinking in students*.

Table 8

Respondents' top-three most important reasons to be a STEM educator

Reason to be a STEM educator	Number of participants (percent)
I have a passion for teaching.	23 (79%)
I like to work with children/adolescents.	17 (58%)
To contribute to the production of a scientifically-literate community.	14 (48%)
STEM-related subjects are instrumental in fostering problem-solving and critical thinking in students.	14 (48%)
I have a sound knowledge of STEM-related subject(s).	8 (27%)
I have effective teaching skills.	7 (24%)
To help steer student towards STEM-related professional careers.	7 (24%)
Professional stability	7 (24%)

4.1.6 TCs' views on what makes an effective STEM educator

Participants' (n=29) responses regarding what makes an effective STEM educator were grouped into five main categories (NVivo nodes), some of which were based on Shulman (1986). These were: pedagogical content knowledge (PCK), content knowledge (CK), communication skills (CS), passion for STEM (PS), and personality traits (PT).

Table 9 shows each category, its definition, their respective number of coded responses, and specific examples of participants' responses. As demonstrated by the examples below, participants gave great importance to educators' pedagogical content knowledge, content knowledge, and effective communication skills. However, even more important than those was the educators' emotional attachment with both STEM and the teaching profession. It seems that for TCs, passion for STEM is an essential characteristic of effective educators, and this is an attribute that they ought to have in them from the beginning. Pedagogical content knowledge, however, important as it may be, is something that can be acquired over time through professional development and practice.

Table 9

Respondents views on what makes effective STEM educators

Category (node)	Definition	# of coded responses	Examples of participants' responses
Passion for STEM (PS)	Educators' emotional attachment with STEM	18	Passionate; able to share that passion; my holistic and emotional connection to my subject area can inspire and spark curiosity in students; having the passionate heart about science and teaching.
Pedagogical Content	Educator's knowledge and	15	Practices scientific method in class; has a solid understanding of material along

Category (node)	Definition	# of coded responses	Examples of participants' responses
knowledge (PCK)	skills to adopt adequate pedagogical practices to facilitate student learning.		with a mindset to develop skills in students related to problem solving and critical thinking; able to make abstract concepts relatable and interesting; empowers students to think critically; can interconnect all areas of STEM.
Content Knowledge (CK)	Educators' knowledge of specific subject contents	6	Knowledgeable about concepts; solid understanding of content.
Communication Skill (CS)	Educators' ability to communicate effectively with their target audiences	5	Able to communicate at an appropriate age-level; able to explain a complex idea in a simple, yet inspiring way; effective in communicating with youth.
Personality Traits (PT)	Educators' personal characteristics	2	Empathetic; dedicated and self-reflexive

4.1.7 TCs' self-reported strengths

The responses below reflect respondents' (n=29) self-reported strengths as educators at that time of the study. Like in the previous sub-section, the responses were categorized into PCK, CK, CK, PS, and PT.

Table 10 shows the number of comments coded for each category as well as some examples. It is interesting to note that, contrary to what emerged in Sub-section 4.1.6, great emphasis was given to personality traits. Pedagogical content knowledge, and PS were also highly emphasized. Effective communication skills, however, were only mentioned twice.

Table 10

Respondents' self-reported strengths as educators

Category (node)	# of coded responses	Examples of participants' responses
Personality Traits (PT)	22	Good organizational skills; care for the students; energetic; patience and motivation; enthusiastic; creative; strong drive to be helpful to other people; passionate and caring; strong self-reflective tendencies; approachability; critical and open; hard worker; empathetic to students.
Pedagogical Content Knowledge (PCK)	17	Creative lessons; I practice scientific method; I have 20 years of experience teaching all ages; explaining things in simple terms; doing hands-on activities; integrating social issues and science; to encourage critical thinking and curiosity; understanding students' struggles and weaknesses; weaving in the use of technology in the classroom; I have a solid understanding of STEM content and am able to make connections to students' lives; able to break down difficult concepts
Passion for STEM (PS)	14	My passion for STEM subjects; a passion for science; passionate and excited about science; love of biology; I love both learning and teaching; I'm passionate about teaching.
Content Knowledge (CK)	6	Understanding of concepts; my science education is broad; I have a solid understanding of STEM content; knowledgeable.
Communication Skill (CS)	2	Explaining things in simple terms; I can explain things at a more basic level to students who may not understand the intricacies yet.

4.1.8 TCs' self-reported limitations

The responses here reflect participants' (n=29) self-reported limitations as STEM teachers at that time of the study. In other words, participants were asked to report what they lacked. The responses were categorized into: Lack of Pedagogical Content Knowledge (LPCK),

Lack of Content Knowledge (LCK), Poor Communication Skills (PCS), Inadequate Affective Skills (IAS), and Inadequate Personality Traits (IPT).

Table 11 shows the number of comments coded for each category as well as some examples. It is important to note that most responses involved LPCK and LCK. The responses regarding IPT were also significant, though not very numerous. On the other hand, the least commented limitations regarded participants' communication and affective skills. Having poor communication skills was only reported as a limitation by one respondent. On the other hand, in Sub-section 4.1.7, having effective communication skills was reported as a strength by only two respondents. So, it seems that for most TCs their communication skills were neither a strength nor a limitation. The results for affective skills, however, were consistent with the findings from Sub-section 4.1.7.

Table 11

Respondents' self-reported limitations as STEM educators

Category (node)	**# of coded responses**	**Examples of participants' responses**
Lack of pedagogical content knowledge (LPCK)	24	Limited knowledge on technology and applying it to the classroom and my ability to make certain STEM topics exciting to those who have limited interest; don't practice scientific method; limited experience in labs; not used to creating lessons; interdisciplinary connections are difficult; lack of teaching experience; limited experience with unmotivated and difficult youth; my hesitation in answering questions; my tendency to focus on the answer more than on the process; poor time-management; difficulty in maintaining authority in a classroom; influenced by my own education which was rigid and lacked student input; not used to inquiry guided teaching.

Lack of content knowledge (LCK)	13	Lack expertise in some fields of science; personal struggle with physics; my own knowledge is not vast enough; limited knowledge on other STEM fields; difficulty with higher level math; not well versed in engineering or mathematics, don't have a lot of experience with chemistry and physics; knowledge gaps in math and physics.
Inadequate personality traits (IPT)	6	Dislike of following orders without justification; lack patience; not a morning person; lack of confidence; shy.
Poor affective skills (PAS)	1	When I get emotional, I sometimes don't care about students.
Poor communication skills (PCS)	1	I speak too quickly.

4.1.9 TCs' predictions about what they'd need to effectively facilitate activities at FMSD

It is relevant to highlight that respondents (n=29) answered to the survey prior to their participation at FMSD. Therefore, the responses here reflect their predictions about the type of skills and knowledge they thought they would need to effectively facilitate the activities at the event. The responses were categorized into PCK, CK, CS, AS, and PT.

Table 12 shows the number of comments coded for each category as well as some examples. Participants reported having a sound PCK, effective communication skills, appropriate personality traits and affective skills as being highly important. However, using questions to guide their interactions with visitors was mentioned only once. Interestingly, as it will be shown in the data from the focus group discussions and interviews in Section 4.2, most interviewees reported the importance of asking questions to facilitate their activities. The results here suggest that most survey respondents did not anticipate that when they did the survey.

Table 12

Respondents' predictions about knowledge and skills needed to effectively facilitate activities at FMSD

Category (node)	**# of coded responses**	**Examples of participants' responses**
Pedagogical Content Knowledge (PCK)	19	Knowledge of activity and its various results; being able to connect demo to larger concepts; ability to engage children with science explanations; able to modify the level of science explanation depending on the age and background knowledge of the guests; keeping people interested during scientific explanations; ensuring safety; engaging and approachable presentation to young people; to be able to manage a large crowd; planning skills; asking questions; time management.
Personality Traits (PT)	17	Confidence; try not to be emotional; good social skills; enthusiastic; friendly; personable; adaptable; approachable; flexible; organized; patient; dynamic; respectful.
Communication Skill (CS)	16	Public speaking skills; good communication to explain things simply; to explain the demo at a variety of levels; able to answer questions; engaging and approachable presentation to young children; ability to talk and present; asking questions; ability to build rapport quickly with visitors; to be able to manage a large crowd of children.
Affective Skills (AS)	09	Try not to be emotional; to be engaging and friendly; be engaging with young kids; to show enthusiasm; ability to engage students; be able to engage the audience; ability to build rapport quickly with booth visitors; inspiring curiosity and wonder.
Content Knowledge (CK)	02	To be comfortable with the topic of my demo; to be knowledgeable about the topic.

4.1.10 TCs predictions about how they would benefit from FMSD

Again, it is relevant to highlight that participants (n=29) answered to the survey prior to their participation at FMSD. Therefore, the responses here reflect their predictions about how they thought they would benefit from facilitating activities at the event. The responses were categorized into: PCK, CK, CS, AS, and PT.

Table 13 shows the number of comments coded for each category as well as some examples. Most of participants' responses related to their PCK. In other words, facilitating activities at FMSD would help them gain experience in putting their content knowledge into practice to facilitate learning. To this end, their communication skills were also expected to be enhanced, especially considering they would be interacting with multiple age groups. Interestingly, refining the presentation as the FMSD event unfolded was only mentioned once. However, as will be demonstrated by the results from the focus group discussions and interviews in Section 4.2, refining their presentation during the event was reported as one of the most significant aspects of their experiences.

Table 13

Respondents' predictions about how they would benefit from their participation at FMSD

Category (node)	# of coded responses	Examples of participants' responses
Pedagogical Content knowledge (PCK)	27	To practice generating genuine interest in a STEM topic in all age groups; to observe my fellow colleagues; valuable experience in interacting both with youth and their parents; seeing different reactions to the same activity; to explain things in simple enough terms so the younger children understand; modifying my lesson for each level; opportunity to work on a hands-on science learning experience; to learn a variety of entertaining and engaging

		activities; to try and implement some of the theories we are learning; how to refine a science demo; focus on the new curriculum.
Communication Skill (CS)	11	How to interact with students of different ages; to explain things in simple enough; modifying my lesson behind the demo for each level; explaining the same topic at a variety of levels; experience answering questions from children; it will help me practice engaging with an audience; see how difficult it is to be on the spot for presenting an idea.
Affective Skills (AS)	3	Be more confident; It will help build my confidence; to practice how to control my emotions.
Content Knowledge (CK)	2	To learn a variety of entertaining and engaging activities/demos that can be used in the secondary STEM classrooms; how to integrate other science concepts into my biology classroom.

4.2 Focus Group Discussions and Individual Follow-up Interviews

This section will present the results from 11 different sources, two focus group discussions (n=46) plus nine individual interviews (n=9). As explained in Sections 3.3 and 3.4, the protocols used in the focus group discussions and individual interviews were very similar. As expected, the similar questions used to elicit participants' experiences about their FMSD participation generated similar themes. Hence, the decision to analyse both sets of data together.

Both focus group discussions were conducted two days after TCs had facilitated their activities to the public at FMSD, whereas the interviews two to five days after the same event. All 46 TCs from two of the three sections of the *General Science Secondary Methods* course participated in the focus group discussions. The two group discussions were conducted according to the course groupings. Thus, one group had 26 participants and the other 20. As explained in

Sub-section 3.3.2, the unusually large number of participants in both discussion groups was due to the constraints of the realities of the context of the study at that time. Furthermore, nine of the focus group participants were subsequently individually interviewed.

Both focus group discussions and eight of the individual interviews were audio-recorded. The remaining interview was conducted via e-mail message. Once the audio-recordings were made, their contents were transcribed. As the study aimed at investigating how this outreach experience impacted their pedagogical content knowledge, communication skills, motivation towards STEM, and understanding of how STEM is effectively taught and learned, emergent themes were identified within these parameters. In total, 11 (A-K) themes (or NVivo nodes) were identified. Subsequently, the participants' comments were carefully re-examined and coded according to the pre-identified themes. Table 14 shows the themes, their corresponding number of coded comments, and the number of sources the comments came from.

Table 14

Number of themes (nodes), sources, and codded comments

Theme	Theme (node) title	# of sources	# of comments
A	TCs' PCK	11	93
B	Activity facilitation and performance	11	67
C	Communication skills	11	42
D	Importance of hands-on activities	11	38
E	Using questions to facilitate activities	10	35
F	Appreciation of parental engagement	10	35
G	TCs' confidence and visitors' excitement	11	31

H	Event preparation	11	24
I	Importance of STEM outreach	11	23
J	Suggestions for future events	9	19
K	Evidence of learning	8	13

Although the focus of the analysis was qualitative, the number of sources and comments are also relevant as they indicate how recurrent the themes were. As indicated in Table 14, the greatest number of comments (93) was coded for theme A (TCs' PCK). Many of those comments, however, were also coded for some other themes as they refer to how TCs: a) prepared for the 2017 FMSD event; b) facilitated their activities; c) interacted with visitors; d) reflected on their performances; and e) streamlined their facilitations during the event to increase the effectiveness of their activities.

Furthermore, the data analysis was informed by two NVivo queries. The first, *Themes Clustered by Word Similarity*, indicates how connected the themes are according to the wording of their respective coded comments. As shown in the horizontal branching diagram (Figure 7), the most similar themes are clustered together on the same branches, whereas the least similar ones are further apart. Thus, "TCs' PCK", which is a central theme for this study, is connected to "Activity facilitation", "Importance of hands-on activities", "TCs' confidence and visitors' excitement", "TCs' communication skills", "Using questions to facilitate activities", "Evidence of learning", and "Event preparation".

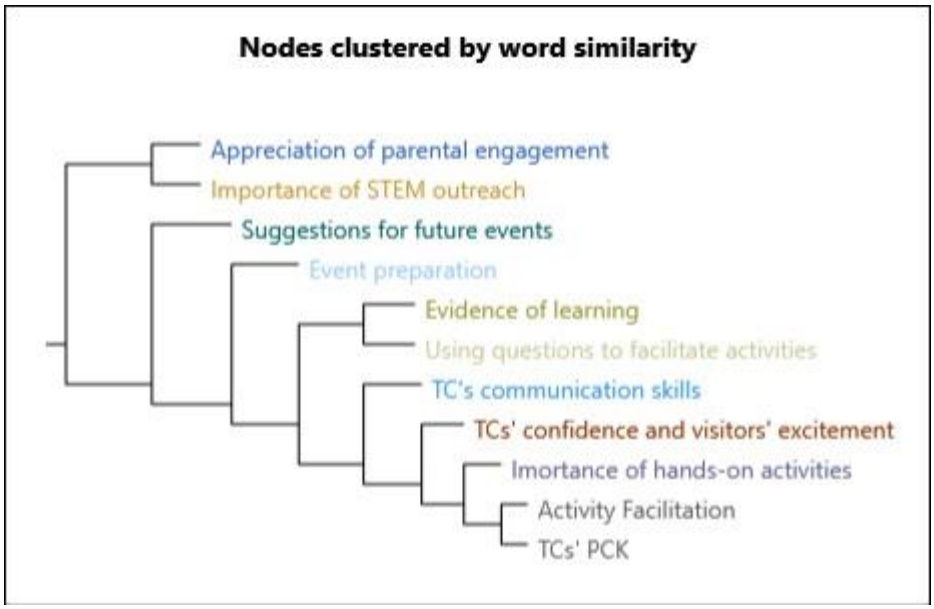

Figure 6. Themes Clustered by Word Similarity.

The second NVivo query, *Pearson Correlation Coefficient*, indicates the correlation between two variables or, in the case of this study, two themes. *Pearson Correlation Coefficient* values range from 0-1. Thus, the greater the value, the greater the relationship between the correlated themes. As shown in Table 15, all values are greater than zero, which shows a positive linear relationship between any two themes. To help the visualization and interpretation of the data, the same letters and colour scheme were used in Tables 14 and 15. Besides, in Table 15 the themes were rearranged according to their *Pearson Correlation Coefficient* value in relation to theme A. This helps the identification of the themes most correlated to "TC's PCK" (theme A).

Table 15

Pearson Correlation Coefficient between any two correlated themes

	A	B	D	C	G	E	I	K	H	J	F
A	-										
B	**0.933**	-									

D	**0.836**	**0.828**	-								
C	**0.809**	0.740	0.621	-							
G	**0.797**	0.777	**0.793**	0.652	-						
E	**0.763**	0.798	0.660	**0.649**	0.660	-					
I	**0.747**	0.694	**0.813**	0.621	0.774	0.615	-				
K	**0.720**	0.715	0.695	0.551	0.602	**0.687**	0.629	-			
H	**0.718**	0.707	0.622	0.548	0.570	0.594	0.509	0.530	-		
J	**0.595**	**0.561**	0.555	0.445	0.487	0.403	0.513	0.524	0.524	-	
F	0.576	0.541	0.654	0.531	0.633	0.482	**0.713**	0.549	0.397	0.341	-

The correlations in bold will be examined in Sub-sections 4.2.1 – 4.2.9. They were chosen due to their: a) relevance to answer RQs 1 and 3; b) high *Pearson Correlation Coefficient* value (Table 15); and c) position in the *Themes Clustered by Word similarity* diagram (Figure 6). Moreover, an attempt was made to contemplate all 11 themes in the discussion. The limitation of such decision was that some correlations with high *Pearson Correlation Coefficient* values were not directly inspected. This is because several of the comments coded for the themes whose correlations were not included in the analysis had also been coded for themes described in other correlations. Therefore, such comments had already been analyzed through other correlations. Moreover, addressing every single correlation separately would have made the analysis lengthy and repetitive.

Another limitation regards the number of themes created to code TCs' comments. The high Person Correlation Coefficient values between some of the themes may indicate that they are not separate themes. Thus, "TCs' PCK", "TCs' communication skills", and "Using questions

to facilitate activities", for example, could have been merged into one theme. As a consequence of having fewer themes, there would have been fewer theme correlations, and this would have made data analysis more accurate.

4.2.1 TCs' PCK and event preparation

According to Table 15, the highest *Pearson Correlation Coefficient* (0.718) between theme H and any other theme is with theme A, which suggests that "Event preparation" is most correlated to "TCs' PCK". Moreover, Table 14 shows that 24 comments from 11 sources were coded for theme H. The A-H connection is important because the way the TCs prepared themselves to facilitate the activities at the FMSD had a positive impact on their PCK, and that is illustrated by the examples below.

"So, I made sure we had all the equipment we needed. I went, the day before, I tested it out, and also, at home researched the experiment, the science behind it, and kind of I made a kind of a script for me. Just like questions that might come up or talking points that I would want to tell the kids, and kind of thought about different levels I could relate it to." (interview 6)

"For ours, it was a strawberry DNA extraction and we run through it when we were making a video beforehand so we kind of were able to see what worked and what didn't… it helped because we run through it beforehand, so, we were able to think of explanations about each step so as to why we were doing those steps." (Focus group 1)

"I had to do research to learn above and beyond the details to be able to answer what people generally would know. I had definitely to do some research, especially for the Wilmshurst generator. My partner and I spent hours figuring out how to explain that to the visitors." (interview 8)

The comments above exemplify that TCs prepared themselves for the event in ways that included: a) researching about the topic; b) predicting questions that might be asked; c) rehearsing explanations; and d) practicing the experiment procedures. Although that preparation was useful, most TCs reported refining and changing their activity facilitation as the event unfolded. Evidence of that will be provided in the next sub-section.

4.2.2 TCS' PCK and activity facilitation and performance

As indicated in Table 15, "TCS' PCK" (theme A) and "Activity facilitation and performance" (theme B) have the highest *Pearson Correlation Coefficient* (0.933). Furthermore, the *"Themes Clustered by Word Similarity"* diagram (Figure 6) shows that A and B are the closest of all themes. Moreover, Table 14 indicates that these two themes had the greatest number of coded comments (93 and 63, respectively) from 11 sources.

The fact that TCs facilitated their activities multiple times and to different age groups helped them realize the need to refine and change their facilitation according to the target audience. The reported changes include TCs: a) reducing their own speaking time; b) gauging content and language to suit visitors; c) asking and answering questions; d) using analogies to further engage visitors; and e) providing real-life examples to connect activity content to visitors' context. Instances of that are shown below:

"…in the first couple of times, it was very much "Ok, I'm gonna say this", but as they moved on I thought I might use questions a little more. And I think as it went on, I though which analogies worked best." (interview 6)

"... as the day went on I streamlined my explanation... Then, I tried to build on what they'd known ... to find something they are already interested in and try to relate it to what you are talking about, so they are more engaged." (focus group 2)

"I definitely refined the demos as I went along. I came up with an explanation beforehand when I did the demo at home to prepare, but then, as it went along, I could tell what parts of the explanation people found more interesting and then I elaborated on those parts. I also used a lot of questions." (interview 1)

"... the demos got progressively better. So, at first, some of the contents we were trying to explain were too difficult for some of the children, so we had to simplify language. And also, the way we presented as well. We became more interactive" (interview 7)

The examples above illustrate what TCs did to improve and refine their work on the day. However, TCs showed further reflexive skills when asked what they would do to improve their performance if they had the opportunity to facilitate again at FMSD. Here are some reflections:

“it would have been nice to use some visual aids or some written things. I mean, sometimes you remember it more if you see the word and if you have a little picture drawn than just hearing things. Because, again, the experiment can be very exciting… It would have been nice to have something else to remind the learners about the science behind it.” (interview 4)

“There are a few things I'd wanna change… The way we did at the end of FMSD that would have been good to start with. Also, I would have liked to have a chemical model just so, I could show students what the compound looks like." (interview 7)

“I'd search for a faster demonstration from start to conclusion of the demonstration. This is because the thing with biology is that some of the processes are so slow and you can’t engage these kids who will be at your stations for just a minute or two.” (interview 1)

In this sub-section, examples of how TCs refined and enhanced the way they facilitated their activities at the 2017 event were given. The examples showed TCs’ ability to reflect on what they had being doing and take immediate actions to improve their facilitation. Also, TCs reported some actions they would take to better their performance even further were they to facilitate at FMSD again in future. These comments indicated a PCK growth and illustrated how the TCs viewed STEM teaching and learning. The next sub-section will bring evidence of the importance that TCs gave to hands-on activities.

4.2.3 TCs’ PCK, importance of hands-on activities, and activity facilitation and performance

As indicated in Table 15, “TCS’ PCK” (theme A) and “Importance of hands-on activities” (theme D) have the second highest *Pearson Correlation Coefficient* (0.836) of all related themes. Furthermore, Figure 6 illustrates the A-D proximity. Moreover, according to Table 14, 38 comments from 11 sources were coded for theme D.

The examples below illustrate that TCs appreciated the use of hands-on activities because of their potential to spark an interest in STEM subjects, to make contents more meaningful to visitors, and to motivate learners to ask questions. Moreover, doing hands-on activities indicated

to TCs the importance of being well prepared to deal with difficult questions, and even to ensure that the fun side of the activity did not overshadow the science behind it.

> "Because in schools especially you see a lot of just writing out equations or learning things by the book, but I think it's really important to have the hands-on and the fun side of it… I think you can inspire them to be more motivated about science and math… And I think learning that earlier opens up possibilities for students." (interview 6)

> "Being able to see all the other demonstrations gives me some ideas of what kind of demonstration I can bring to my classroom in the future." (interview 1)

> "I think our experiment was very exciting…, but I think sometimes the experiment overshadowed the science a little." (interview 6)

> "I love the types of experiments… They used simple materials… So, I think that was really valuable, an opportunity for kids to play and have a fun day and have a positive experience about science... I think that (a demo/experiment) is a really awesome activity and a good opportunity especially at the start of a unit where you want to inspire that inquisitive thinking and get to explore different avenues and get them excited about the subject." (interview 4)

> "I think the process of doing it did… thinking in advance about what I wanted to do, which is something that I not always do before I present or do experiments. Thinking in advance how I'm gonna speak, what questions the students might have ..." (focus group 2)

It is important to highlight that some of the comments above were also coded for theme B ("Activity facilitation and performance"). The relation between themes B-D is illustrated by their proximity (Figure 6), and by the high (0.828) *Pearson Correlation Coefficient* (Table 15).

This sub-section illustrated that the experience of facilitating hands-on activities contributed to increasing TCs' awareness of the pros and cons of this approach to STEM teaching and learning, positively impacting their PCK. An integral part of conducting hands-on activities is effective facilitator-visitor communication, and this will be analyzed in the next sub-section.

4.2.4 TCS' PCK and communication skills

According to Table 15, "TCs' PCK" (theme A) and "Communication skills" (theme C) have a high Correlation Coefficient (0.809). Moreover, as indicated in Table 14, 42 comments from 11 sources were coded for theme C.

Effective communication on the TCs' part was essential for producing age-appropriate interactions as it was through them that: a) prior knowledge was assessed, b) ideas and concepts were conveyed, and c) a more interactive approach to teaching and learning was adopted. Here are the examples:

"I thought that it was a really interesting opportunity to explain the same concepts in different ways to different people, and even, it was a good chance to think about how you are asking questions for younger kids giving them more options to pick from, and older kids just kind of more holistic, more open-ended questions." (interview 6)

"I think at the start it was ok, but at the end I was way better. So, I think overall it went really well. I thought I was being able to engage more with the kids, to have more dialogue with them, which is what I want. I don't wanna be just lecturing at them." (interview 2)

"I thought it was really helpful to see the reactions of the kids depending on how you explained different things depending on how old they were." (focus group 1)

"I tried to probe for prior knowledge… Explaining scientific reasoning and processes in simple English was not an easy task." (interview 9)

"I did gauge it towards their age. I asked guiding questions to gauge where their knowledge was at. One of the things I'm gonna take away from this (FMSD) is how to ask guiding questions, like open-ended, inquiry questions. Being a little bit older, I never had that sort of experience (as a student)." (interview 8)

The examples above illustrate that TCs became increasingly aware of the importance of grading language and content to successfully communicate with different age-groups as the event progressed. Moreover, TCs reported that they realized that using questions was a key pedagogical strategy to effective instruction. Questioning enabled TCs to assess visitor prior knowledge, increase learner motivation towards activity content, and guide student reasoning.

Furthermore, it is important to explain that some of the comments quoted above were also coded for theme E ("Using questions to facilitate activities"). Moreover, Table 15 shows that the *Pearson Correlation Coefficient* for themes A-E (0.763) and C-E (0.649) are also high. Put together, these factors indicate that the effective use of questions enabled TCs to enhance their activity facilitation, which connects themes A, C, and E.

In line with the above, the next sub-section will show that effective facilitator-visitor communication was also relevant because it produced instances that indicated visitor learning.

4.2.5 TCs' PCK and evidence of learning

As indicated in Table 15, "TCs PCK" (theme A) and "Evidence of learning" (theme K) have a high *Pearson Correlation Coefficient* (0.720). Moreover, Table 14 shows that 13 comments from 8 sources were coded for theme K. As is often the case with STEM learning in informal environments, evidence of visitor learning is not gathered through tests or exams. In the case of FMSD, visitor learning was identified in the questionings and meaningful interactions during the activities, as illustrated by the examples below.

"A lot of the children I interacted with, they were really relating the topic with the school and they were asking a lot of questions... When I was in school, my science project just ended in the classroom, but now with the inquiry… So, I think it was a good opportunity for them to ask questions and find answers." (focus group 1)

"At my demo we had a lot of animal bones, skeletons and we did a lot of seeking prior knowledge. I think when students have to remember and explain things, that can be learning. Because one of the best ways to learn is to teach it. So, in that way, in seeking prior knowledge the students are learning because they are sharing what they already know. We were also able to explore some questions... So, there were all these interesting questions that came about and I think that if inquiry is learning and asking questions is learning..." (interview 5)

"I was really impressed with the types of questions that kids came up with... I did not see that coming." (interview 2)

"... when I gave the demonstration and the child asks "Oh, what happens if ..." Only by asking what happens if, that's sort of the application of the knowledge that I'd given, right? The kid asked "What happens if you move the electrons a little further away?" And I thought that was great. I never asked that

myself, so we found out... I think that shows me that the kid is thinking about what's happening and trying to pose a question about what would happen." (interview 1)

The examples above indicate that TCs' activity facilitation was beneficial to visitor learning. The learning instances emerged, among other things, due to the interactive, student-centred way in which activities were facilitated, which included the effective use of questions. Had TCs adopted a more lecture-like approach to deliver their activities, the learning instances would not have emerged as they did. This reinforces the idea that STEM learning in informal settings cannot be assessed through the traditional instruments more commonly utilised in classroom environments.

Moreover, some of the quoted examples above were also coded for "Using questions to facilitate activities" (theme E). The close relation between themes E-K is further emphasized by their high (0.687) *Pearson Correlation Coefficient* (Table 15) and their proximity in the *Themes Clustered by Word Similarity diagram* (Figure 6). The next sub-section will bring examples to support that the hands-on approach that characterized FMSD contributed to increase TCs' PCK and confidence, and visitors' excitement about STEM.

4.2.6 TCs' PCK, TCs' confidence and visitors' excitement, and importance of hands-on activities

According to Table 15, the *Pearson Correlation Coefficient* is high (0.797) between "TCs PCK" (theme A) and "TCs' confidence and visitors' excitement" (theme G), and between the latter and theme D "Importance of hands-on activities" (0.793). Moreover, Figure 6 shows a G-D proximity. Furthermore, according to Table 14, 31 comments from 11 sources were coded for theme G.

Themes A-G-D are interconnected because the hands-on, interactive manner through which the activities were facilitated positively impacted TCs and visitors alike. The examples below illustrate that TCs felt excited and confident about their performances, especially towards the end of the event.

"I do feel more confident working with this younger group because I normally work with children aged between 10-18. I do feel I'm better interacting with that younger group now." (interview 1)

"... when you see them leave, they are all smiling… and some of the parents were taking pictures or filming me talk. They were actually interested in what I had to say. They said they really enjoyed the station and I think it definitely increased my confidence." (interview 3)

"Yeah... seeing that I have the ability to engage with the students without just saying "Here's the right answer." I realized that I can engage with them so that we can together find what the right answer is… I feel pretty good about it... Especially towards the end." (interview 2)

"It seemed very effective. I had a lot of comments from parents, and that was very flattering… So, it was very gratifying to have that direct feedback that the way I was explaining things was effective... Those nice comments from parents definitely boosted my confidence." (interview 8)

Moreover, visitors were also reported to have benefitted from FMSD. As indicated by the examples below, the hands-on, interactive nature of the activities contributed to raise visitors' interest in and excitement about STEM.

"So, we started allowing them touching and doing the experiments ... So, when they were able to be involved, they got more excited…" (interview 6)

"As soon as they realized they could put their hands more on the experiment, they were more engaged, and they cared more about what happened." (focus group 1)

"… they were very excited and were asking questions and participating, younger and older kids, equally. So, I think it was a provoking event for all of us." (focus group 2)

"And for some people that attend, it might trigger something in them. It might inspire them, you know. It might spark an interest." (interview 5)

"If nothing else, it (FMSD) got them excited about science." (interview 4)

"I'm happy about it (her performance) because it seemed everyone was really excited about it when they left... I'm happy I got to do it as many times as I did, the repetitions, because I thought I got better and better at each time." (interview 9)

The comments in this sub-section showed that FMSD was a positive experience for TCs and visitors. Moreover, they suggest that TCs are likely to transfer this hands-on approach to the classroom environment in future as they felt stimulated by the positive impact the activities had on visitors. Furthermore, the findings indicate that the children left the event with a reassuring attitude towards STEM. The next sub-section will provide evidence of TCs' positive views about STEM outreach.

4.2.7 Importance of hands-on activities, importance of STEM outreach, and TCs' PCK

According to Table 15, "Importance of hands-on activities" (theme D) and "Importance of STEM outreach" (theme I) had a high *Pearson Correlation Coefficient* (0.813). Moreover Table 14 shows that 23 comments from 11 sources were coded for theme I.

The comments below indicate that TCs acknowledged the fact that FMSD allowed more people to have access to STEM. Furthermore, they show an important connection between the success of STEM outreach and the hands-on approach that characterizes the FMSD event.

"I think it's important that it's a free event... I think that's really valuable because it doesn't put a barrier of access to science." (focus group 1)

"So, I thought all the TCs came up with really cool experiments… there was a range from chemistry, physics and biology... It was educational, but it was also fun… I liked that they (visitors) came away with something and that sparked their interest." (interview 2)

"I could definitely see the value of the event for the children because I never got to an event like this as a child and I think that if I had it would have probably sparked an interest in science earlier on for me." (interview 1)

"I had something else prepared that I wanted to say, but then, I'd ask the kids what they knew, I just let them roll with it … just kind of fostering that information and interest." (focus group 1)

The comments above provide evidence to support that TCs acknowledged STEM outreach as a valuable opportunity to motivate children to engage with STEM, especially when there is a strong hands-on component in the activities. Furthermore, as shown by the examples

below, this outreach experience was also beneficial to enhancing TC's PCK. In line with this, Table 15 shows a high *Pearson Correlation Coefficient* (0.747) between "TC's PCK" (theme A) and "Importance of STEM outreach" (theme I).

"Outreach events and visits to science centres seem valid to STEM education since it focuses on interdisciplinary and applied approach. I think it is important to promote hands-on learning." (interview 6)

"It was fun and engaging for volunteers, kids, and parents. I think it was a great opportunity for TCs to experience the teaching and preparation for such an event… Since STEM education focuses on interdisciplinary and applied approach, I think it is important to promote hands-on learning." (interview 9)

Because this event is a lot more student-driven, whereas teaching in a classroom I'd have objectives and aims… In FMSD, it was all about tangents and inquiry." (interview 4)

This sub-section provided evidence that this outreach experience was beneficial to young visitors, families, and TCs for reasons that include: a) allowing more people to gain access to STEM without any financial constraint; b) enhancing visitors' interest in STEM; and c) providing TCs with a valuable out-of-school teaching experience. Another important aspect of FMSD was the presence of parents. Evidence of that will be provided in the next sub-section.

4.2.8 Importance of STEM outreach and appreciation of parental engagement with STEM education

According to Table 15, "Importance of STEM outreach" (theme I) and "Appreciation of parental engagement with STEM education" (theme F) had a high *Pearson Correlation Coefficient* (0.713). The relation between themes I-F is further emphasized by their proximity in the *Themes Clustered by Word Similarity* diagram (Figure 6). Moreover, Table 14 shows that 35 comments from 10 sources were coded for theme F.

The comments below illustrate TCs' appreciation for the fact that parents accompanied their children at the FMSD event. For them, this contributed to further motivate the young visitors to develop a positive attitude towards STEM. Evidence of that is provided below.

“I thought it was interesting that both groups (parents and children) seemed to be engaged in the demonstrations… I could see the parents were encouraging their kids to listen to the explanations.” (interview 1)

“I was talking about this with a friend this morning "What are the parents promoting with their kids by taking them to this?" It is like you're promoting that science is a viable career.” (interview 3)

"… the parents in that case are like the teacher, they model positive interactions with science and the children will have the same dispositions. But, I didn't actually make that connection until actually going to the event and seeing it there…I found that the students who had parents who were engaged did seem to connect more with the content.” (interview 7)

“I was at the microscope station and I saw one of the parents. He told me that his kid always wanted a microscope but then he wasn't sure if they should get it or not. But then, at the end, he loved it really much and he told me that this Christmas he is getting one microscope for his kid.” (focus group 1)

The examples above exemplify TCs’ high appreciation for parental participation, which was said to increase children’s connection with the activities and motivation towards STEM. The next sub-section will bring TCs’ suggestions for the next FMSD editions.

4.2.9 Suggestions for future FMSD events, TCs’ PCK, and activity facilitation & performance

According to Table 15, “Suggestions for future events” (theme J) had the highest *Pearson Correlation Coefficient* (0.595) with “TCs’ PCK” (theme A) and the second highest (0.561) with “Activity facilitation & performance” (theme B). Moreover, Table 14 shows that “19 comments from 9 sources were coded for theme J.

The FMSD event has been running since 2010, and during this period it has increased in size and popularity. Although TCs were complimentary about the 2017 edition of the event, suggestions were made to enhance TCs’ experiences and the event itself. These are exemplified below.

“I think it would have been nice to see some of the other experiments in action. There was a little bit of time to wander around after we set up the experiment, but most people weren't performing their

experiment… I think it would be cool to, logistically, have more rooms so as to have less crowding of experiment.” (interview 6)

“… practicing (the demonstration) with each other. Someone can get his ideas together and then they'd just practice in front of the class. (focus group 1)

“I think we put a lot of work for a short, like, it was only two hours and a half. So, I'd be open to make it a little bit longer” (focus group 1)

“Maybe in class we could have done some worksheet or had some discussion like "Oh, how would you describe this concept to a 5-year old?", "How would that change when you explain it to a 10-year old or to an adult?", just to get a little bit more prepared for things like that.” (focus group 2)

“Maybe I would have changed the position of the stations to make kind of a cycle in that area… And even, I'd put a sign up "Start here and then come around.” (interview 8)

This sub-section provided TCs’ suggestions to improve FMSD. These included: a) having a longer event; b) communicating with facilitators from previous years to learn about the visitors’ profile; c) using some class time to prepare the presentations; d) allowing more time during the event for TCs to visit other stations; and e) changing the disposition of some stations. Moreover, these suggestions indicate that this outreach experience positively impacted TCs’ PCK. In the next sub-section, a summary of the results will be presented.

4.3 Summary of Results

4.3.1 Online survey

The data from the online survey (n=29), collected prior to TCs’ activity facilitation at FMSD, were instrumental in answering this study’s RQs. The findings were particularly relevant in the case of RQ 2, which deals with TCs’ self-reported strengths and limitations as STEM educators. Moreover, that instrument generated relevant supporting information to answer the other two RQs as it encompasses TCs’: a) predictions about the benefits of the outreach experience on their PCK and communication skills, and b) perceptions about the makings of effective STEM educators.

Regarding their main strength as STEM educators, 22 (75.8%) of the 29 respondents reported having an appropriate personality, whereas 17 (58.6%) a sound PCK. The latter findings are surprising considering that 13 (44.8%) respondents subsequently reported lack of PCK as their main limitation as STEM educators. Added to that is the fact that nine respondents (31%) reported having no school-based teaching experience, whereas nine (31%) had no teaching experience in out-of-school settings. Another relevant self-reported limitation as STEM educator refers to TCs' lack of content knowledge (13 respondents or 44.8%). This is both significant and surprising considering that 28 TCs (96.5%) had bachelor's degree in science-related areas.

Furthermore, 27 (93.1%) of the 29 respondents predicted that facilitating activities at FMSD would be beneficial to their PCK. As will be shown in the next sub-section, that prediction was consistent with the data subsequently collected after the event. Another potential benefit of FMSD, reported by 11 (37.9%) respondents, referred to communication skills. However, as indicated by the data collected after the event, the benefits of activity facilitation at FMSD to TCs' communication skills were even greater than had been predicted.

4.3.2 Focus group discussions and individual interviews

The data from the 11 sources, two focus group discussions (n=46) and nine individual interviews (n=9), generated crucial information to answer RQs 1 and 3. As the study aimed at investigating TCs' perceptions of how this outreach experience impacted their PCK, communication skills, motivation towards STEM, and understanding of how STEM is effectively taught and learned, eleven (A-K) themes were identified within these parameters.

Theme A (TCs' PCK) was found to be central to this study. According to Table 14, TCs' PCK had the greatest number of coded comments (93) from all 11 sources. Many of those comments, however, were also coded for other themes as they are related to how TCs: a)

prepared for the outreach event; b) facilitated their activities at FMSD; c) reflected on their activity facilitation; and d) viewed STEM education. Furthermore, Table 15 shows that theme A had some of the highest *Pearson Correlation Coefficients* of all correlated themes.

Moreover, according to the *Themes Clustered by Word Similarities* diagram (Figure 6), themes A ("TCs' PCK") and B ("Activity facilitation and performance") are closely connected, which indicates that that the hands-on approach through which the activities were facilitated at FMSD positively impacted TCs' PCK. Thus, apart from relating to each other, themes A-B were also strongly related to theme D ("Importance of hands-on activities"). This is in tandem with the data from Table 15, which shows a high *Pearson Correlation Coefficient* between A-D (0.836) and D-B (0.828).

As indicated by Table 14, theme C ("Communication skills") was also found to be relevant (42 coded comments from 11 sources). Effective communication enabled TCs to convey their activity contents more effectively to the visitors. Moreover, the fact that TCs took steps to refine their facilitation during the event to make it more engaging, age-appropriate, and student-centred through an effective use of questions further indicates TCs' PCK growth. Table 15 shows a high *Pearson Correlation Coefficient* (0.809) between themes A and C.

"Communication skills" (theme C) was also found to be related to theme E ("Using questions to facilitate activities") as several of the comments coded for C referred to using questions to make activity facilitation more inquiry-like. These findings connect themes A-E and C-E, and that is supported by the high *Pearson Correlation Coefficient* between A-E (0.763) and C-E (0.649), as indicated in Table 15.

Moreover, the hands-on approach that characterizes FMSD positively impacted TCs and visitors. The comments coded for theme G ("Participants' confidence and visitors' excitement")

suggest that the TCs are likely to transfer this hands-on approach to the classroom environment in future. In turn, the visitors left the event with a reassuring attitude towards STEM. These findings are supported by the high G-D *Pearson Correlation Coefficient* (0.793) from Table 15. Furthermore, several of the comments coded for theme G indicate TCs' PCK growth, as is demonstrated by the high (0.793) A-G *Pearson Correlation Coefficient* (Table 15).

Another interesting finding was that FMSD allowed more people to have access to STEM. For TCs, this access was facilitated because the event was free and attractive to visitors due to the interactive, hands-on nature of the activities. The high *Pearson Correlation Coefficient* (0.813) demonstrated in Table 15 corroborates the connection between themes D ("Importance of hands-on activities") and I ("Importance of STEM outreach"). Moreover, the fact that the event was family-oriented was found to be essential to allowing more visitors to gain access to STEM. This explains the close connection between themes I and F ("Appreciation of parental engagement with STEM education"), and this is supported by the high (0.713) I-F *Pearson Correlation Coefficient* (Table 15).

Furthermore, some relevant findings relate to TCs' suggestions for the future FMSD editions. These encompass comments about actions that have the potential to maximize activity facilitation and enhance visitor learning, and those reflect TCs' PCK growth. According to Table 15, "Suggestions for future events" (theme J) had the highest *Pearson Correlation Coefficient* (0.595) with "TCs' PCK" (theme A), and the second highest (0.561) with "Activity facilitation and performance" (theme B).

This chapter presented the study results. In the next, these findings will be discussed, and the research questions answered.

Chapter 5: Discussion

This chapter discusses the results from the survey, focus group discussions, and individual interviews considering the three research questions this study aims at answering.

5.1 Research Questions:

5.1.1 RQ1: How does participation in a public STEM outreach experience impact teacher candidates' (TCs) pedagogical content knowledge, communication skills, motivation to teach STEM-related subjects, and understandings of how STEM is best taught and learned?

As this RQ encompasses several themes, each one of them will be addressed separately. This will allow a more thorough answer.

5.1.1.1 Impact of the STEM outreach experience on TCs' PCK

The most recurrent theme that emerged from the study's data was "TCs' PCK" (theme A). Responses to the online survey indicated that the respondents identified having a sound PCK as one of the most important characteristics of effective STEM teachers. Moreover, data from the focus group discussions and individual follow-up interviews collected after TCs' FMSD facilitation reinforced the relevance of theme A. In fact, theme A was found to be strongly connected to how TCs: a) prepared for FMSD; b) facilitated their activities at the event; c) reflected on their activity facilitation both during and after the event; and d) perceived STEM education.

Regarding event preparation, TCs took steps to: a) organize the materials needed for the activities; b) learn the specific STEM content behind the activity; c) take notes of specific points to be addressed during the activity facilitation; d) run the experiment or practice the activity procedures; e) predict some questions that visitors might ask; and f) prepare their speech.

During the event, however, after facilitating their activities multiple times, TCs realized that they needed to change their "script" to make their facilitation more effective. To this end, TCs: a) reduced their speaking time; b) assessed visitors' prior content-specific knowledge of the relevant topics; c) asked more guiding questions; d) encouraged visitors to ask questions, raise hypothesis and provide explanations; e) avoided using technical terms and scientific jargon as much as possible; f) adjusted language and content to suit visitors; and g) used analogies and real-life examples to make scientific concepts more understandable. All these changes aimed at making their facilitation more interactive, age-appropriate, and student-centred.

Subsequently, in retrospect, some TCs reported that they would like to make further changes to improve their activity facilitation if they were to facilitate activities at FMSD again. These changes would include: a) creating games to address activity contents; b) using visuals/models to emphasize specific contents; c) utilizing activities that have a strong hands-on component; d) choosing activities that display shorter processes from start to finish; and e) changing the sequence or disposition of the activities in some of the rooms to make the overarching themes or "big ideas" more evident and understandable to the event visitors.

5.1.1.2 **Impact of the STEM outreach experience on TCs' communication skills**

Some online survey respondents seem to have underscored the importance of educators' ability to communicate effectively with their target audiences as only five (17.2%) out of 29 chose "communication skills" as one of the most desirable characteristics of effective STEM educators. Moreover, a relatively low number of survey respondents (11 or 37.9%) predicted that the outreach facilitation would be beneficial to their communication skills. However, most focus group participants and interviewees acknowledged that having effective communication skills was crucial to the success of their activity facilitation. The fact that the online survey was done

before the FMSD facilitation, whereas the group discussions and interviews were done after the event, seems to have impacted their views.

Having to interact with visitors of different ages and various backgrounds at FMSD made TCs realize the importance of adjusting language and content accordingly. Thus, TCs avoided the unnecessary use of technical language and scientific terms as those might be unfamiliar to the audience. Instead, concepts were explained in simple language, and this made them more accessible to the visitors.

Furthermore, TCs realized they needed to make their presentations less lecture-like and more interactive. To this end, they reduced their speaking time and started to ask more guiding questions. Using questions was reported to be instrumental to assess visitors' prior knowledge, increase their interest, guide their reasoning, and check for understanding, among other things.

Moreover, TCs also encouraged visitors to ask questions of their own, raise hypothesis and provide explanations. Several TCs reported being impressed by the quality of some of the visitors' questions, which shows, among other things, active listening skills on the part of TCs. In summary, one can argue that if TCs were asked again about the importance of effective communication skills, the clear majority would rate it even higher than they did at the time of the online survey, especially the TCs who had limited experience with outreach events before.

5.1.1.3 Impact of the STEM outreach experience on TCs' motivation to teach STEM

Teacher candidates were clear about the value of FMSD to all parts involved (i.e., TCs, parents, and children) for the following reasons. First, FMSD has in its core the participation of parents, many of whom were already interested in STEM. For TCs, parents were instrumental in instilling STEM interest in their children. Second, TCs had the unique opportunity to put into practice some of their teaching skills when interacting with learners, and that was highly

appreciated considering the theory-oriented nature of the teacher education program. Third, the event was well-timed as it took place few weeks before TCs started their school-based practicum. Fourth, the event consisted of many hands-on STEM activities, and this is likely to help visitors, especially children, to develop a positive attitude towards STEM. Fifth, TCs felt motivated to use hands-on activities in future for their cognitive and affective value.

Furthermore, the TCs who already had previous outreach experiences appreciated the inclusive nature of FMSD. In turn, the novice TCs were impressed by the impact of FMSD on the community. Moreover, the FMSD experience made TCs proud of their accomplishments and confident to use hands-on activities again with their future students.

5.1.1.4 **Impact of the STEM outreach experience on TCs' thinking about effective STEM education**

One of the most significant findings that emerged from the group discussions and interviews was that TCs felt the need to refine and change the way they facilitated their activities to the public as the FMSD event unfolded. In facilitating their activities multiple times to different age-groups, TCs realized that their original "scripts" needed to be modified to suit visitors' ages, interests, and prior knowledge of relevant topics. In other words, TCs adopted strategies to make their activity facilitation more interactive, dynamic, meaningful, and thus more effective.

Another relevant finding concerns the use of inquiry-based learning through which TCs encouraged visitors to ask and answer questions and raise and test hypotheses during the activities. In doing so, the process was emphasized more than the product. This suggests that TCs were adopting strategies that are in tandem with the new BC curriculum, which has inquiry as one of its central values.

Moreover, the findings from the focus group discussions and interviews indicated that TCs have a high appreciation for hands-on activities. This reflected not only TCs' sound PCK but also their views on STEM teaching and learning. In addition, TCs reported that through hands-on activities visitors were more engaged and more likely to develop positive attitudes towards STEM. On their part, TCs reported feeling confident and encouraged to use hands-on activities again with their future students.

5.1.2 RQ2: What do teacher candidates perceive their own strengths and weaknesses as STEM teachers to be?

Three main themes related to TCs' self-perceptions of their strengths as STEM teachers have emerged from the analysis of their responses to the online survey (n=29): 1) Adequate personality traits; 2) Sound PCK; and 3) Passion for STEM. Although, content knowledge and communication skills were also mentioned, the number of comments coded for these last two themes were nowhere near as numerous as the ones coded for the first three. In fact, the TCs who felt they had the right personality to be effective STEM teachers (22) outnumbered those who felt prepared regarding their PCK (17). This is understandable given that all respondents were still in their teacher education program and had not yet facilitated their activities at FMSD at the time of the survey.

Moreover, the results from the online survey showed that most of the respondents (24) reported lack of PCK as their major limitation. This finding is somehow puzzling as 17 TCs had previously reported having a sound PCK as their strengths. One way to interpret this finding is that although TCs felt that their PCK was good, there was still room for improvement.

Another distinctive finding concerns TCs' communication skills. Although only one respondent had reported having poor communication skills, only two TCs indicated

communication skills as their strengths. This could be connected to lack of teaching experience at the time of the survey. Nine of the 29 respondents did not have any school-based teaching experience, whereas nine reported not having any teaching experience in out-of-school settings.

Moreover, even though 28 of the 29 survey respondents had B.Sc. degrees, lack of CK was also reported as one significant limitation. A possible explanation to that may be the fact that STEM encompasses multiple subjects, some of which may not be directly connected to respondents' B.Sc. degrees. Thus, some TCs may feel insecure to teach certain STEM contents.

5.1.3 RQ3: How do teacher candidates perceive what it means to be an effective STEM teacher?

The 29 survey respondents considered the following as the most desirable characteristics of effective STEM teachers. First, teachers should bear a great passion for STEM and the teaching profession. The second characteristic refers to teachers' knowledge and skills to adopt adequate pedagogical practices to facilitate student learning. In other words, teachers should have a sound PCK. Teachers' CK was considered the third most important characteristic of effective STEM teachers. Lastly, TCs reported teachers' ability to communicate effectively with their target audiences.

The data from the focus group discussions (n=46) and interviews (n=9) obtained after TCs had facilitated their activities at FMSD confirmed the importance of a sound PCK, which also encompasses CK. However, contrary to what had emerged from survey results, focus group participants and interviewees gave a lot more emphasis to effective communication. Being able to effectively communicate with their target audiences was regarded as an essential skill as it enabled TCs to: a) assess visitors' prior knowledge of relevant content; b) produce meaningful

age-appropriate interactions to facilitate learning; c) reduce their own speaking time; d) adopt a more interactive, inquiry-based approach to teaching; and e) assess visitors' learning.

In summary, data from focus group discussions and interviews suggest that TCs showed more appreciation for effective communication skills after they had facilitated their activities multiple times to different age groups at FMSD. Moreover, focus group participants and interviewees reported that the effective use of guiding questions was one key factor to the success of their activity facilitation at FMSD.

Chapter 6: Conclusions

Data from the pre-event online survey revealed TCs' passion for STEM-related activities as their greatest self-reported strength, whereas lack of PCK was self-reported as their greatest limitation. Moreover, TCs predicted that activity facilitation at FMSD would enhance their teaching skills by allowing them to put their content knowledge into practice to facilitate visitors' learning.

Data from post-event focus group discussions and individual interviews, however, indicated that TCs benefitted from the outreach experience as it: a) enabled them to expand their PCK; b) made them more aware of the importance that effective communication has on STEM teaching and learning; c) increased or reinforced their appreciation of STEM hands-on activities for cognitive and affective reasons; d) enhanced or strengthened their understanding of the importance of parental engagement with their children's STEM education; and e) gave them the opportunity to put in practice some of the theory they had been learning in the teacher education program. Instances of the above emerged during TCs' preparation for the event, activity facilitation at FMSD, and in post-event reflections. The above findings do not seem to have connections to whether TCs had previous teaching experience.

Their event preparation, for example, included the following steps: a) deciding on the activities to be facilitated to the public; b) organizing the required materials and equipment; c) running the activities to familiarize themselves with the procedures; d) researching and revising specific contents; e) taking notes on related topics; f) predicting problematic issues that might arise from related contents; and g) foreseeing some questions that might be asked by visitors during activity facilitation. Moreover, TCs produced videos depicting their activities. All these

steps seem to have had a positive impact on what Shulman (1986) refers to as PCK, which is a combination of CK and PK.

Furthermore, during the event, after presenting the same activity several times to visitors of diverse backgrounds, TCs reported that they realized that changes were needed to make their facilitation more interactive and age-appropriate both linguistically and content wise. For example, to make contents more relevant and understandable to visitors, some TCs used real-life situations and analogies. Moreover, they reduced their own speaking time and started asking more guiding questions. These moves were considered effective as they made the activities more inquiry-like and in tandem with the new BC curriculum. In line with Geiken et al. (2016), the use of questions was regarded as effective to increase learners' interest, guide their reasoning, assess prior knowledge, and check for understanding. In addition, TCs reported avoiding the use of technical jargons and scientific terminologies as these would hinder visitors' understanding of the activities.

The change in approach mentioned above also contributed to TCs' realization of the importance of communication in STEM education. Evidence from the focus group discussions and individual interviews indicated that TCs felt more satisfied about their presentation once they had been refined and streamlined. Thus, the more interactive facilitations done towards the end were better regarded than the more teacher-centred, lecture-like ones done at the beginning of the event. All in all, these findings indicate that TCs adopted an active role in their learning process. Besides, in line with Milner-Bolotin (2017b), Savec (2016), and Vygotsky (1978), TCs' learning was facilitated by their meaningful interactions with peers, visitors, materials, and technology.

Another important characteristic of TCs' participation at FMSD refers to their appreciation of hands-on activities. Evidence from the focus group discussions and interviews highlights the importance of such an approach to STEM learning and teaching for their cognitive and affective value. Regardless of having previous teaching experiences, TCs acknowledged that hands-on activities were effective at inspiring and motivating learners to engage with STEM-related subjects. Moreover, TCs indicated that using hands-on activities would be an integral part of their future teachings in school contexts to start a unit or to relate contents to real-life situations, for example. These findings are in keeping with Luft (2001) and Marshall and Alston (2014), for whom well-designed inquiry-based instruction is beneficial for pre- and in- service secondary science teachers as well as students.

Further evidence that corroborates the idea that FMSD positively impacted TCs' PCK relates to the post-event reflections. In them, TCs acknowledged that they would like to make additional changes to their activities, if they were to participate in FMSD again. Some of these changes would include: a) choosing shorter activities; b) utilizing activities with a stronger hands-on component; and c) using games or visual aids such as models to highlight certain contents and to emphasise the science behind the activities. In addition, TCs made suggestions for future FMSD events. These included: a) communicating with facilitators from previous years to learn about the visitors' profile; b) using some class time from the secondary science methods course to prepare the activities and presentations; c) allowing more time during the event for TCs to visit other stations; and d) relocating some stations to make overarching themes more evident to event visitors.

Another relevant finding refers to the positive impact that activity facilitation had on TCs' confidence. The TCs with previous teaching experience felt the event gave them

opportunities to improvise and try new ways of explaining concepts. The ones with limited or no teaching experience, however, came out of the event feeling pleased with their ability to deal with visitors from different age groups and backgrounds. Furthermore, they appreciated the opportunity to put some theory learned in the teacher education program into practice, especially considering that FMSD took place right before the beginning of their school-based practicum. Overall, TCs reported feeling encouraged by the way visitors left their stations at the end of the presentations and by the positive feedback they had from parents during the event. These findings are in line with Jung and Tonso (2006) who found that out-of-school experiences positively impacted TCs' affective domain as they gained confidence in their abilities to teach.

Moreover, the study highlighted the importance that TCs gave to parental engagement with their children's education. The TCs with little or no experience in outreach events were impressed by the influential effect that parents had on children, whereas TCs with previous participation in such events reported that FMSD reinforced what they had already experienced. Overall, parental engagement was regarded as positive because parents: a) paraphrased some of the TCs' explanations to make them more relevant to children; b) encouraged children to ask questions; and c) helped children to relate the activity contents to situations previously experienced by the family in other contexts. These findings are aligned with research evidence from Green et al. (2007) and Hango (2007), for whom parental engagement is key to children's education.

Furthermore, TCs acknowledged the importance of outreach events to make STEM more widely available to the community and to inspire children to develop a positive attitude towards STEM. This finding is in keeping with Marotto and Milner-Bolotin (2018) who reported that

89.6% of the study participants stated that accompanying their children to science centres and STEM-related events is effective to motivate children to engage with STEM.

In summary, the points made above indicate that the process leading up to FMSD as well as the participation at the event contributed to TCs' education in several ways. Apart from broadening their PCK, TCs gave a lot more emphasis to the role of effective communication in STEM education once they had facilitated their activities at the event. Data from the online survey done prior to FMSD facilitation indicated that TCs did not anticipate that their communication skills would be key to successful performances at the event, and this is another contribution of the FMSD experience to TCs' education.

To finalize, once the data were analyzed and the conclusions reached, a question may be raised about the use of the term STEM by TCs. In other words, are TCs clear about the meaning of STEM or are they sometimes referring solely to science when speaking about STEM? At times, one has the impression that TCs may think of STEM and science as being interchangeable. If that is the case, there is a mismatch between the researcher's definition of STEM, which is in line with DeCoito (2016) and Zan (2016) described in Sub-section 2.2.1, and what some TCs may mean by that acronym. All this despite the *General Science Secondary Methods* course instructor's attempts to emphasize that STEM education entails the teaching of science, technology, engineering and mathematics in an integrated manner.

Based on the findings above, some suggestions to improve STEM education can be made to researchers, educators, course instructors, and TCs:

1. As mentioned earlier, only the TCs from two of the three sections of the *General Science Secondary Methods* course were required to facilitate activities at FMSD. Considering the

benefits of the experience, this requirement could be extended to TCs from all three sections of the course.

2. The instructors of UBC teacher education program could work together to select a few pedagogical practices that they would like TCs to focus on during their activity facilitation at FMSD. That would guide TCs' event preparation, allowing them to put in practice some of the theory learned during the education program.
3. Further research could be done to assess the impact of the experience of facilitating activities at FMSD on TCs' teacher knowledge. This could encompass areas such as use of technology, STEM-related content knowledge, and motivation towards STEM teaching, among others.
4. Educators from other teacher education programs could consider adding informal, out-of-school teaching experiences to their existing programs. To do this, they could create their own outreach model, adapt FMSD model to their own context or even work collaboratively with some well-established outreach organizations like Let´s Talk Science or Genome BC.

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Appendices

Appendix A: On-line questionnaire

1. What is your age group?

19 years old or younger	20-24 years old	25-29 years old
30-34 years old	35-40 years old	41 years old or older

2. What subject area is your bachelor's degree in? (Select all that apply.)

Mathematics	Physics	Chemistry	Other
Biology	Science	Physics	

3. If you have selected "other" for question 2, please specify.
4. What teaching experiences do you have in formal educational settings? (Select all that apply.)

Elementary school level (Kindergarten-Grade 8)	University/college level	I do not have any teaching experience in formal educational settings yet.
Secondary school level (Grades 9-12)	Graduate level	Other

5. If you have selected "other" for question 4, please specify.
6. What teaching experiences do you have in informal (out-of-school) settings? (Select all that apply.)

science museum	botanical gardens	in-company programs
aquariums	after-school programs	art galleries
Other	None of the above	

7. If you have selected "other" for question 6, please specify.
8. Select the 3 most important reasons why you want to be a STEM educator.

Because of professional stability.	To contribute to the production of a scientific-literate community.	Because I like to work with children/adolescents.
Because of financial reasons.	To help steer student towards STEM-related professional careers.	Because I have effective teaching skills.
Because I have a sound knowledge of one or more STEM-related subject(s).	Because STEM-related subjects are instrumental in fostering essential skills in students, e.g., problem-solving, critical thinking etc.	Because I have a passion for teaching.
Other		

9. If you have selected "other" for question 8, please specify.
10. In your view, what makes an effective STEM educator?
11. In your view, what are two of your main strengths as a STEM educator?

12. In your view, what are two of your main limitations as a STEM educator?
13. What skills do you think you'll need to be an effective activity facilitator at Family Math and Science Day?
14. How do you think your participation at Family Math and Science Day might contribute to your journey as a STEM educator?
15. May I contact you to discuss how participating at Family Math and Science Day could help you to become a more effective STEM educator?

    ( ) No ( ) Yes
16. If your answer to question 15 is YES, and you would like to discuss your ideas with me, please leave your first name and email address (or phone number) in the space below. I would be happy to contact you.

Appendix B: Focus Group Discussion Protocol

1. What were your impressions of the FMSD event?
2. Have you participated in similar outreach events before?
3. Who are the stakeholders in STEM education?
4. How do you think FMSD contributes to bringing stakeholders closer to STEM education?
5. How valid are outreach events like FMSD to STEM education?
6. How important is the participation of the parents/families in the FMSD event?
7. What activity did you facilitate at the event? Why did you choose this activity?
8. How did you prepare to facilitate your activity at the event?
9. Why did you prepare the way you did? Did you anticipate any problems?
10. In hindsight, would you change anything to your preparation?
11. What worked well in your interactions with the public? Can you give some examples?
12. What did not work so well in your interactions with the public? Can you give some examples?
13. How do you compare your activity facilitation at the beginning of the event with the ones done towards the end of the event?
14. Would you do anything different if you were to facilitate again at the event in the future?
15. How do think this experience has contributed to your teacher education?
16. What suggestions would you make to improve the next editions of the event?

Appendix C: Individual Interview Protocol

1. What were your impressions of the FMSD event?
2. Have you participated in similar outreach events before? If so, which one(s)?
3. Who are the stakeholders in STEM education?
4. How do you think FMSD contributes to bringing stakeholders closer to STEM education?
5. How valid are outreach events like FMSD to STEM education?
6. How important is the participation of the parents/families in the FMSD event?
7. What activity did you facilitate at the event? Why did you choose this activity?
8. How did you prepare to facilitate your activity at the event?
9. Why did you prepare the way you did? Did you anticipate any problems?
10. Did you work with anybody during the preparation? What about at the event?
11. In hindsight, would you change anything to your preparation?
12. What worked well in your interactions with the public? Can you give some examples?
13. What did not work so well in your interactions with the public? Can you give some examples?
14. How do you compare your activity facilitation at the beginning of the event with the ones done towards the end of the event? Which facilitations were more effective?
15. Would you do anything different if you were to facilitate again at the event in the future?
16. How do think this experience has contributed to your teacher education?
17. Did you use any particular teaching strategy during your facilitation at the event?
18. What suggestions would you make to improve the next editions of the event?