K-12 STEM LEARNING ECOSYSTEMS: THE ROLE AND POSITION OF UNIVERSITY-BASED OUTREACH UNITS AS KNOWLEDGE BROKERS

by

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Abstract

To address the projected Science Technology Engineering and Mathematics (STEM) workforce needs and future demands in Canada, one strategy involves the promotion of K-12 STEM learning ecosystems. K-12 STEM learning ecosystems consist of formal learning experiences provided to students by educators within schools, as well as informal learning experiences that are directly or indirectly supported by stakeholders. The purpose of this research is to explore the conceptual position and role of Canadian university-based STEM Outreach Units (SOUs) as knowledge brokers within K-12 STEM learning ecosystems.

This dissertation used an explanatory three-phase naturalistic case study approach involving both quantitative and qualitative data collection and analysis to examine each research question. Phase 1 served as a starting point for generating an environmental scan of university-based STEM outreach units across Canada by utilizing an online search strategy to conduct an environmental scan, followed by a website analysis using quantitative descriptive statistics. Phase 2 consisted of an online survey designed with both closed and open-ended questions to explore SOUs organizational features, the conceptualization of K-12 STEM learning ecosystems, and SOUs' role as knowledge brokers. In Phase 3, semi-structured qualitative interviews were conducted with managers of SOUs to generate individual case studies that are used to further explore SOUs views on K-12 STEM learning ecosystems and the concept of SOUs as knowledge brokers.

The first finding from this research suggests that there is a commonality in SOUs' mission statements and target audiences, with a common interest in expanding their efforts towards increasing the number of underrepresented and underserviced youth who are participating in STEM outreach programs such as Black, Indigenous, racialized youth, those from low socio-economic communities, and girls. However, there is a large variability of other organizational features. Looking at the K-12 STEM learning ecosystem, the second finding indicates that SOUs have established mutually beneficial reciprocal
partnerships with their host institution, K-12 schools, students, and community groups, and mixed with others. This particular result suggests that SOUs role within K-12 STEM learning ecosystems could be optimized with increased priority towards establishing collaboration, especially with key stakeholders that have the control/power to both enhance and limit youth’s STEM learning experiences. The third finding indicates that university-based SOUs are well-positioned within the K-12 STEM learning ecosystem as knowledge brokers to facilitate, share and communicate STEM knowledge using brokering functions to a variety of target audiences. In fact, many are already delivering initiatives that can be categorized as one of the following high-priority brokering functions: engagement, awareness, and accessibility. There was also an identified common link between SOUs using the brokering functions to purposefully increase the number of underrepresented and underserviced youth in STEM.

The findings of this study affirm that university-based STEM outreach units have a role to play in educating the current K-12 student population, as they comprise the future workforce. This dissertation concludes that university-based SOUs can play the role of STEM knowledge brokers, spanning the boundaries between stakeholders and other participating groups, within a K-12 STEM learning ecosystem. The outcomes and impact of SOUs as knowledge brokers within a collaborative multi-partner K-12 STEM learning ecosystems could yield an increase in the number of young adults with STEM knowledge and skills, that in pursuing post-secondary STEM education and a STEM career, may potentially close the projected Canadian workforce gap.
Acknowledgements

This Ph.D. dissertation has been a journey like no other. Over the last six years of my life, trying to write my dissertation and complete my degree part-time, while working full-time, and starting a family, had its challenges. I am beyond happy to have reached the end and could not have done so without the involvement of several people, whom I would like to acknowledge.

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I am grateful to my supervisor Dr. Amanda Cooper. I remember the exciting feeling I had when we first met and discussed the idea of me starting a Ph.D. under your supervision. Six years later, I still get that exciting feeling when we meet. You have been more of a mentor than a supervisor and I am grateful to have been learning from you. By completing my dissertation and getting a “ticket to the show”, I look forward to the next journey alongside you.

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# Table of Contents

Abstract ................................................................................................................................. ii
Acknowledgements ............................................................................................................... iv
List of Figures ........................................................................................................................ x
List of Tables ........................................................................................................................ xi
Key Term and Definitions ................................................................................................... xii
Chapter 1 Introduction ......................................................................................................... 1
  K-12 STEM Learning Ecosystems ...................................................................................... 2
  K-12 STEM Outreach Units within an Ecosystem ........................................................... 3
Statement of the Challenge – STEM Outreach Units in K-12 STEM Learning Ecosystems .... 6
STEM Outreach Units as Knowledge Brokers ................................................................. 8
Purpose and Research Questions ....................................................................................... 10
Rationale ............................................................................................................................... 10
Significance of Research .................................................................................................... 11
Situating the Researcher ...................................................................................................... 12
Dissertation Overview ......................................................................................................... 14
Chapter 2 Literature Review ............................................................................................. 16
Systematic Literature Review: K-12 STEM Outreach ..................................................... 16
  STEM Outreach Units and Initiatives ............................................................................. 24
  K-12 STEM Education Outreach Multi-Stakeholder Partnerships .................................. 29
  Model 1: STEM Education Outreach Model ................................................................. 30
  Model 2: Systematic STEM Education .......................................................................... 33
  Model 3: STEM Learning Ecosystems Community of Practice .................................. 34
  Model 4: K-12 In-School STEM Outreach Delivery ..................................................... 37
STEM Outreach Learning Ecosystem Impact and Recommendations ......................... 39
Summary of STEM Outreach Literature Scoping Review ............................................... 40
Brief Literature Review – Knowledge Mobilization and Knowledge Brokers .................. 43
  Knowledge Broker Models ............................................................................................ 45
Conceptual Framework – Exploring the Conceptualization of STEM Outreach Units as Knowledge Brokers within a K-12 STEM Learning Ecosystem .............................................................. 51
Chapter 3 Methodology .................................................................................................... 56
Methodological Approach – Multi-Case Study ................................................................. 56
Chapter 5 Findings

Ensuring Trustworthiness and Credibility

Chapter 4 Findings

RQ 1 - What are the Organizational Features of STEM Outreach Units in Canada? 

STEM Outreach Units' Mission Statements or Objectives

Intended Target Audiences of STEM Outreach

Types of Initiatives STEM Outreach Units Offer

STEM Outreach Units' Staffing Capacity

STEM Outreach Units Financial Resources

Evaluating STEM Outreach Units' Programs and Overall Impact

RQ 2 - How are STEM Outreach Units Involved in a K-12 Learning Ecosystem?

Partners of STEM Outreach Units within a STEM Learning Ecosystem

Chapter 5 Findings – Phase 2: Online Survey

RQ 1 - What are the Organizational Features of STEM Outreach Units in Canada?

STEM Outreach Units' Mission Statements or Objectives

Intended Target Audiences of STEM Outreach

Important Stakeholders of STEM Outreach Units

STEM outreach units' staffing capacity

STEM Outreach Units Financial Resources

Annual Operating Budgets of STEM Outreach Units

Growth of STEM Outreach Units Over Five Years

Facilitators and Challenges of Delivering STEM Outreach

Research Design, Recruitment and Sampling – Sequential Three-Phase Approach

Phase 1 – Website Analysis

Phase 2 – Online Survey

Phase 3 – Semi-Structured Interviews

Data Collection

Phase 1 – Website Analysis

Phase 2 – Online Survey

Phase 3 – Semi-Structured Interviews

Data Analysis

Phase 1 – Website Analysis

Phase 2 – Online Survey

Phase 3 - Semi-Structured Interviews

Ensuring Trustworthiness and Credibility

Chapter 4 Findings – Phase 1: Environmental Scan and Website Analysis

Phase 1: Environmental Scan and Website Analysis

Phase 2: Online Survey

Phase 3: Semi-Structured Interviews
RQ 2 - How are STEM Outreach Units Involved in a K-12 Learning Ecosystem? ............................................ 97

Partners of STEM Outreach Units within a STEM Learning Ecosystem ......................................................... 97

Multiple STEM Outreach Units in the Same K-12 STEM Learning Ecosystem ................................................. 99

RQ 3 – To what extent are STEM Outreach Units Knowledge Brokers within an Ecosystem? ............... 100

Similarities and Differences between STEM Outreach Units and Knowledge Brokers .................. 100

Knowledge Brokering Functions Being Used by STEM Outreach Units ..................................................... 101

Chapter 6 Phase 3 – Case Study Descriptions ................................................................................................. 103

Individual Case Study Descriptions ............................................................................................................. 104

Case Study 1 (SOU # 1) ................................................................................................................................. 104
Case Study 2 (SOU # 4) ................................................................................................................................. 105
Case Study 3 (SOU # 14) ............................................................................................................................... 107
Case Study 4 (SOU # 15) ............................................................................................................................... 109
Case Study 5 (SOU # 20) ............................................................................................................................... 111
Case Study 6 (SOU # 22) ............................................................................................................................... 112
Case Study 7 (SOU # 24) ............................................................................................................................... 113
Case Study 8 (SOU # 25) ............................................................................................................................... 114
Case Study 9 (SOU # 39) ............................................................................................................................... 116
Case Study 10 (SOU # 65) ............................................................................................................................ 118
Case Study 11 (SOU # 71) ............................................................................................................................. 120
Case Study 12 (SOU # 73) ............................................................................................................................. 121

Case Study Summary and Cross-case Analysis .............................................................................................. 123

Chapter 7 Findings – Phase 3: Interviews ......................................................................................................... 126

RQ 1 - What are the Organizational Features of STEM Outreach Units in Canada? ................................. 126

Evaluating STEM Outreach Units’ Programs and Overall Impact ................................................................. 126

RQ 2 - How are STEM Outreach Units Involved in a K-12 Learning Ecosystem? ................................. 129

Similar to RQ1, Phase 1 and Phase 2 have already presented several results sections related to RQ2.
The following sections provides findings from the Phase 3 case studies that contribute towards
exploring how SOUs are involved within a K-12 STEM learning ecosystem ................................................. 129

Partners of STEM Outreach Units within a STEM Learning Ecosystem ....................................................... 129

Why SOUs Engage in Partnerships? .............................................................................................................. 134

Benefits of a STEM Learning Ecosystem ...................................................................................................... 138

Drawbacks of a STEM Learning Ecosystem .................................................................................................... 139

Competition Within Learning Ecosystems ..................................................................................................... 141
Role of STEM Outreach Units within a K-12 Learning Ecosystem .......................................................... 142
RQ 3 – To what extent are STEM Outreach Units Knowledge Brokers within an Ecosystem? ............ 143
Similarities and Differences between STEM Outreach Units and Knowledge Brokers ....................... 143
Knowledge Brokering Functions Being Used by STEM Outreach Units ................................................. 145
High priority knowledge brokering functions for SOUs. ........................................................................ 151
Low priority knowledge brokering functions for SOUs. ........................................................................ 153
Mixed priority knowledge brokering functions for SOUs. ..................................................................... 153
Knowledge Brokering Relevance for STEM Outreach Units ................................................................. 154
Chapter 8 Discussion ............................................................................................................................... 157
Theme 1: K-12 STEM Learning Ecosystems Already Exist but could be Optimized with Increased Priority Towards Establishing Collaboration, Partnership, and Relationships within the Ecosystem ...................................................... 162
Practical Implication for SOUs ............................................................................................................. 165
Theme 2: There is a Large Variability of University-based SOU Organizational Features, with a
Common Focus on Engaging Youth Who are Under-represented and Underserviced in STEM, Across the Pan-Canadian Landscape ....................................................................................................... 168
Practical Implication for SOUs ............................................................................................................. 170
Theme 3: Increasing the Number of Underrepresented and Underserviced Youth Involved in STEM
Outreach is a Lens That Overlaps All KMb Brokering Functions for University-based SOUs within a K-
12 STEM Learning Ecosystem .................................................................................................................. 171
Practical Implication for SOUs ............................................................................................................. 174
Theme 4: University-based SOUs are Interested in Shifting their Evaluation Efforts from Individual
Program Outputs to Focus on Program Outcomes and Impact .................................................................. 177
Practical Implication for SOUs ............................................................................................................. 178
Limitations ........................................................................................................................................... 182
Instrument Design ................................................................................................................................. 183
Myself as the Instrument ......................................................................................................................... 185
Recommendations ................................................................................................................................. 186
Conclusion ............................................................................................................................................ 190
References ............................................................................................................................................ 192
Appendix A Research Design Information .............................................................................................. 200
A1 – General Research Ethics Board Approval .................................................................................... 200
A2 – Participant Recruitment Script(s) .................................................................................................. 201
Phase 2 – Online Survey. ......................................................................................................................... 201
Phase 3 – Interviews.................................................................................................................. 202
A3 – LOI’s and Consent Forms .................................................................................................. 203
Phase 2 – Online Survey. ......................................................................................................... 203
Phase 3 – Interviews.................................................................................................................. 205
A4 – Phase 2 Survey Questions ............................................................................................... 207
A5 – Phase 3 Interview Protocol & Questions.......................................................................... 209
A6 – SOU Twelve Case Study Summary and Integration Table ............................................. 214
List of Figures

Figure 1 *The position of STEM Outreach Units within a K-12 STEM Learning Ecosystem* ............................................. 7
Figure 2 *STEM Outreach Scoping Review Process* ........................................................................................................ 18
Figure 3 *Summary of STEM Outreach Types, Goals, and Organizational Features* ................................................. 25
Figure 4 *Summary of Formal vs. Informal STEM Outreach* .......................................................................................... 27
Figure 5 *Ward’s (2015) Systematic STEM Outreach Model* ........................................................................................ 31
Figure 6 *STEM Learning Ecosystem Partners* ............................................................................................................. 35
Figure 7 *Conceptual Framework - STEM Outreach Units as Knowledge Brokers* ...................................................... 51
Figure 8 *Mixed Methodological Strategies Adapted from Patton (2002)* ................................................................. 58
Figure 9 *Summary of Phase 1 Website Analysis Data Extraction Process* ............................................................... 64
Figure 10 *The Distribution of STEM Outreach Units across 52 Universities for Phase 1* ........................................... 74
Figure 11 *Common Words describing STEM Outreach Units Mission Statements* ................................................... 75
Figure 12 *STEM Outreach Units in Phase 2 Annual Operating Budget* ................................................................ 93
Figure 13 *KMb Knowledge Brokering Functions used by Phase 2 SOUs* ................................................................. 101
Figure 14 *Relationships between SOU and Ecosystem Groups Identified by Phase 3 Participants* .................... 130
Figure 15 *Updated Conceptual Framework of K-12 STEM Learning Ecosystem Highlighting STEM Outreach Partnerships* ..................................................................................................................................... 133
Figure 16 *Brokering Functions Themes as Provided by Phase 3 Interview Participants* ........................................ 151
Figure 17 *The Updated Conceptual Framework Highlighting SOU Position and Role within a K-12 STEM Learning Ecosystem* ............................................................................................................. 160
List of Tables

Table 1 Keywords Grouped Based on Fields ........................................................................... 17
Table 2 Aims and Components of Reviewed STEM Outreach Articles ........................................ 19
Table 3 Literature Review STEM Outreach Articles Organized by Number of Partnership in Model ...... 29
Table 4 Aims and Components of KMb Brokering Models .......................................................... 46
Table 5 Organizational Features of Organizations ....................................................................... 53
Table 6 Knowledge Mobilization Brokering Functions (Cooper, 2014). ............................................ 54
Table 7 Keywords Grouped Based on Fields ............................................................................... 62
Table 8 Examples of STEM Outreach Search Strings ................................................................... 62
Table 9 The Distribution of Phase 1 Target Audiences of the STEM Outreach Units ............................. 77
Table 10 Phase 1- Types of Initiatives and their Frequency in STEM Outreach Units ....................... 78
Table 11 Phase 2 - Geographical distribution of the number of SOU participants ............................ 84
Table 12 Phase 2 - STEM Outreach Mission Statement Categories ............................................... 85
Table 13 Phase 2 - Target Audience Frequency and their Influential Ranking ................................. 87
Table 14 Phase 2 - Summary of Stakeholder Frequency and their Influential Ranking .................... 89
Table 15 Phase 2 - Summary of Frequency of Staffing Types versus STEM Outreach Units Size ........... 91
Table 16 Phase 2 - STEM Outreach Units Sources of Funding ....................................................... 92
Table 17 Phase 2 - K-12 STEM Learning Ecosystem Partners ....................................................... 98
Table 18 Synthesis of Case Study Data Grouped by Number of Two-way Partnerships ...................... 124
Table 19 Themes and description of what SOUs contribute and receive from partnerships. ................... 136
Table 20 Phase 3 - Brokering Functions Major Themes and Descriptions ......................................... 146
Table 21 Updated Description of Knowledge Brokering Functions for SOUs ................................. 175
Table 22 Principles of Collaborative Approaches to Evaluation Recommended for University-based SOUs ........................................................................................................................................... 180
Table 23 Practical Recommendations for University-based SOUs towards Ecosystem Groups .......... 187
## Key Term and Definitions

<table>
<thead>
<tr>
<th>Key Term</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td><strong>Science, Technology, Engineering, and Mathematics (STEM)</strong></td>
<td>A multidisciplinary approach to solving complex problems by integrating the four subject areas to see if/how they inform one another (DeCoito, 2016; Howard-Brown &amp; Martinez, 2012).</td>
</tr>
<tr>
<td><strong>STEM Workforce</strong></td>
<td>The scientists and engineers who further scientific and technological progress through research and development (R&amp;D), workers in non-R&amp;D fields who use STEM knowledge and skills to devise or adopt innovations, and workers in technologically demanding jobs who need STEM capabilities to accomplish occupational tasks (National Science Board, 2015)</td>
</tr>
<tr>
<td><strong>K-12 STEM Learning Ecosystem</strong></td>
<td>Harnessing the unique contributions of both formal (in-school) and informal (out-of-school) learning opportunities, provided in collaboration by various groups, in multiple settings, to enable young people to become engaged, knowledgeable, and skilled in STEM</td>
</tr>
<tr>
<td><strong>White Space</strong></td>
<td>The areas between clear boundaries, departments, or organizations in which no one takes explicit ownership or responsibility (Rummler and Brache, 1995).</td>
</tr>
<tr>
<td><strong>Partnership</strong></td>
<td>Groups within a K-12 STEM learning ecosystem who collaborate with SOUs to deliver in-person STEM learning opportunities and have a direct influence on the ecosystem.</td>
</tr>
<tr>
<td><strong>Stakeholders</strong></td>
<td>Groups that have a stake or an active interest in (e.g., somehow vested in) a K-12 STEM learning ecosystem. Primary stakeholders include those groups or individuals who have a strong interest in the ecosystem and who potentially have the power to make or influence decisions. Secondary or tertiary stakeholders have an indirect influence on the overall ecosystem. (Alkin, 2011)</td>
</tr>
<tr>
<td><strong>Knowledge Mobilization</strong></td>
<td>The reciprocal and complementary flow and uptake of research knowledge between researchers, knowledge brokers, and knowledge users in such a way that may benefit users and create positive impacts (Social Sciences and Humanities Research Council of Canada, 2019).</td>
</tr>
<tr>
<td>Knowledge Broker</td>
<td>A person or organization that facilitates the creation, sharing, and use of knowledge between at least two or more groups of stakeholders, who have an active role to catalyze knowledge mobilization between them (Cooper, 2014; Honig, 2004; Meyer, 2010; Ward, 2017).</td>
</tr>
<tr>
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<tr>
<td>Evaluation</td>
<td>The systematic assessment of the design, implementation, or results of an SOU initiative for learning or decision-making (Canadian Evaluation Society, 2015)</td>
</tr>
<tr>
<td>Collaborative</td>
<td>An approach to program evaluation wherein trained evaluators work in partnership with members of a given community to produce evaluative knowledge (Shulha, Whitmore, Cousins, Gilbert, &amp; Hudib, 2016).</td>
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Chapter 1

Introduction

Science, Technology, Engineering, and Mathematics, a combination more commonly known as STEM, is described as a multidisciplinary approach to solving complex problems by integrating the four subject areas to see if/how they inform one another (DeCoito, 2016; Howard-Brown & Martinez, 2012). According to the Government of Canada’s 10-year labor market projection, some of the biggest areas of shortage leading up to 2022 occur in the STEM workforce (Conference Board of Canada, 2013; Council of Canadian Academies, 2014). Furthermore, by 2067, it is projected that 70% of the top-ranking jobs in Canada will require STEM knowledge and skills (Parkin & Crawford Urban, 2017).

The STEM workforce includes, but is not limited to, the scientists and engineers who further scientific and technological progress through research and development (R&D), workers in non-R&D fields who use STEM knowledge and skills to devise or adopt innovations, and workers in technologically demanding jobs who need STEM capabilities to accomplish occupational tasks (National Science Board, 2015). To address the projected STEM workforce needs, gaps, and future demands, one strategy is to focus on the kindergarten through to Grade 12 (K-12) STEM education stakeholders who can directly and/or indirectly influence a student’s STEM trajectory both in their academic and professional pathways (Conference Board of Canada, 2013). It is this broad view of the K-12 STEM education system that will be referred to as the K-12 STEM learning ecosystem throughout this dissertation. The purpose of this dissertation is to explore the position and role that STEM outreach units (SOUs) have within the conceptualization of K-12 STEM learning ecosystems. Chapter 1 begins by broadly describing K-12 STEM learning ecosystems, before focusing on describing SOUs within the ecosystem and their conceptual role as knowledge brokers, leading to this dissertation's research questions.
K-12 STEM Learning Ecosystems

The concept of a learning ecosystem approach to enhance K-12 STEM education for students by enabling them to become engaged, knowledgeable, and skilled in STEM disciplines has increased over recent years (Bisbee O’Connell, Keys, & Storksdieck, 2017; Traphagen & Traill, 2014). In addition to K-12 students who are the intended audience and primary focus of K-12 STEM education, one stakeholder group within the K-12 STEM learning ecosystem is traditional schooling in which students participate in various learning activities and experiences. The STEM learning experiences are often unique to individual students from different schools, but at the same time, follow specific provincial guidelines as outlined in relevant curriculum documents. STEM education within a school setting can differ due to a range of factors, including (but not limited to) the school/school board’s resources to support students and STEM, the allocated teaching time to cover STEM content within the classroom, the teaching and learning strategies used to deliver and explore STEM content, as well as the influence or support provided by classroom educators and administration. Outside of formal K-12 education, other stakeholder groups that can either directly and/or indirectly contribute to a student’s STEM learning include (Traphagen & Traill, 2014):

- Home (families, parent, guardians)
- Community settings (including after-school and summer programs; STEM-expert museums, science centers or discovery centers; libraries; and community-based youth organizations)
- Post-secondary institutions such as universities and colleges
- STEM-related industry/businesses
- Government (Federal, Provincial, and Ministries of Education)
- K-12 STEM outreach units (including university-based, for-profit, charitable/non-profit, government agencies)
This dissertation will focus specifically on the direct and/or indirect contributions that K-12 STEM outreach units have within a K-12 STEM learning ecosystem.

**K-12 STEM Outreach Units within an Ecosystem**

The four most common types of K-12 STEM Outreach Units (SOUs) include those embedded within post-secondary institutions; non-profit/charitable or volunteer organizations; private-sector STEM-based organizations; and various levels of government agencies or initiatives (DeCoito, 2016; Turner et al., 2007). Of these four types, the largest number of SOUs are found at post-secondary institutions, followed by the non-profit sector. SOUs are of particular interest within a learning ecosystem as they seek to engage a variety of target audiences and work with K-12 education stakeholders and community partners to achieve these goals. Also, SOUs have access to federal financial resources (such as CanCode grants) to help STEM outreach initiatives as they support Canada’s goal of closing the projected STEM workforce gap.

The CanCode program was established by the Department of Innovation, Science, and Economic Development of Canada, and in 2019 allocated $60 million over two years to support K-12 STEM learning initiatives that provide educational opportunities for students and educators to develop their digital literacy skills. This large federal investment is being used towards developing digital skills (e.g., coding, data analytics, and digital content development) and understanding how new technologies can be used to solve real-world problems (Government of Canada, 2019). Furthermore, in 2017, Canada’s federal funding agency, the Natural Sciences and Engineering Research Council of Canada’s (NSERC) budget included an additional investment of $10.8 million across five years towards building STEM knowledge, experience, and awareness. NSERC’s PromoScience program is a national and ongoing source of public funding whereby Canadian organizations can apply for financial support to help them provide the hands-on learning experiences that both students and teachers need to develop an understanding of STEM— particularly in underrepresented groups. The significance of federal funding programs
such as CanCode and PromoScience lies in the notion that funding is available and accessible to SOUs, who are planning to expand their current K-12 STEM education initiatives.

This research explores K-12 STEM learning ecosystems through the specific lens of university-based outreach units. Within a university, there may be multiple departments and faculties that provide STEM outreach initiatives. Typically, such outreach units are affiliated with a STEM faculty (such as the Faculty of Science or a Faculty of Engineering and Applied Science), but they may also be affiliated with a Faculty of Education. More often, because of multiple factors (such as separate funders, individual passion projects, motivation to showcase STEM knowledge, or community engagement), there can be multiple SOUs within a given university. However, there is a difference between embedded units within a STEM department that deliver the odd initiative and a formalized SOU whose primary role focuses on outreach.

Formalized university-based SOUs are units or groups that employ trained and practiced STEM outreach practitioners to organize and provide a breadth of learning experiences across diverse STEM fields to a defined target audience (DeCoito, 2016). These learning experiences are delivered as formal and/or informal educational lessons and activities targeting the K-12 audience (Brawley, Judith, Cole, Gott, & Norton, 2008; DeCoito, 2016). Formal opportunities for outreach are seen as complementary to the traditional K-12 curriculum often delivered to students in-class. These opportunities focus on the development and delivery of fundamental STEM concepts by using a range of activities (Finegold, 2011; Mann & Oldknow, 2012). Formal STEM outreach initiatives within schools may include career advice for students and educators, students participating in a STEM-focused workshop within the school day, a guest speaker presenting a STEM topic, or teachers building STEM capacities during PD opportunities (Bagiya, 2016).

Informal STEM outreach opportunities include all other initiatives not directly connected to specific in-school curriculum expectations but are equally important and purposeful in their efforts to engage K-12 students in STEM. Examples of informal STEM outreach opportunities include after-school clubs, summer camps, and library programs (Bagiya, 2016; Ward, 2015).
However useful these STEM outreach efforts may be in theory, there is limited empirical research exploring the long-term impact of informal STEM outreach initiatives. According to DeCoito (2014, 2015), there is an indication that outreach efforts have a positive effect and can support young people to (a) develop increased interest in STEM, (b) productively engage them in STEM learning activities, (c) value the goals of STEM and STEM learning activities, and (d) develop an appreciation of STEM and consider future STEM pathways.

Although STEM outreach initiatives and their method of delivery can look different depending on a variety of factors (e.g., the SOU providing the initiative, the target audience, the experience of the outreach practitioner(s), the funding sources), the most common goal is to increase students’ STEM knowledge and skills. Outreach providers do so through support and enriching their learning experiences, motivating, and/or inspiring students to continue pursuing STEM subjects, and providing awareness of the career opportunities that can open up with a STEM qualification (Brawley et al., 2008; DeCoito, 2016; Eilam, Bigger, Sadler, Barry, & Bielik, 2016; Turner et al., 2007). In addition to increasing students’ STEM knowledge and skills, other possible objectives, specifically for university-based SOUs, include recruitment to their higher-education institutions, opportunity to generate revenue for services, build local industry-community relations, provide professional development in STEM education, or target prominent social issues including gender, culture, socioeconomic status, and Indigenous perspectives that are often neglected in STEM fields (Bagiya, 2016; DeCoito, 2016; Rammel, Adonis, & Sainsbury, 2006). In summary, university-based SOUs can engage with one and/or many target audiences (predominately K-12 youth) through formal and/or informal outreach, are eligible to access financial resources from the federal government, as well as have possible connections to education stakeholders within their local learning ecosystem. The diversity of roles and positions that university-based SOUs can have within a STEM learning ecosystem is a complex challenge that motivates this research.
Statement of the Challenge – STEM Outreach Units in K-12 STEM Learning

Ecosystems

Given the influx of financial investment from the Canadian federal government towards increasing students’ STEM knowledge and skills through programs such as CanCode and PromoScience, it is assumed the capacity and role of SOUs within learning ecosystems across the country are changing due to the increase in available resources. Using an ecosystem lens suggests that instead of STEM learning opportunities for K-12 students occurring independently of each other, regardless of whether they are being delivered formally in-school or informally, the STEM education ecosystem would benefit from collaborative partnerships. Collaborative partnerships across multiple STEM education stakeholders within a K-12 STEM learning ecosystem could lead to an increase in the number/quality/diversity of learning opportunities for students.

Investigating how K-12 STEM learning ecosystems that involve multiple stakeholders and partners working collaboratively towards the delivery of STEM outreach, has been recognized as important henceforth was explored by the NSERC’s PromoScience grant.

In January 2019, PromoScience put out an open call to organizations that were successful in receiving a PromoScience grant, to see if they were interested in participating in a pilot project that focused on STEM outreach partnerships. To participate and possibly receive additional funding, selected organizations had to have the following characteristics: an interest in collaborating with other organization(s) from the STEM learning ecosystem (e.g. university-based STEM outreach, science centers, museums, scientific societies, industries); and have involvement from within the formal STEM learning ecosystem (e.g. educators, school boards, ministries of education). One of the objectives of the PromoScience pilot project aligns closely with this dissertation research: exploring the complex roles of university-based SOUs within a K-12 STEM learning ecosystem, with an additional focus on partnerships.
At present, there is some evidence supporting the added value of K-12 outreach initiatives to both the individual stakeholders (i.e., students, schools, communities) (DeCoito, 2014; 2016; Government of Canada, 2019) and the larger STEM learning ecosystem (Bisbee O’Connell, Keys, & Storksdieck, 2017). However, there remains a gap in the literature that investigates where SOUs are positioned within the ecosystem itself. This research conceptualizes SOUs to be positioned predominately in the ‘white space’ of a K-12 STEM learning ecosystem. The ‘white space’ of a system refers to the areas between clear boundaries, departments, or organizations in which no one takes explicit ownership or responsibility (Rummler and Brache, 1995). This conceptualization suggests that SOUs could be involved in spanning the boundaries of the various K-12 STEM education stakeholders (as shown in Figure 1).

**Figure 1**

_The position of STEM Outreach Units within a K-12 STEM Learning Ecosystem_

*Note.* STEM outreach units are positioned in the center of the learning ecosystem, surrounded by other stakeholder groups.
The rationale for this white space conceptualization (Rummler & Brache, 1995) draws from an understanding that SOUs can be directly involved with some/all of the above-listed stakeholders whereas some of the other stakeholders can have direct or indirect involvement with only one another. For example, institutions of higher education have a primary objective of educating students at the post-secondary level but may also have an outreach organization embedded within the institution to provide educational opportunities to primary and secondary students. Keep in mind, SOUs can also access funding from the government to provide learning opportunities for K-12 students, parents, and education practitioners. The funding link suggests that SOUs act as a link between government initiatives and individual STEM learning ecosystem stakeholders. However, the stakeholders involved within each ecosystem are unique and so is the fluidity of the SOUs position in the ecosystem, thereby making their role complex. In addition to the conceptual positioning of SOUs within the white space of the ecosystem, this research also draws from the field of knowledge mobilization (KMb) to conceptualize a possible role of SOUs within a K-12 STEM learning ecosystem as knowledge brokers who utilize a combination of brokering functions.

**STEM Outreach Units as Knowledge Brokers**

Alongside the focus on K-12 STEM learning ecosystems has been a call for greater knowledge mobilization across Canada. Knowledge Mobilization (KMb), although defined differently by various scholars (e.g. Cooper, 2014; Levin, 2004; Ward, House, & Hamer, 2009; Ward, Smith, House, & Hamer, 2012), is defined by the Social Sciences and Humanities Research Council of Canada (SSHRC) as the reciprocal and complementary flow and uptake of research knowledge between researchers, knowledge brokers, and knowledge users in such a way that may benefit users and create positive impacts (2019). In this dissertation, the definition of knowledge used includes both empirical research knowledge as well as tacit experiential knowledge. One aspect emerging from the KMb field is the need for knowledge brokering organizations to bridge and connect multi-stakeholder partnerships for system improvement.
A knowledge broker is understood to be a person or organization that facilitates the creation, sharing, and use of knowledge between at least two or more groups of stakeholders, who have an active role to catalyze knowledge mobilization between them (Cooper, 2014; Honig, 2004; Meyer, 2010; Ward, 2017). Knowledge brokers function primarily in addressing the gaps between knowledge producers and various audiences to mediate change that will provide value beyond what the individual parties can do alone (Meyer, 2010). Brokers are unique in that they often fill a void by occupying the white space and can address issues of interconnections through their presence and work between the organizations (Cooper, 2014; Honig, 2004; Ward, 2017).

For this research exploring the role of university-based SOUs within K-12 learning ecosystems, the definition of a knowledge broker is a unit that facilitates the creation and sharing of STEM knowledge, both empirical and tacit, to address gaps in STEM education between two or more stakeholders. In doing so, the knowledge broker provides value beyond what the individual parties can do alone.

Another important factor to note is that STEM education KMb occurs through a social and iterative cycle involving the intentional efforts made among two or more different groups or contexts to facilitate knowledge use in research, policy, and practice at multiple levels to improve the larger K-12 STEM education system. Exploring the concept of SOUs being positioned and acting as brokers within the white space of the STEM learning ecosystem arises from KMb literature that highlights that brokers have an in-between vantage point that is critical to their function (Cooper, 2014; Honig, 2004; Meyer, 2010). The role of brokers is to establish durable and reliable connections across diverse boundaries or stakeholders, keeping in mind the impact they have on students’ learning opportunities. Provided that knowledge brokers are emerging as value-added to education, the same foundation is potentially transferred to the context of K-12 STEM learning ecosystems.

By drawing upon and combing the white space and knowledge brokering conceptualizations, this research explores how SOUs are involved within a K-12 STEM learning
ecosystem to enhance STEM education. This research is unique because the concepts of SOUs involvement within its community and knowledge brokering, have been understudied in K-12 STEM education.

**Purpose and Research Questions**

The purpose of this research is to identify the organizational features of university-based SOUs within Canada and to explore if/how conceptualizations of learning ecosystems and knowledge brokering inform their work. Three research questions guiding this study are:

1. What are the organizational features of university-based K-12 SOUs in Canada?

2. To what extent do university-based SOUs have multi-partner collaborative approaches to STEM outreach within a K-12 STEM learning ecosystem?
   - What are the benefits and drawbacks of a STEM learning ecosystem?

3. To what extent do university-based SOUs have the capacity to act as knowledge brokers within their K-12 STEM learning ecosystem?
   - What knowledge brokering functions do university-based SOUs use?
   - In what ways is the concept of knowledge brokering relevant for SOUs?

**Rationale**

Over the past several years, increasing amounts of focus and funding from the federal government have been put towards STEM outreach (Government of Canada, 2019). There is some evidence to suggest that K-12 STEM outreach, often delivered independently by STEM education stakeholders, have the potential to support students in developing STEM knowledge and skills and inspiring students to pursue careers in STEM (Brawley et al., 2008; DeCoito, 2016; Eilam et al., 2016; Turner et al., 2007). However, increased focus and funding are presumably contributing towards larger and increasingly more complex K-12 STEM learning ecosystems.

NSERC’s PromoScience program has suggested that collaborative partnerships between STEM education stakeholders may improve STEM learning opportunities and outcomes for
students by systematizing the complex and evolving K-12 STEM learning ecosystems. By having a K-12 STEM learning ecosystem that focuses on shared, sustainable, and diverse learning opportunities for students, collaboration can help bridge, integrate, and strengthen independent learning opportunities offered by various stakeholders (Traphagen & Traill, 2014). This increase in learning opportunities will consequently strengthen the STEM knowledge and skills of students to close the projected STEM workforce gap. Furthermore, the idea behind a systematic collaborative approach from all stakeholders within an ecosystem, including SOUs, who offer their unique lens on STEM education, is to strengthen the impact of STEM education for youth.

Looking at STEM outreach through an ecosystem lens, as well as the KMb lens, has led to the assumption that these two fields could apply and inform STEM outreach units. However, there is limited research available that seeks to understand if/how STEM learning ecosystems work in practice, and an unexplored gap investigating SOUs as knowledge brokers. This unexplored gap in the literature focused on the complex role of SOUs and how they are involved in K-12 STEM learning ecosystems provides the foundational rationale for this research study.

Secondly, the rationale for drawing upon the field of knowledge mobilization to conceptualize SOUs as knowledge brokers within the ecosystem is used to provide a new lens in which to view STEM outreach activities, while also utilizing emerging evidence from one field of education to see if the knowledge and concepts can inform another.

**Significance of Research**

In gaining a better understanding of the K-12 STEM learning ecosystems from the perspective of university-based SOUs in Canada, findings will contribute significantly towards informing the field of STEM outreach and K-12 STEM education. Firstly, this research will contribute to the field of STEM outreach by describing the organizational features of university-based SOUs within Canada that may inform other STEM outreach practitioners. These include the types of STEM outreach initiatives being offered to engage students, who their stakeholders and partners are, and their collaborative approaches to enhancing their local K-12 STEM
ecosystem. Secondly, in learning more about if/how outreach organizations collaborate with K-12 STEM education stakeholders, it is possible to explore the extent to which SOUs work as knowledge brokers. These findings will contribute to the field of STEM education in exploring the understudied K-12 STEM ecosystems, and if/how SOUs act as knowledge brokers.

By exploring STEM outreach, their partnerships, and brokering functions at multiple universities across the country, it is possible to learn more about the complexities of the changing landscapes in a variety of Canadian contexts, while identifying the benefits and challenges of STEM learning ecosystems. For example, some potential benefits include identifying:

- Gaps and/or duplication of STEM outreach initiatives within a given community.
- STEM knowledge brokering functions, which may be successfully utilized to enhance the reciprocal exchange of knowledge between stakeholders within a learning ecosystem.
- Efficient use of resources (such as funding from the federal government) to support informal STEM outreach initiatives and the broader goals of STEM education to increase the STEM knowledge and skills of students.

One of the possible challenges of an ecosystem approach includes obtaining credible and highly engaged partnership buy-in from organizations and stakeholders who have their respective objectives, mission, resources, accountability frameworks, beliefs around the value-add of partnerships. However, one of the possible contributions of this research is linked back to KMb in that the results could be used to inform SOUs, stakeholders, and other groups within the ecosystems about the advantages and disadvantages of an ecosystem mindset. This multi-partner collaboration towards STEM education and outreach can lead to a larger impact than any one organization can have by itself (Young et al., 2017).

**Situating the Researcher**

Personal training and experiences as both an engineer, a certified teacher, and a STEM outreach manager inform this research. This dissertation provides an opportunity to continue
drawing from my experience(s) as a professional engineer to systematically generate ideas and
explore possible solutions to broad, complex, and open-ended challenges in society, that are
directly linked to K-12 STEM education. In addition to the primary investigator role of this
research, I also have prior experience as a high-school classroom teacher and experience as a
STEM outreach practitioner and manager. To increase transparency, it is important to
acknowledge these previous experiences and how they relate to this study.

After several years of engineering experience, I returned to Queen’s University to
complete my Bachelor of Education in my hometown of Kingston, Ontario. Throughout the
program duration, I had the opportunity to connect with classroom teachers and school
administrators across two local school boards, establishing a network of colleagues within the
community. Following the completion of my degree, I worked as an occasional teacher within
one of the boards, continuing to establish professional teaching relationships, a network of
educators in the community, and (from my perspective) a positive image of myself and my
passion for STEM education. This passion led me to a full-time within the Faculty of Engineering
and Applied Science at Queen’s University as a STEM outreach coordinator, then into an
outreach manager position.

Within my current role as a manager of an outreach organization, part of my role is to be
aware of the knowledge (background, current, and emerging) and best practices regarding STEM
outreach efforts, which inform my role as a researcher. My managerial role has allowed me to
meet and establish communication channels and working relationships with managers at other
Canadian university-based SOUs. Finally, as the STEM outreach manager, I can continue
working with and supporting the network of educators that I have established a positive
relationship with the Kingston community. Through the conversations and working relationships
with SOUs across the country as well as individuals within the Kingston community, combined
with my own professional experiences as an engineer and researcher, I am motivated to explore
the role of university-based SOUs as knowledge brokers within a K-12 STEM learning ecosystem and if/how they are contributing towards STEM education.

By having this nested role as a STEM outreach practitioner and a researcher, I was well-positioned to conduct this research. Throughout the study, I demonstrated transparency regarding the purpose of the data collected and ensured organizational confidentiality and anonymity. Additionally, it was made clear to all those contacted that participation is voluntary and will not impact any current/future working relationships with the researcher.

**Dissertation Overview**

This dissertation used a sequential multi-method multi-phase format to examine each of the three research questions. The remainder of this dissertation presents the following chapters. Chapter 2 is a literature review of the two relevant fields, K-12 STEM outreach, and knowledge mobilization with a focus on knowledge brokering. Both literature searches have an intentional focus on models that include multi-partner relationships and two-way relationships. Additionally, Chapter 2 proposes an introductory framework conceptualizing the position and role of SOUs within a STEM learning ecosystem as well as their organizational features, and their knowledge brokering functions. Chapter 3 outlines the research design for this dissertation, detailing the sample strategies, participant recruitment, data collection, and analysis. Broadly, the methods span three phases which are outlined below:

- Phase 1 consisted of an environmental scan and website analysis of university-based K-12 SOUs across the Canadian landscape.
- Phase 2 consisted of an online survey that explored specific SOUs' organizational features including mission, capacity, resources, target audiences, and partnerships within their local STEM learning ecosystem.
- Finally, Phase 3 further explored the role of SOUs as knowledge brokers through semi-structured interviews, unpacking the brokering functions SOUs use within their local
community. In addition, Phase 3 explored SOUs views on the broader concept of K-12 STEM learning ecosystems and knowledge brokering.

Chapters 4 and 5 present the synthesized research findings from Phase 1 and Phase 2 respectively. Chapter 6 presents the case study descriptions for twelve individual SOUs that participated in the Phase 3 interview, and Chapter 7 presents the findings from Phase 3 and the case study analysis. Finally, Chapter 8 discusses four key themes that emerged from the results as they relate to the research questions, then offers a conclusion and implications of the findings that link back to the conceptualization of SOUs' position and role as potential knowledge brokers within a K-12 STEM learning ecosystem. These conclusions and implications will provide a distinct contribution to the fields of K-12 STEM education and KMb. Limitations of the study and areas for future research are also discussed before bringing the dissertation to a conclusion.
Chapter 2
Literature Review

This chapter begins with a review of the empirical research on K-12 STEM outreach and STEM learning ecosystems. This chapter will then draw from the field of knowledge mobilization to conceptualize the role of SOU’s as knowledge brokers within a learning ecosystem. Following this, the chapter highlights a brief literature review on knowledge brokering models in education that inform this research. Finally, this chapter illustrates a conceptual framework built on a synthesis of the combined literature which explores the role of SOUs as knowledge brokers and examines how collaborative K-12 STEM learning ecosystems function in practice.

Systematic Literature Review: K-12 STEM Outreach

As the underlying concepts of STEM learning ecosystems in education are new and therefore not well-operationalized or explored, a broad but systematic approach to deliberately identify a wide range of articles was required when considering the scope of this study. This chapter contains a systematic scoping review of the empirical research related to K-12 STEM outreach and knowledge brokers. A scoping review was determined to be appropriate as it uses a systematic, transparent, and replicable search strategy aiming to “rapidly map the key concepts underpinning a research area and the main sources and types of evidence available, especially where an area is complex or has not been reviewed comprehensively before” (Mays, Roberts, & Popay, 2001, p. 194). This process is used to examine the extent, range, and nature of research activity (Arksey & O'Malley, 2005) concerning STEM learning ecosystems in K-12 education.

The online search strategy was generated using a combination of the keyword sets (Table 1) and was applied in the general keyword searches starting in Google Scholar and then across a broad range of relevant databases (Academic Search Complete, Canadian Theses Portal, ERIC, JSTOR, Summon).
Table 1

*Keywords Grouped Based on Fields*

<table>
<thead>
<tr>
<th>Keyword 1 (with synonyms)</th>
<th>Keyword 2 (with synonyms)</th>
<th>Keyword 3 (with synonyms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEM Outreach</td>
<td>Framework</td>
<td>Ecosystem</td>
</tr>
<tr>
<td>STEM Education</td>
<td>Model</td>
<td>Network</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partnerships</td>
</tr>
</tbody>
</table>

Since STEM education is a rapidly growing field of practice, search criteria were limited to articles published in 2008 (10 years before the start date of this dissertation) and onwards. Granted that the ecosystem concept and terminology itself are important for this dissertation, it was important to include synonymous terms including network and partnerships.

The first step was to pilot the screening criteria using the keywords to ensure it was capturing the intended scope of the research. To identify relevant empirical studies, the search criteria were modified to only include peer-reviewed and non-peer-reviewed articles (such as conference proceedings, dissertations/thesis, and reviews/reports). The inclusion/exclusion criteria were informed by reviews related to educational STEM outreach (DeCoito, 2016). Based on the results from this screening process, it was determined that by adding the keyword ‘ecosystem’ (and its synonyms) to the STEM outreach group, there was a significant decrease in the number of recovered articles. Therefore, keyword 3 was purposefully removed from the STEM outreach grouping at this stage of the review process.

After the pilot screening, a two-stage screening process was used to assess the relevance of the articles based on titles, abstracts, and the existence of a framework. Stage one of the screening process eliminated irrelevant titles such as ‘STEM cells’ in group 1. Selected articles that emerged from stage 1 were transferred into Microsoft Excel for the next phase of processing and documentation. Stage 2 of the screening process continued to narrow the available literature, excluding those articles that did not provide, nor discuss, collaboration or partnerships with other groups that could inform SOUs within a K-12 STEM learning ecosystem. For example, STEM
outreach articles were excluded if they generally described one specific STEM outreach initiative (such as a workshop or program). In addition to the keyword search, reference lists were screened for additional articles that could contribute to this work.

The database search yielded 1069 original articles for STEM outreach and following the complete screening process (Figure 2), ten articles were identified that could be used to inform SOUs as potential knowledge brokers within a K-12 STEM learning ecosystem.

**Figure 2**

*STEM Outreach Scoping Review Process*

![STEM Outreach Scoping Review Process Diagram](image)

*Note.* This figure illustrates the STEM outreach article identification and screening process used to identify relevant articles for this research.

Of the STEM outreach articles that emerged for the full review, five had been applied or tested within their intended context, suggesting that empirical-based research observing multi-partner STEM outreach initiatives is in its infancy. Table 2 identifies the ten articles that emerged from the literature search. It also identifies the aim of their outreach model, a description of the main components and collaborators, a summary of the results of the study, and a conclusion.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Aims of the framework</th>
<th>Description of the main components</th>
<th>Model applied or tested?</th>
<th>Methods</th>
<th>The frameworks’ conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Struminger, Zarestky, Short, &amp; Lawing (2018)</td>
<td>To guide the development of informal STEM initiatives that share best practices for delivering outreach.</td>
<td>Framework includes 1) Place-based informal learning activities; 2) STEM content; 3) Approaches for learner engagement (community, contextualized, discovery-based, experiential, inquiry-based, service); and 4) Approaches for science learning (interest in STEM, content, and practice).</td>
<td>The conceptual framework was developed from the survey.</td>
<td>Currently not tested.</td>
<td>Serves as a guide for stations in the development of their informal STEM education initiatives.</td>
</tr>
<tr>
<td>Karmokar &amp; Shekar (2018)</td>
<td>To use the triple helix model to encourage STEM.</td>
<td>Framework includes 1) Government; 2) University; and 3) Industry as an overlapping collaborative Venn diagram.</td>
<td>Six workshops to connect STEM to entrepreneurship with students, parents, teachers, and business’</td>
<td>Passive observations.</td>
<td>The approach of involving community role models, educators, and government representatives in a STEM activity has proven to be successful.</td>
</tr>
<tr>
<td>Young, et al. (2017)</td>
<td>To help the project team</td>
<td>Framework includes 1) Pre-program student characteristics &amp; Measure changes in student</td>
<td>Pre/post-test using pre-</td>
<td>Researchers shared best practices and lessons learned.</td>
<td>Researcher shared best practices and lessons learned.</td>
</tr>
</tbody>
</table>
| Framework/Study             | To describe how/To determine if outreach is a | Framework includes 1) Student-centered; 2) Connections among direct interactions (home, school, out-of-school, neighborhood); 3) Contexts influencing students indirectly (school board, institutions, workplace, geographical context); and 4) Broad influences (government, customs, history, values) | The framework includes 1) Internal relationships (claims for legitimacy, knowledge, perception); and 4) Outcomes (career identity, knowledge, personal skill). | Survey and interview data from STEM Hub staff and partners to assess features of the local STEM Hub community. | Eleven STEM Hub sites. | Connections between STEM Hubs are needed to create a community that can improve STEM education. Many STEM Hubs expressed interest in developing connections among networks, but need support. |}

| Bisbee, O'Connell, Keys, & Storksdieck (2017) | STEM Hubs has begun to create STEM teaching and learning community. | explore student experiences (socio-demographic traits, academic preparation, personal and social experiences); 2) Organizational context (local and program structure, policy, practice, and teaching culture); 3) Individual student experience (assessment, knowledge, perception); and 4) Outcomes (career identity, knowledge, personal skill). | The partnership provided staff with a research-based curriculum, advancing faculty members’ research. A multi-partner collaboration can lead to a larger impact than any one institution. | | | |}

| Eilam et al. (2016) | | | | | STEM outreach that is top-down within a university will have | |}

<p>| Eilam et al. (2016) | To describe how outreach is a | The framework includes 1) Internal relationships (claims for legitimacy, knowledge, perception); as well as contextual elements. | The partnership provided staff with a research-based curriculum, advancing faculty members’ research. A multi-partner collaboration can lead to a larger impact than any one institution. | | | |
| DeCoito (2016) | To review existing literature on STEM outreach and its impact on teaching and learning in K-12 settings. | The framework includes 1) Peer-reviewed articles; 2) Knowledge sources; 3) Expert knowledge (university-based STEM outreach, non-profit organizations, public-private organizations, governments) | The conceptual framework was developed from a scoping review of the literature. Currently not tested. | N/A | STEM education in Canada is characterized by localized research and outreach initiatives. Lack of large-scale research to allow for a complete view of the impact of STEM initiatives on K–12 teaching and learning. |</p>
<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Description</th>
<th>Framework</th>
<th>Data Collection</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dahl &amp; Droser (2016)</td>
<td>To demonstrate how a university department could establish an outreach program on a small budget.</td>
<td>The framework includes 1) Oversight by the Department; 2) Graduate student program manager who is the bridge; 3) K-12 students and community events; and 4) Budget management, student volunteers, and materials management.</td>
<td>The conceptual framework developed from experience within a program of 5 years.</td>
<td>N/A</td>
<td>Allows departments to establish a program without a large start-up budget. The simplicity and flexibility of the program can be adapted to the needs of local communities.</td>
</tr>
<tr>
<td>Bagiya (2016)</td>
<td>To develop a STEM outreach model through the views of the receiver, facilitator, and provider.</td>
<td>This framework includes 1) STEM outreach practitioners (providers); 2) School staff members promoting STEM (facilitator); 3) Mediator promoting STEM (supporter), and 4) Students (receivers).</td>
<td>The conceptual framework is developed from evidence obtained from multiple perspectives. Participants include outreach providers, classroom teachers, facilitators, and students. Qualitative data collected through interviews with outreach facilitators (n =16), teachers (n =10) in STEM subjects. Quantitative data through surveys.</td>
<td>Students are offered STEM outreach throughout compulsory education. A generic evaluation tool is needed to capture more rigorous and meaningful data and to develop a STEM outreach Quality Framework. STEM outreach practitioners require training to ensure maximum interaction and impact on young people.</td>
<td></td>
</tr>
<tr>
<td>Author(s)</td>
<td>Method</td>
<td>Description</td>
<td>Source of Framework</td>
<td>Tested</td>
<td>Application</td>
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<tr>
<td>Ward (2015)</td>
<td>To summarize the complex system of the interacting elements comprising STEM educational outreach.</td>
<td>This framework includes four domains affecting STEM education: 1) K–12 student domain; 2) K-12 teacher domain; 3) Academic, Technical, and non-STEM Higher Education domain; 4) the general community.</td>
<td>The conceptual framework developed from sessions involving faculty, outreach providers, science educations faculty, and administrators. Currently not tested.</td>
<td>N/A</td>
<td>Administrators, researchers, outreach professionals, and school districts have met the model enthusiastically. Used in discussions with researchers while developing impact components of research proposals, helping to better understand ways their STEM-EO projects can influence the STEM pipeline.</td>
</tr>
<tr>
<td>Traphagen &amp; Traill (2014)</td>
<td>To describe the attributes of STEM learning ecosystems</td>
<td>This framework includes 1) School; 2) Libraries; 3) Science Centers &amp; Museums; 4) After-school programs; 5) Businesses; 6) Higher Education; 7) Community; 8) Home; and 9) Students</td>
<td>The conceptual framework developed from experience.</td>
<td>N/A</td>
<td>Six strategies for ecosystems: 1) Build the capacity of educators; 2) Equip educators with tools and structures to enable sustained planning and collaboration; 3) Link formal and informal STEM learning; 4) Create learning progressions; 5) Focus curricula and instruction on inquiry, and 6) Implement programs to engage families and communities.</td>
</tr>
</tbody>
</table>
Using the above-identified articles in Table 2, the following sections will synthesize and discuss the relevant literature review findings using the following three categories: Types of STEM outreach units and their initiatives; STEM outreach models that involved collaboration; and the reported impact of ecosystem partnerships, along with future recommendations.

**STEM Outreach Units and Initiatives**

Provided that STEM education already encompasses four very broad disciplines (Science, Technology, Engineering, and Mathematics), outreach efforts may manifest themselves differently depending on the organization in charge and the target audience they engage. The top four types of organizations currently delivering K-12 STEM educational outreach initiatives in Canada include post-secondary institutions; non-profit/charitable or volunteer organizations; private-sector STEM-based organizations; and government agencies (DeCoito, 2014). A visual representation generated by the researcher summarizing the literature of the types of SOUs and their initiatives is shown in Figure 3.
Figure 3

Summary of STEM Outreach Types, Goals, and Organizational Features

Note. This figure illustrates the types of STEM outreach organizations at the bottom, their common mission(s), and the organizational features that can push back on achieving the mission.

One of the primary goals of SOUs is to increase: knowledge, skills, and awareness of opportunities in STEM fields by supporting and enriching K-12 students’ learning experiences (Brawley et al., 2008; Eilam et al., 2016). These learning experiences not only introduce STEM activities and topics, such as robotics and coding, but simultaneously target prominent social issues including gender, culture, socioeconomic status, and Indigenous perspectives that are often neglected when teaching STEM topics (DeCoito, 2016). Some SOUs also exist for reasons outside of STEM education, including recruitment to higher-education institutions, opportunity to generate revenue for services, development of industry-community relations, or to build capacity...
for educators looking for professional development in STEM concepts (Bagiya, 2016; Rammel, Adonis, & Sainsbury, 2006).

Several of the articles identified within this scoping review discuss how organizational features such as the size, scope, purpose, governance, and overall structure of an SOU, hindered or helped their organizations achieve their desired aims (Bagiya, 2016; Bisbee O'Connell, Keys, & Storksdieck, 2017; Ward, 2015). Although there can be a variety of features that influence an SOU, the most common was the need to have dedicated resources for funding (Bagiya, 2016; Bisbee O'Connell, Keys, & Storksdieck, 2017). The second most common feature that influenced STEM outreach was if the outreach practitioners have formal training in education, abilities to make connections to the strands of STEM curriculum, and if their instructional approaches helped meet the needs of the students (Bagiya, 2016; Bisbee O'Connell, Keys, & Storksdieck, 2017).

For example, outreach practitioners that lacked training in educational pedagogy or that often mistake STEM outreach as sharing their personal experience and enthusiasm in STEM with a niche group of teachers or students may hinder themselves in achieving the goals mentioned above. On the other hand, trained STEM outreach practitioners do this as well but can also develop content for the initiatives that are age-appropriate and connected to the learning that is currently happening within the classroom (Bisbee O'Connell, Keys, & Storksdieck, 2017; Dahl & Droser, 2016; Eilam et al., 2016). With formalized training as educators, outreach practitioners become more competent and confident in their abilities to deliver initiatives with a variety of target audience ages, interests, and abilities (Karmokar & Shekar, 2018; Struminger, Zarestky, Short, & Lawing, 2018; Ward, 2015; Young, et al., 2017).

According to a STEM education learning report (Rammell, Adonis, & Sainsbury, 2006), there are three broad categories of outreach activities: enrichment activities for youth (such as career advice, clubs or booster classes, links with employers or work experience, gender, or ethnic minority-focused bursaries); teacher professional development; and teacher recruitment
and retention (Rammell, Adonis, & Sainsbury, 2006). This report also suggests that six key elements need to be considered when planning an effective outreach initiative (p. 47):

1. Stimulating hands-on practical learning that is relevant to work, life, and local conditions.
2. Interactive scientific inquiry and problem-solving.
3. An enriched curriculum, with informal experiential learning and extracurricular activities.
4. Confidence building in STEM, especially for disadvantaged groups.
5. Information and advice on STEM study, qualifications, and careers.
6. Continuing professional development for STEM teachers.

Depending on the mission statement and objectives of the SOU, their initiatives may be accomplished through either formal and/or informal education that students may not otherwise be exposed to in traditional school settings (Brawley et al., 2008; DeCoito, 2016) shown in Figure 4.

**Figure 4**

*Summary of Formal vs. Informal STEM Outreach*

*Note.* This figure provides examples of STEM outreach initiatives that can be classified as formal or informal.
Formal opportunities for STEM outreach can be seen as complementary to traditional classroom learning and thus seek to further the learning of key concepts within the STEM curriculum through a range of activities (Finegold 2011; Mann and Oldknow 2012). Formal outreach opportunities focus on the development and delivery of key concepts from the K-12 STEM curriculum through a range of activities (Finegold, 2011; Mann & Oldknow, 2012) and often surround topics of STEM career opportunities and are presented as one-time in-school STEM workshops (Bagiya, 2016). In contrast, informal STEM outreach opportunities include initiatives that are not directly tied to formal education but are equally important and purposeful in their efforts in engaging youth with STEM disciplines. Informal STEM outreach opportunities include after-school clubs, camps, and library programs (Bagiya, 2016).

Within the articles identified in this scoping review, one of the major differences that emerged was the context in which the outreach organizations existed. Some models focused on specific delivery methods such as formal in-school workshops (Bagiya, 2016), informal after-school programs (Struminger, Zarestky, Short, & Lawing, 2018), or multi-week summer programs and camps (Eilam et al., 2016). Other models focused on a more systematic approach outlining the overarching stakeholders within a student’s STEM education pathway (Ward, 2015) or depicting a STEM learning ecosystem for a given community (Bisbee O’Connell, Keys, & Storksdieck, 2017). Although the specific content of a STEM outreach initiative may vary depending on several different factors, the STEM outreach practitioners involved in providing these opportunities seek to interact, inspire, and motivate young people to study STEM subjects beyond their compulsory schooling. They also guide students through the possible careers that can arise when one is well versed in STEM competencies (Turner, et al., 2007). Regardless of the STEM outreach effort being classified as formal or informal, outreach initiatives traditionally involve K-12 students working in collaboration with at least one other stakeholder group within the broad STEM learning ecosystem (such as teachers, not-for-profits).
**K-12 STEM Education Outreach Multi-Stakeholder Partnerships**

Across all ten STEM outreach articles, the application or testing process was not a primary concern for the authors, but rather, their focus was to report key learnings from outreach initiatives. Within the ten STEM outreach articles identified from this scoping review that presented an empirically tested model, only four of them purposefully explored multi-partner STEM outreach programs (Bisbee O’Connell et al., 2017; Karmokar & Sekar, 2018; Traphagen & Traill, 2014; Ward, 2015). A major similarity that emerged from the ten articles in the STEM outreach review was the importance of a relationship between a university STEM outreach and at least one other partner or stakeholder within their local K-12 STEM learning ecosystem. Table 3 illustrates which K-12 STEM outreach stakeholder groups were involved in a working relationship, not just as a target audience, in each ecosystem.

**Table 3**

*Literature Review STEM Outreach Articles Organized by Number of Partnership in Model*

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>University</th>
<th>School</th>
<th>Business</th>
<th>Government</th>
<th>Community</th>
<th>Parents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward (2015)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Bisbee O’Connell, Keys, &amp; Storksdieck (2017)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Traphagen &amp; Traill (2014)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>DeCoito (2016)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karmokar &amp; Shekar (2018)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dahl &amp; Droser (2016)</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bagiya (2016)</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3 suggests that although few models exist which depict a systematic approach to STEM outreach involving collaboration among multiple partners/stakeholders. Additionally, there is a perceivable gap in the literature investigating the application of the models into practice and their evaluation or impact. To gain further insight into the models that depict multi-partner STEM learning ecosystems, three articles (in italicized font within Table 3) were selected for further exploration as they are particularly informative for this research. These three articles were selected because there is a reference to all 6 of the stakeholders identified in a K-12 STEM learning ecosystem (except for explicitly mentioning educators).

**Model 1: STEM Education Outreach Model**

Viewing STEM education through a systematic lens involving various stakeholders has been recognized by Ward (2015) and used at the Center for Science and the Schools (CASTS) at Pennsylvania State University. The CASTS’ mission is to facilitate mutually beneficial and sustainable relationships among researchers and K-12 school districts to enhance STEM education locally, state-wide, and nationally. The goal of the model produced by Ward (2015) was to promote a strategic STEM education outreach program that involves various stakeholders who are cohesive and balanced to optimize resources so that other universities might benefit from implementing a more systematic approach to design and evaluation. The model developed by Ward (2015) summarizes the complex system of interacting elements as shown below in Figure 5. This model is unique compared to the other models identified within this scoping review, as it
is the only one illustrating the STEM education system and process as its primary focus. The other models to be discussed later have more of a target audience focus within STEM education.

**Figure 5**

*Ward’s (2015) Systematic STEM Outreach Model. This figure has been reproduced with permission from Research Management Review, Volume 20, Number 2, 2015.*

*Note.* The model depicts a STEM education pathway from a K-12 student domain, into a higher education domain, eventually leading towards STEM employers. It also depicts the reciprocated influence among all domains, including a teacher domain and a general community domain.
At the core of the framework in Figure 5 are the various STEM education pathways that a student could pursue from kindergarten through to the STEM workforce. Although this model is within the context of the U.S. education system, the pathway remains relevant to the Canadian education system. The systematic model suggests that there are four domains of STEM education outreach (student, teacher, higher education, and general community), each of which has a different focus and can directly or indirectly influence other domains that revolve around the student pathway. One thing to note about this model is that the gray arrows indicate how each domain can influence one another. However, it is not overly explicit as to where purposeful SOUs are positioned. Figure 5 may imply that SOUs are involved in the gray arrows within this entire model, which could be interpreted as functioning within the ‘white space’ between the other domains. The bottom of the framework specifies the goals and dimensions of the STEM outreach system that were derived because of collaborative efforts of stakeholders (Ward, 2015), which align with literature around STEM outreach (Bagiya, 2016; Bisbee O’Connell, Keys, & Storksdieck, 2017). The goals are to be used to provide focus when designing STEM outreach initiatives and to identify evaluation criteria, while the dimensions describe the various context where outreach initiatives take place. Figure 5 is still in its conceptual stages as the researchers are in the process of implementing the first iteration of collecting feedback from outreach professionals as to how it relates to their context, and how they can impact the various domains.

In terms of practice, the model in Figure 5 provides a framework for quantitatively monitoring investments for various projects within the university, as well as guiding practitioners’ awareness of learning goals when designing initiatives. In terms of research potential, this model can inform STEM researchers’ proposals while forming the basis for a collaborative research agenda investigating the impacts and challenges of STEM outreach for various stakeholders. The main component from Ward’s (2015) model that is used in this doctoral research is the four domain categories and the concept that all domains influence one another.
Model 2: Systematic STEM Education

The STEM education systematic model described by Bisbee O'Connell, Keys, & Storksdieck (2017) is another example that depicts the position of stakeholder groups and the influence they can have on a student’s STEM education. The student-centered model depicted by Bisbee O'Connell, Keys, & Storksdieck (2017) illustrates the range of interactions that stakeholder groups can have with a student. Although this model is focused more explicitly on students and less on the role and position of SOUs, it still highlights the STEM learning ecosystem. The stakeholders who have direct interactions include home, school/childcare, out-of-school (previously described as informal community learning opportunities), and the neighborhood in which the student lives. The model, expanding outwards, identifies the contexts and stakeholder groups that have indirect influence (such as geographical context, school board, and institutions), and well as cultural influences (such as government, customs, and values).

Similar to Ward’s (2015) model, the Bisbee O’Connell et al. (2017) model highlights the interconnections among the various contexts, however, does not illustrate where SOUs are positioned. Overall, the purpose of the Figure 6 model was to provide insight on collaboration between stakeholder groups within the system, and to collect program evaluation data based on progress, areas of improvement, accomplishments, and partnership contributions to the ecosystem. Conclusions from the study suggest that connections between the STEM education stakeholder groups are needed to create a community of practice to improve STEM education. Many of the established STEM learning ecosystems expressed interest in developing connections but need support (such as a lead organization, funding, and allocated staff personnel to strengthen partnerships) to do so. Although the conclusions from this study provide insight towards multi-partner STEM learning ecosystems, it lacked details in support of the elements and interconnections that may help the overall impact of the ecosystem. The main influence of this
model is the awareness that some of the learning ecosystem stakeholders can have a direct influence on SOUs and some will have an indirect influence.

**Model 3: STEM Learning Ecosystems Community of Practice**

This idea of key stakeholders within the STEM education system collaborating to increase the influence on students has also been described as STEM learning ecosystems. STEM learning ecosystems:

Encompasses schools, community settings such as after-school and summer programs, science centers and museums, and informal experiences at home and in a variety of environments that together constitute a rich array of learning opportunities for young people. A learning ecosystem harnesses the unique contribution of all these different settings in symbiosis to deliver STEM learning for all students. Designed pathways enable young people to become engaged, knowledgeable, and skilled in the STEM disciplines as they progress through childhood into adolescence and early adulthood (Traphagen & Traill, 2014, p. 2).

The ecosystem approach to STEM education focusing on strategic partnerships was identified in the United States' five-year strategic plan for STEM education as a key to success (National Science and Technology Council, 2018). The STEM ecosystem community of practice has grown over the past several years to become a thriving network of hundreds of organizations and thousands of individuals, from within a local micro-ecosystem, to a larger STEM macro-system across the United States, collaborating to increase equity, quality, and STEM learning outcomes for all. One of the goals of this approach is to increase STEM innovation and evidence-based practices in teaching and learning. STEM learning ecosystems consist of multi-sector partnerships as shown in Figure 6, which are similar to the various domains identified within Ward’s (2015) model in Figure 5 and Bisbee O’Connell’s (2017) model.
The STEM ecosystem approach is supported by recent research on effective programming that recommends integrated approaches to teaching and learning, recognizing that learning does not only occur within the traditional K-12 classroom (Bisbee O’Connell et al., 2017). These STEM learning ecosystems focus on creating connections between local programs to help ensure that collectively, they are creating impacts for students which are greater than any one organization could achieve individually. According to Traphagen & Traill (2014), four strategies to be considered when designing STEM learning ecosystems include:

1) Cultivate cross-sector partnerships: Assess gaps, identify partners, and determine collective goals based on each community’s needs, assets, and interests.

2) Create and connect STEM-rich learning environments: Ensure that STEM learning opportunities are high quality, accessible, youth-centered, and connected so learners can deepen their skills and interests and tackle increasingly complex challenges.
3) Equip educators: Build educators’ capacity through high-quality, relevant professional development, cross-sector experiences, and sharing of practices.

4) Support youth pathways: Enable young people to become engaged, knowledgeable, and skilled in STEM as they progress from childhood into early adulthood.

Traphagen & Traill’s (2014) key strategies for K-12 STEM learning ecosystems have similarities to the six key elements of planning STEM outreach initiatives (Rammell, Adonis, & Sainsbury, 2006). Both highlight the importance of continuous capacity building for STEM educators (both within formal and informal education settings) focus on having enriched curricula that foster hands-on project-based learning with relevance to the real-world, informal learning experiences, and extracurricular activities to build confidence in STEM and support student success in STEM education. However, as the concept of STEM learning ecosystems is still emerging, ecosystems need to overcome challenges to reach optimal efficiency, sustainability, and impact on providing STEM learning opportunities. For example, one strategy towards minimizing these challenges for STEM outreach is to leverage the expertise from other organizations within the STEM learning ecosystem that have expertise in certain areas, such as content development or program evaluation. This expertise within the ecosystem can be used to compile information and share best-practice for impactful STEM outreach delivery. Common challenges facing an active STEM learning ecosystem include adequate and sustained funding, collecting, and assessing program data, navigating cultural differences, engaging families, identifying leaders within the ecosystem, finding a fulfilling role/contribution towards the ecosystem, and transitioning through leadership changes (Traphagen & Traill, 2014).

Components from Traphagen & Traill’s (2014) model in Figure 6 that influence this dissertation are the groups of community partners (such as libraries, science centers, and museums) who are involved within the K-12 ecosystem but have not been previously identified.
Another component of interest is from the ecosystem recommendations suggesting it is important
to learn about how ecosystems operate in practice, the need for assessing the impact of the
interconnections within the ecosystem, and to make research accessible to stakeholders.

**Model 4: K-12 In-School STEM Outreach Delivery**

At times, informal STEM learning opportunities are not always accessible due to
constraints such as the geographical location of the event or imposed criteria (e.g., number of
spaces available, resources, or funding limitations) (Bagiya, 2016). To ensure that STEM
outreach remains largely accessible, one option is to focus on in-school delivery (Bagiya, 2016).
Bagiya’s (2016) study evaluated the effectiveness of STEM outreach within the school system
from various perspectives. Although Bagiya’s (2016) proposed STEM outreach model does not
include as many stakeholder groups as the previous three models, it highlights the use of a
mediator promoting STEM. It also focuses on the relationship between a STEM outreach
practitioner and a school community within four key areas: the outreach practitioner; a school
staff member; a mediator; and students (Bagiya, 2016).

In this model, the key characteristics of the STEM outreach practitioners, include the
ability to motivate, engage, and enrich both students and educators about STEM concepts and
careers. School staff members can be an educator within the school who takes on the
responsibility of selecting activities to be delivered by the practitioner. The third contributor
described is the role of a mediator promoting STEM and is a support role for both the
practitioners and the educators to connect and strengthen the relationship. The difference between
a STEM outreach practitioner and the mediator is that a practitioner is responsible for the in-
person delivery of the learning experience, whereas the mediator has a working relationship with
the two groups and is solely responsible for facilitating the connection between the two, working
towards establishing clear dialogue and expectations. This mediator role may be a reference to the
capacity of certain personnel within specific SOUs who broker relationships between stakeholders. The final contributors are the students themselves who are the receivers of the workshop and will be able to make informed decisions about a STEM pathway.

It is important to note that in Bagiya’s (2016) proposed STEM outreach model, the information boxes are based on the results of the study and its future recommendations. The first key finding, which appears between all relationship arrows, suggests that for outreach to be effective, there needs to be dialogue before and after the event. A second key finding suggests that each relationship is a collaborative partnership. This collaborative approach is visible within the model as the two-way process (doubled-ended arrow), which helps to ensure the expectations/needs of all stakeholders are being met. However, the arrow between students and school staff is not double-ended. It is possible that the reasoning behind this is purposeful and is linked to the facilitator as it could imply that the teacher is less involved in delivering the outreach content.

Focusing on the elements specifically related to the STEM outreach practitioners, Bagiya’s (2016) study reaffirms some of the literature about resource constraints faced by outreach providers (such as time, finances, and administrative support) as well as the need for formal education training (Bisbee O’Connell et al., 2017; Traphagen & Traill, 2014; Ward, 2015). The last key finding was the importance of program evaluation (evaluation toolkit) and a recommendation for a STEM outreach quality framework to explore the impacts on students. Missing from this model is the program evaluation and impact assessment specifically related to the mediators promoting STEM (such as SOUs within an ecosystem). Components that inform this dissertation research are related to the importance of multi-directional dialogue between groups, the position of a mediator, and the recommendation for program evaluation.
STEM Outreach Learning Ecosystem Impact and Recommendations

An important factor that emerged from interpreting the STEM outreach literature was the need to increase focus on program evaluation and measuring the impact of the outreach initiatives to inform future outreach. As an illustration, five of the articles indicated the use of feedback or evaluation of their initiatives (Bagiya, 2016; Bisbee O’Connell et al., 2017; Karmokar & Shekar, 2018; Ward, 2015; Young et al., 2017). Of these articles, only one described the role of evaluation in-depth and viewed feedback as a critical component to further program success (Bagiya, 2016). Of the studies that included an impact evaluation of STEM outreach, many focused on single STEM subjects or the impact of STEM outreach from the perspective of one initiative (e.g., Archer, 2013; Atkins, 2013; Thorley, 2014). Based on this work, there is some indication that outreach programs are having a positive effect and can support young people in (a) increasing interest in STEM, (b) productively engaging in STEM learning activities, (c) valuing the goals of STEM and STEM learning activities, and (d) developing an appreciation of the world of science and consider future STEM pathways (Bagiya, 2016; Belkhodja & Landry, 2007; DeCoito, 2016). Yet, evaluation could be expanded greatly across all programs to better understand if and how STEM outreach initiatives are achieving their intended outcomes of increasing the target audience’s knowledge and skills, as well as the broad societal impact of students’ pursuit of STEM careers. All articles consistently indicated that program evaluation was their next step to ensure that initiatives are reaching their intended outcomes and impacts.

When considering evaluation, a recommendation for STEM outreach is to use qualitative feedback to inform their initiatives and carry out longitudinal studies as many practitioners are not rigorous in their approaches to evaluation. This notion of evaluating STEM outreach programs has started to increase as several articles focus on the evaluation of one specific outreach program (Dahl & Droser, 2016; Duschl, Schweingruber, & Shouse, 2007). If an outreach initiative is of low quality or practitioners are unprepared to interact with the students,
this negative introduction to STEM could act as a barrier in motivating or enhancing interest in STEM (Bagiya, 2016).

A recommendation for STEM outreach practitioners is to receive training to boost their knowledge in curriculum links, pedagogy, appropriate language, and the selection of dynamic, interactive, simple, and affordable activities (Ward, 2015). With training, outreach practitioners may be better equipped to ensure that the purpose and process are appropriate for the intended audiences. For example, when working with Kindergarten to Grade 3, the goal may be to ‘plant the STEM seeds’; whereas in Grades 4-6/Grades 7-9 the goal may be to engage and raise aspirations, whereas the goals in Grades 10-12 may be focused on retention and supporting decision making while highlighting STEM careers.

A central limitation to the STEM ecosystem models discussed within this review is the minimal supporting evidence, especially in Canada, as to how they function in practice. Therefore, another recommendation focuses on future research and suggests the need for a multi-partner STEM learning ecosystem framework. In doing so, a collaborative approach may encourage practitioners to learn from each other’s experiences while adapting to their context and constraints, to work towards the goal of providing STEM educational opportunities for students of all ages during compulsory education. The STEM outreach framework could also act as a guide for practitioners in providing outreach, focusing on the outreach system, not an activity.

**Summary of STEM Outreach Literature Scoping Review**

Overall, this scoping review suggested that the concept of systematic STEM outreach within a K-12 learning ecosystem in practice is relatively under-explored as there is minimal empirical evidence that can support the potential benefits. At the time of conducting this literature review, no empirical evidence has acknowledged the essential components needed to develop and sustain a STEM learning ecosystem. Some STEM outreach models describe what STEM learning ecosystems might look like in terms of their partner composition; however, they lack depth in
terms of the key elements that inform how they might function in practice. Thus, there is a need for developing a model that could be shared within the STEM education community to help pre-existing STEM learning ecosystems and/or those who are interested in establishing one. Developing and sharing this framework could inform and encourage SOUs to work towards the goal of operationalizing a local STEM learning ecosystem. The synthesized findings leading to principles that are important to keep in mind when designing a STEM learning ecosystem conceptual framework include:

1. Established organizational features, structures, and capacities of each partner organization, especially a credible and highly engaged lead organization, to contribute to the ecosystem.

2. Dynamic and diverse partnerships that respect each other, have a shared/common goal to identify and eliminate barriers to equitable access to high-quality STEM learning, mechanisms to support one another, and a willingness to embrace the values, beliefs, interests of diverse cultures in their community.

3. Effective methods of communication between the stakeholder groups to build STEM capacity. This includes prioritizing time for reflection and evaluation.

4. Multi-directional communication channels for knowledge sharing between the stakeholders within the ecosystem to share research evidence, tacit best practices (grounded in the educational curriculum), and informed decision-making strategies.

When reviewing all of the elements involved in STEM education outreach, it is clear that the goals, target audience, delivery method, and initiatives can take many different forms depending on internal organizational factors (such as their mission, size, partners, stakeholders, target audience, training, staff roles, and resources) as well as external factors (such as funding, geographical location, ministries of education, and private-sector support) (DeCoito, 2014, 2016;
Struminger, 2018). At this present moment, SOUs and individual practitioners within Canada are in a vulnerable situation as the initiatives need to be able to provide explicit value to all stakeholders. This makes it challenging for outreach practitioners as minimal studies are focusing on STEM outreach and its role or value within the STEM education system.

Ecosystems can be focused on collaboration between STEM education researchers and practitioners, using evidence from research to inform their educator professional development programs in STEM instruction, as well as integrating evidence within formal/informal outreach delivery activities for students. In addition to the systematic approach to STEM outreach, the degree of complexity is changing based on emerging literature which suggests that for STEM outreach to be effective, there is a need for using evidence or knowledge to support teaching and learning during STEM outreach initiatives. Although there is potential for STEM outreach organizations to become involved in the knowledge mobilization process, potentially through the role of knowledge brokers, there is limited research to understand if/how this could happen.

To step beyond the obvious and generate ideas towards developing a conceptual framework that could inform the unexplored field of STEM learning ecosystems, one strategy is to look to see if other multi-partner collaborative relationships exist in education. By exploring the literature within the field of education, the goal was to identify any conceptualizations that could be used to inform a STEM learning ecosystem's conceptual framework, guiding this dissertation research. Knowledge Mobilization (KMb), also referred to as knowledge translation, knowledge to action, knowledge transfer, research use, and knowledge exchange (Cooper, Levin, & Campbell, 2009) is one emerging field that offers practical implications, that could inform STEM outreach units role within a learning ecosystem. Therefore, the next step was to conduct a brief literature review of KMb brokering models. This review of KMb is not intended to fully cover the breadth or depth of the field, but to explore concepts to see if/how they could inform the
conceptual framework that guides my research exploring the role and position of SOUs within STEM learning ecosystems.

**Brief Literature Review – Knowledge Mobilization and Knowledge Brokers**

Traditionally, the most widely held view in education towards knowledge mobilization refers to how the knowledge (meaning explicit empirical evidence in this context) from a specific piece of empirical research is viewed as factual, unambiguous, discrete, and able to be straightforwardly applied to practice (Nutley, Walter, & Davis, 2007; Sheldon & Chilvers, 2000). This approach is aligned with the knowledge-driven or problem-solving models (Weiss, 1979), a producer-push model (Landry et al., 2001), or even a ‘dissemination model’ (Landry, Amara, & Lamary, 2001). When knowledge is used in this manner, it is referred to as instrumental (Nutley, Walter, & Davis, 2007) and remains to be a widely used evidence-based approach that informs policy decisions and practice (Feldman, Nadash, & Gursen, 2001). However, there is an oft-cited gap between research, policy, and practice that acts as the driving force behind exploring knowledge use and knowledge mobilization as a field of inquiry (Davies, Nutley, & Smith, 2000; Nutley, Walter, & Davis, 2007; Pfeffer & Sutton, 2006).

In education, one of the challenges that exist within KMb is the accessibility to research by everyday users. It is uncommon that educators, from recent graduates to veteran teachers, obtain knowledge from peer-reviewed research found in academic journals (Cordingley, 2008; Levin, Cooper, Arjomand & Thompson, 2010) for STEM knowledge/expertise, STEM teaching tools, learning opportunities, or the latest issues in STEM education. More commonly, educators tend to engage with research knowledge indirectly (conceptual use or indirect use) by subtle means such as through colleagues or personal contacts (Coburn & Stein, 2010; Huberman, 2003), professional development, the media, and often through various third-party organizations (Coburn & Stein, 2010; Nutley, Walter, & Davis, 2007) whereby people interact on an ongoing basis to share knowledge and expertise about common practices, problems, or topics (Wenger, 1998).
This form of engagement would be aligned with the enlightenment model (research having gradual influence over time) (Weiss, 1979) or an interactive model (Landry, 2001), and is where the field of KMb is situated.

The interactive model for KMb acknowledges that learning is a social process involving knowledge producers, such as researchers, working alongside knowledge brokers, and knowledge users, such as educators who often have tacit or experiential knowledge built from years of practice, in equal partnership to move knowledge to where it is most useful (Landry, 2001). For the context of this dissertation research, it means that educators most commonly engage with STEM education research knowledge through personal contacts, colleagues, and third-party organizations or groups within their STEM learning ecosystem.

One possible strategy for strengthening interactive approaches to KMb efforts is to focus on the roles of knowledge brokers (Cooper, 2014; Ward, 2017). According to Honig (2004), knowledge brokers are particularly difficult to identify and study because many studies refer to brokering organizations without defining what makes them a broker. Honig (2004) suggested that knowledge brokers are:

- Organizations that occupy the space in between at least two other parties.
- Brokering organizations primarily function to mediate or to manage change in both those parties. Brokering organizations operate independently of these two parties and provide distinct value beyond what the parties alone would be able to develop or to amass by themselves. At the same time, brokering organizations depend on those parties to perform essential functions. (p. 67).

KMb activity within education has highlighted the increasing diversity of brokering organizations such as charitable foundations, research centers, government agencies, bridging organizations, professional organizations, and individual researchers (Nutley, Walter, and Davies,
as well as media, interest groups, think tanks, labor groups, policy entrepreneurs, private companies, and consultants (Levin, 2004). This list of brokers can take a variety of forms depending on their context, purpose, target audience, and where they fit within the education system. In essence, if one possible strategy towards strengthening KMb is to focus on knowledge brokers (Cooper, 2014; Ward, 2017), and the most common KMb mechanisms for mobilization STEM education knowledge is through peers, then SOUs, who are already active within the K-12 STEM learning ecosystem, have potential to be conceptualized as knowledge brokers. To learn more about if the field knowledge brokering and its relevance for SOUs within a K-12 STEM learning ecosystem, a brief scoping literature review was conducted.

**Knowledge Broker Models**

The scoping review database search yielded 1209 original articles for KMb brokering. After the screening process, five articles were identified to inform a conceptual framework for SOUs as knowledge brokers (Table 4). Of the five articles that met the review criteria, all of them had been published since 2009, implying that the empirical-based research observing KMb brokers is just beginning.
<table>
<thead>
<tr>
<th>Author, Sector, Setting</th>
<th>Aim of the framework</th>
<th>Description of the main components</th>
<th>Model tested?</th>
<th>Methods</th>
<th>The frameworks’ authors’ conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward (2017) Health care, KMb broker</td>
<td>To review the KMb literature on KMb models to inform brokering.</td>
<td>The framework includes 1) What type of knowledge to mobilize; 2) Why to mobilize; 3) How to mobilize knowledge, and 4) Whose knowledge to mobilize.</td>
<td>Derived from a scoping review of the literature. The framework is not tested.</td>
<td>Scoping review and synthesis of 47 models</td>
<td>This framework is to guide KMb brokers in personal reflection &amp; learning, team &amp; project development, evaluating KMb, network &amp; communicating, and identify tools/approaches.</td>
</tr>
<tr>
<td>Melim, Education KMb broker (2014)</td>
<td>To explore the role of brokering strategies for linkages and partnership.</td>
<td>The framework includes 1) Research (specific field); 2) Policy document; 3) Practitioners (teachers); 4) Brokering connections; 5) Products (tools &amp; resources); 6) Events (professional development); and 7) Networks – multidisciplinary collaboration (school staff, support program consultants, parents, and additional expertise).</td>
<td>Sequential multiple methods. Document analysis, semi-structured interviews, and case study notes. (n = 6) with 7-10 participants per case.</td>
<td>Qualitative multi-case study.</td>
<td>Social context plays a critical role in KMb. Relationships have an impact on all KMb efforts. By recognizing and responding to the enablers and barriers, KMb might improve linkages between research and practice.</td>
</tr>
<tr>
<td>Year</td>
<td>Domain</td>
<td>KMb Broker</td>
<td>Framework Overview</td>
<td>Research Methodology</td>
<td>Findings</td>
</tr>
<tr>
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<tr>
<td>2014</td>
<td>Education</td>
<td>To extend knowledge on KMb brokers in education.</td>
<td>The framework includes 1) Research production; 2) Research Use; 3) Brokers; 3a) Type of organization (government, non-profit, profit, membership); 3b) Organizational features (mission, scope, target audience, size, resources, membership composition); and 3c) KMb processes (strategies, functions, dissemination mechanisms).</td>
<td>Systematic website analysis of KMb efforts of brokering organizations in Canada</td>
<td>Organizations vary across features (especially resources), focus on product strategies more than events and networks which are less powerful than personal interactions. Levels of effort range from low to high.</td>
</tr>
<tr>
<td>2013</td>
<td>Healthcare</td>
<td>To review existing literature on brokering roles in a system.</td>
<td>The framework includes 1) identifying brokers and brokering opportunities; 2) generation and integration of innovation; 3) knowledge brokering, and 4) trust.</td>
<td>Derived from a scoping review and synthesis of 24 articles</td>
<td>Brokers can support the controlled transfer of specialized knowledge between groups, increase cooperation by liaising with people from both sides of the gap, and improve efficiency by introducing “good ideas” from one setting into another.</td>
</tr>
<tr>
<td>2013</td>
<td>Healthcare</td>
<td>To illustrate</td>
<td>The framework includes 1) Problem (identifying, reviewing, clarifying,</td>
<td>Action research with Fieldwork notes (10-</td>
<td>Initiatives to translate research into action have</td>
</tr>
</tbody>
</table>

1) Evolving (lasting, evolving, focusing); 2) Context (exploring, influences, characteristics, personal, interpersonal, organizational, professional); 3) Knowledge (locating, tailoring, assessing, classifying, usability, relevance); 4) Intervention (iterative, integrating, clarifying, negotiating, managing information, developing capacity, supporting decisions); and 5) Use (spreading, sustaining, practicalities, direct, conceptual, political).

A broker and three organizations working on challenging tasks. 15 months), interviews with team members (n = 10) been implemented over recent years, including the use of knowledge brokers. They have yet to prove their worth in terms of efficacy or cost-effectiveness. This framework calls into question the extent to which KMb interventions can add value to naturalistic knowledge exchange processes.
Five identified studies contained a framework to guide and explore the role of KMb brokers and three have been applied to demonstrate how such frameworks can be used to inform practice (Cooper, 2014; Melim, 2014; Ward et al., 2012). The other two are scoping reviews synthesizing a conceptual framework (and thus have not yet been tested). The common goal across the articles was to inform the broader community about the complexities of KMb brokering processes and functions.

One of the key findings from the literature review was that as the demand for evidence-informed education grows within Canada, there is a need for KMb brokering organizations. The size, scope, and diversity of KMb brokering organizations are increasing in education. KMb brokering organizations can take a variety of forms depending on their context, purpose, resources, target audience, role within the education system, and degree of collaboration between researchers and practitioners. Also, knowledge brokering activities can range from plain language summaries through documentation and dissemination, virtual networks along with priority theme areas, face-to-face meetings among multiple stakeholders on priority areas, workshops on tools and techniques for research use and ongoing knowledge building, fellowship training programs for decision-makers in research and policy application (Cooper, 2014; Hoing, 2004; Merlin, 2014). Cooper (2014) also elaborated to suggest that brokering organizations have eight different functions. These KMb brokering functions include linkage and partnership, awareness, accessibility, policy influence, engagement, organizational development, implementation support, as well as capacity building. This range of KMb brokering activities and functions draws attention to the potential effectiveness of a balanced and multifaceted approach consisting of multiple functions.

Another similarity in the KMb brokering articles was the importance of establishing a trusting relationship between research producers and research users (Long, Cunningham, & Braithwaite, 2013; Ward, House, & Hamer, 2009). For KMb to be operationalized in a multidirectional flow of evidence, a trusting relationship is vital for its sustainability. Otherwise, the
researchers and practitioners will remain in independent silos, unaware of the knowledge and experience they may gain from one another. To establish and maintain a trusting relationship, KMb brokers utilize a range of activities and functions depending on the target audience.

The last similarity that emerged from these articles was the need to have dedicated resources such as funding, infrastructure, and personnel tied directly to KMb efforts. As KMb brokers can vary depending on the context, these resources are necessary when considering the questions posed by Ward’s framework for knowledge mobilizers (2017): what type of knowledge is there to mobilize, why mobilize this knowledge, how does one mobilize the knowledge, and whose knowledge will be mobilized? These questions are applicable in the context of K-12 STEM learning ecosystems and purposeful for SOUs to consider. Provided these resources are available, the efficiency of KMb brokers becomes visible in traditional education settings and will also be measured in terms of their role and success. These articles suggest the need for investigating the models empirically in a practical setting so that KMb brokers can establish their value in terms of efficacy or cost-effectiveness.

To shed light on knowledge brokers, Cooper (2014) draws upon previous KMb literature (Hemsley-Brown, 2004; Levin, 2004; Rickinson, 2005; Williams, McConnell, & Wilson, 1997) to design a research brokering organization conceptual framework that helps to clarify what it means to be a broker. Within Cooper’s (2014) framework, there are similarities to Honig’s (2004) definition of brokers but stipulates that there must be three essential elements for KMb: research producing contexts, research using contexts, and the inter-connectedness between them through knowledge brokers, all influenced by the social context within which KMb is embedded. Cooper’s (2014) framework also accounts for the four essential elements of a STEM learning ecosystem identified by the STEM outreach review (variability of resources, sharing a common goal, trusting relationships, and training for communication). It also provides insight into individual components that might be necessary for KMb brokers (organizational features, activities, processes, relationships, and brokering functions) to explore the concept of SOUs as
knowledge brokers within the K-12 learning ecosystem. For these reasons, the components of the Cooper (2014) conceptual framework provide a valuable contribution to the construction of a novel conceptual framework, which will serve as a lens of this dissertation.

**Conceptual Framework – Exploring the Conceptualization of STEM Outreach Units as Knowledge Brokers within a K-12 STEM Learning Ecosystem**

Building upon the K-12 STEM learning ecosystem image (Figure 1), the conceptual framework used to explore SOUs as knowledge brokers is illustrated below in Figure 7.

**Figure 7**

*Conceptual Framework - STEM Outreach Units as Knowledge Brokers*

*Note.* This figure overlays the organizational features and knowledge brokering functions overtop of the proposed central SOU position within a K-12 STEM learning ecosystem.

The first component of the framework explores the types of SOUs based on their location and role within a K-12 STEM education system. Studies across sectors have highlighted the influence of organizational types because they have diverse functions and roles depending on
their purpose and which target audiences they serve (Belkhodja & Landry, 2007; Coburn & Stein, 2010; Honig, 2004; Landry, Amara, & Lamary, 2001; Nutley, Walter, & Davis, 2007). As described earlier, four organizational SOU types, who lead in delivering K-12 STEM outreach initiatives, include post-secondary institutions, non-profit/charitable or volunteer organizations, STEM-related businesses, or industry-based organizations (such as Google), and various levels of government agencies (DeCoito, 2016; Turner et al., 2007). When considering SOUs as knowledge brokers, it will be important to explore their purpose and target audience(s) to make sense of their brokering efforts.

The second component of the conceptual framework investigates the organizational features of SOUs and how the features contribute to (or detract from) their brokering efforts within a K-12 STEM learning ecosystem. Some of the main barriers of STEM outreach and KMb in education are not visible at the individual level but originate in the organizational culture (Honig, 2004). Previous studies have drawn upon organizational ecology literature to explore organizational variables and the impact they might have on KMb efforts (Belkhodja & Landry, 2007; Honig, 2004; Nutley, Walter, & Davis, 2007; Rickinson, 2005). In addition to the organizational variables, the mission statement and target audiences of an organization are also important features to capture. Overall, this component of the conceptual framework provides a synthesis of the organizational features based on literature (Cooper, 2014; Hemsley-Brown & Sharp, 2003; Nutley, Walter, & Davis, 2007) and will be explored in-depth to provide insight into the structure of the SOUs included in this study. Table 5 provides a brief description of the six organizational features within the conceptual framework.
Table 5

Organizational Features of Organizations

<table>
<thead>
<tr>
<th>Component</th>
<th>Description of framework component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission</td>
<td>The purpose and goals of an organization.</td>
</tr>
<tr>
<td>Initiatives</td>
<td>The types of STEM learning opportunities that SOUs engage in (e.g., summer camps, in-school workshops, lectures, weekend events).</td>
</tr>
<tr>
<td>Capacity</td>
<td>The number of full-time employees working for the SOU and strategic roles within an organization (roles, training, and expertise).</td>
</tr>
<tr>
<td>Resources</td>
<td>The funding sources that support the SOU (operating and revenue-generating).</td>
</tr>
<tr>
<td>Target Audience</td>
<td>The groups of people that the STEM outreach initiatives are intended for (e.g., students, parents, teachers, underrepresented groups).</td>
</tr>
<tr>
<td>Partnerships</td>
<td>The groups within a K-12 STEM learning ecosystem that collaborate to deliver in-person STEM learning opportunities and have a direct influence on the ecosystem.</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>Groups that have a stake or an active interest in (e.g., somehow vested in) a K-12 STEM learning ecosystem. Primary stakeholders include those groups or individuals who have a strong interest in the ecosystem and who potentially have the power to make or influence decisions. Secondary or tertiary stakeholders have an indirect influence on the overall ecosystem. (Alkin M. C., 2011)</td>
</tr>
<tr>
<td>Evaluation &amp; Impact</td>
<td>Evaluation is the systematic assessment of the design, implementation, or results of an initiative for learning or decision-making (Canadian Evaluation Society, 2015). Impact refers to the intended and unintended, direct and indirect outcomes produced by an educational initiative. Typically, outcomes are classified as short or medium-term and could include changes to students’ knowledge, skills, and capacities, and what they can do as a result of their new learning/growth/development. Impacts typically refer to the long-term effects on society (BetterEvaluation, 2020).</td>
</tr>
</tbody>
</table>

The third component of the conceptual framework purposefully explores Cooper’s (2014) eight knowledge brokering functions, adapting them to the context of this dissertation. The various functions of knowledge brokers can range from disseminating research and getting it used (Lomas, 2007) to focus on awareness, communication, interaction, and capacity building (Robinson et al., 2005). A list and description of the eight brokering functions is illustrated in
Table 6. This component provides insight as to whom the outreach organizations are interacting with, how they are doing it, what functions they are using, and why they have selected them. It will also highlight which functions SOUs are not using.

**Table 6**

*Knowledge Mobilization Brokering Functions (Cooper, 2014).*

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linkage &amp; partnership</td>
<td>Facilitating connections among diverse STEM education stakeholders and supporting collaboration. Strategies could include talks, conferences, workshops, and social media.</td>
</tr>
<tr>
<td>Awareness</td>
<td>Increasing awareness of empirical/research evidence related to STEM education/outreach. Strategies could include literature review, systematic review, research reports, or conceptual commentary papers.</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Increasing accessibility to STEM education/outreach research by tailoring products to audiences. Strategies could include research summaries, policy briefs, or fact sheets.</td>
</tr>
<tr>
<td>Policy influence</td>
<td>Using STEM education/outreach research to galvanize policy or change. Strategies include media (press release, newspaper article, online forums, and TV or radio), fact sheets, or social media.</td>
</tr>
<tr>
<td>Engagement</td>
<td>Increasing engagement with STEM education/outreach research and content by making it appeal to a variety of our senses. Strategies could include multimedia products, videos, presentations, data visualization.</td>
</tr>
<tr>
<td>Organizational development</td>
<td>Assisting to build strategic plans and processes or evaluating existing programs and practices related to STEM education/outreach. Strategies could include annual meetings, strategic plans, promotional materials, or annual reports.</td>
</tr>
<tr>
<td>Implementation support</td>
<td>Consulting on STEM education or STEM outreach-related topics by assisting to implement initiatives or interventions. Strategies could include toolkits, consultation requests, or support services.</td>
</tr>
<tr>
<td>Capacity building</td>
<td>Facilitating professional learning and skill development around STEM education/outreach. Strategies could include terms/glossaries, online tutorials, workshops, mentorship, or training sessions.</td>
</tr>
</tbody>
</table>
Overall, as education is changing to adapt to the labor market demands and projections, STEM outreach continues to be a valuable resource that remains underutilized. Looking at STEM education from a systems-based and ecological view, it considers multiple stakeholders working together to deliver evidence-based STEM initiatives that could improve outcomes for students. This study explores how SOUs may be in a position to act as knowledge brokers within the K-12 STEM learning ecosystem. My proposed conceptual framework, based on a review of STEM outreach models and KMb brokering models, will be used to explore the potential role of SOUs within the K-12 STEM learning ecosystem as knowledge brokers.
Chapter 3

Methodology

Explanatory research is a method developed to investigate a phenomenon that has not been well explored. This explanatory sequential multi-phase mixed methods design (Creswell, 2009) collects quantitative data in Phase 1 (website analysis) and Phase 2 (survey) before building on these data with qualitative in-depth interviews (Creswell, 2009) in Phase 3, to generate case studies of individual university-based SOUs within a K-12 STEM learning ecosystem. The first part of this chapter outlines the study’s methodological approach, research design, followed by participant recruitment and sampling. The second part includes the method components used for data collection and data analysis. Finally, a description of the approaches used to enhance the trustworthiness of the study is outlined.

Methodological Approach – Multi-Case Study

Case studies are suitable for developing an in-depth understanding of real-life phenomena; paying particular attention to the contextual conditions, which are highly pertinent to the phenomenon under investigation (Merriam, 1998; Yin, 2008). Case studies demonstrate empirical inquiry through investigating a contemporary phenomenon within its real-life context (Yin, 2008); a specific, complex, functioning integrated system (Stake, 1995); or an intensive, holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, or a social unit (Merriam, 1998).

The defining characteristics of a case study, according to Merriam (1998), can be typically categorized as either heuristic (illuminating the reader’s understanding of the phenomenon under study); particularistic (focusing on a particular situation, event, program, or phenomenon); or descriptive (yielding a rich, thick description of the phenomenon). For this dissertation, a heuristic approach is first used to explore the organizational features of university-
based SOUs within a Canadian context. The rationale for starting with this approach is to understand the breadth and diversity of SOUs in Canada in terms of mission and capacity. Following, a particularistic approach is used to examine the concept of K-12 STEM learning ecosystems and the potential role of SOUs as knowledge brokers within them.

Several methodology books describe strategies of conducting a single case research study (Merriam, 1998; Stake, 1995; Yin, 1994; 2008), but only briefly describe multi-case studies. One fundamental difference between a single case study and a multi-case study is that the researcher is studying multiple cases to understand the differences and the similarities between the cases by analyzing the data within cases and across cases (Baxter & Jack, 2008; Stake, 1995; Yin, 2003).

According to Stake (2006), in multi-case study research, a single case is still of interest because it shares common characteristics and belongs to a particular collection of cases that are categorically bound together. This collection of cases, which may include members of a group or examples of a phenomenon, can be labeled as a quintain (Stake, 2006). Although the term ‘quintain’ was developed to describe a collective target, whether it be a program, a phenomenon, or a condition, it can apply to other approaches of multi-case study designs, no matter the epistemological lens. According to Stake (2006), a multi-case study starts with the quintain, but to understand the phenomenon better, it is important to study some of the individual cases. Merriman (1998) also suggested that the more individual cases included in a study, and the greater the variation, the more compelling an interpretation to inform the phenomenon. Other advantages of multi-case studies include: 1) more evidence/samples, upon which to detect consistently (reliable) similarities and differences than that of a single case study (Baxter & Jack, 2008); 2) the creation of a convincing theory and suggestions that are grounded in several pieces of empirical evidence; and, 3) when cases are compared to each other, the researcher can provide literature with an important influence from the similarities/contrasts (Vannoni, 2014; 2015).

In the context of this dissertation, the quintain for investigation is university-based SOUs within their respective K-12 STEM learning ecosystem and the potential role they may have as
knowledge brokers. To understand this quintain, it is important to study multiple diverse individual cases, representing variation in how SOUs are involved in different K-12 STEM learning ecosystems across Canada. Each case includes three data sources, Phase 1 website analysis, Phase 2 survey data, and Phase 3 interviews. Within each case, it is also important to explore the collaborative relationships (from the perspective of university-based SOUs) that they have with other STEM education stakeholders within their local K-12 STEM learning ecosystem.

Research Design, Recruitment and Sampling – Sequential Three-Phase Approach

As Patton describes, borrowing and combining distinct elements from pure methodological strategies and mixing the measurement, design, and analysis components of quantitative and qualitative inquiry can provide a creative methodological approach needed to explore research questions (Patton, 2002). Figure 8 illustrates an adapted version of Patton’s (2002) mixed methodological strategies.

Figure 8

Mixed Methodological Strategies Adapted from Patton (2002)
To best answer the three research questions for this multi-phase explanatory dissertation, a naturalistic inquiry (Patton, 2002) was used. Phase 1 incorporated quantitative data collection and statistical analysis of SOUs organizational websites. Phase 2 (online survey) incorporated a mixture of quantitative and qualitative questions as a form of data collection, requiring both content analysis and statistical analysis. Finally, Phase 3 consisted of qualitative semi-structured interviews and content analysis. Further details about each phase are discussed below.

**Phase 1 – Website Analysis**

Phase 1 used a multi-case study to illuminate an understanding of a bounded phenomenon (Merriam, 1998), which in this case are university-based K-12 SOUs in Canada. As the landscape of K-12 SOUs is not well explored, it required a broad but systematic sampling strategy to deliberately identify a wide range of organizations before selecting those that meet the inclusion criteria within the scope of this dissertation. An environmental scan of the K-12 SOU publicly accessible websites was conducted as a form of document analysis to identify, document, and describe the variety of K-12 SOUs across the Canadian landscape for ongoing study. Website document analysis is a systematic approach to reviewing and interpreting documents to elicit meaning from written text and images (Corbin & Strauss, 2008). The SOU websites were the first step towards exploring who is involved in STEM outreach and their presence within their respective K-12 STEM learning ecosystem. Phase 1 utilized a purposeful sampling strategy and inclusion criteria to examine university-based SOUs at publicly funded universities (excluding post-secondary colleges and privately funded universities). With this inclusion criteria, the maximum number of publicly funded universities within Canada was 82. However, this does not necessarily reflect the maximum number of SOUs within these institutions as there may be multiple K-12 SOUs within a given university. Across these university-based SOUs, Phase 1 focused on collecting data from their publicly available websites, which meant that participant recruitment was not required.
**Phase 2 – Online Survey**

In Phase 2, an online survey (found in Appendix A4) was used to collect data from geographically diverse SOUs. The goal of Phase 2 was to expand on the preliminary findings from Phase 1 by using a survey for personnel from SOUs to explain their role within their K-12 STEM learning ecosystem. Phase 2 used a multi-case study approach to focus on a purposeful sample of SOUs who met inclusion criteria for further study of their organizational profile, role, and partnerships. The priorities of organizations are often reflected in their mission statements, goals, and strategic plans (Bart & Tabone, 1998; Morphew & Hartley, 2006). To best answer the research questions, two inclusion criteria were implemented. The first, only those SOUs from Phase 1 that had a mission statement that explicitly targets K-12 STEM education. The second, the SOUs from Phase 1 that appeared to partner with at least two other STEM education stakeholders within the K-12 STEM learning ecosystem (e.g., government and schools). The rationale for implementing this inclusion criterion was to focus on SOUs that work with multiple groups within the ecosystem and are not completely independent.

For those SOUs that met the criterion, participant recruitment was then targeted at directors/managers of outreach operations. Before contacting the participants by email, the ethics board at each institution was consulted to determine if using publicly available email addresses was approved. At institutions where email contact was viewed as ethically permissible, decision-makers were contacted via email inviting them to participate. All Tri-council ethical guidelines for participants were followed, the complete email recruitment script and a letter of information can be found in Appendices A1 – A4. At the end of the email was a link to the online survey and consent form.

**Phase 3 – Semi-Structured Interviews**

Phase 3 also used a multi-case study design to focus on individual university-based SOUs. In this phase, the only inclusion criterion was to include those university-based SOUs that completed the Phase 2 survey. The rationale for implementing this inclusion criterion is
purposeful to explore a wide variety of SOUs who have different perspectives on the concept of knowledge brokers and can offer insight towards the partnerships with STEM education stakeholders within a K-12 learning ecosystem. The decision-makers within the SOUs participated in semi-structured interviews to probe deeper into their perspectives on the potential role of SOUs as knowledge brokers within their multi-partner K-12 STEM learning ecosystem. Within qualitative research, semi-structured interviews are often used “to enter into the other person’s perspective” (Patton, 2002, p. 341), to learn about situations that preclude the presence of an observer. The semi-structured interview approach was ideal for Phase 3 since it allowed for a pre-determined set of questions that expanded on the quantitative data collected in the website analysis and survey; but during the interview, allowed for some flexibility to adjust the sequence of the questions and to probe specific questions in more detail based on the context of the participants’ responses (Patton, 2002). Also, the conversational style format helps to create a safe and less intimidating environment for outreach directors or managers to speak freely about their university-based outreach organization as well as their local K-12 STEM learning ecosystem. By conducting a variety of in-depth semi-structured interviews as individual cases, it was the best approach towards answering the research questions exploring the concept of SOUs as knowledge brokers, and the broader quintain of SOUs role(s) within K-12 STEM learning ecosystems.

For SOUs that have met the inclusion criteria, the individuals in positions of senior leadership were contacted via email inviting them to participate. Recruitment for Phase 3 was done via the same email address used in Phase 2 which was publicly available through the institutional website. The recruitment email script informed participants of the research through a letter of information (see Appendix A2 and A3). Within the email, there was a link to an online survey and consent form.

Data Collection

Phase 1 – Website Analysis
An online search strategy was applied systematically using a combination of the keywords (Table 7) in major search engines (e.g., Google, Yahoo). When conducting the keyword search involving publicly funded universities, the keyword illustrated within Table 7 as ‘University [insert name]’ is a place holder and when the search was being conducted, this keyword was replaced with publicly funded Canadian universities (such as Queen’s University or the University of Victoria). An example of a search string is in Table 8.

Table 7

<table>
<thead>
<tr>
<th>Keyword 1 (with synonyms)</th>
<th>Keyword 2 (with synonyms)</th>
<th>Keyword 3 (with synonyms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>STEM Outreach</td>
<td>University [insert name]</td>
</tr>
<tr>
<td>Canadian</td>
<td>STEM Camp</td>
<td></td>
</tr>
</tbody>
</table>

Table 8

Examples of STEM Outreach Search Strings

<table>
<thead>
<tr>
<th>Sample search string</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Canada) AND (“STEM Outreach”) AND (“University of British Columbia”)</td>
</tr>
<tr>
<td>(Canada) AND (“STEM Camp”) AND (“University of Victoria”)</td>
</tr>
<tr>
<td>(Canada) AND (“STEM Outreach”)</td>
</tr>
</tbody>
</table>

In addition to the keyword internet search, a secondary search was conducted by reviewing collaborative partnerships with other publicly funded universities identified on the SOU websites as a form of snowball sampling (Patton, 2002). These partners were also explored via a Google search to see if they met the inclusion criteria to be included in the sample.

The data extraction from the SOUs websites was purposeful in its attempt to start creating an organizational profile and to highlight if they interact with other stakeholders within a K-12 STEM learning ecosystem. To start creating an organizational profile, data was extracted based on its organizational features as discussed in Chapter 2. The following list highlights the
categories of data that were extracted: province, university name, affiliated faculty, SOU name, mission statement, target audience(s), types of outreach initiatives (workshops, camps), size (full-time employees), and sources of funding. Secondly, data extracted from the websites looked to determine if they partnered with any other STEM education stakeholder groups included within a K-12 STEM ecosystem as shown in Figure 1. Combining the organizational and partnership components, there were 15 data extraction categories for each SOU website.

The process/protocol for obtaining the organizational profile data varied for each organization based on the format of websites. For every organization, a first pass of the website was performed to gain an understanding of what information was available. Departmental outreach branches typically did not have independent websites and rather, presented their organization’s information on a single page with a contact email for those interested in learning more. The data extraction process for organizations with informative resources was done using the protocol shown in Figure 9.
Summary of Phase 1 Website Analysis Data Extraction Process

1. About Us
   - Affiliated faculty
   - Mission statement
   - Type of organization
   - Size (staff)

2. Services
   - Target audience
   - After-school programs
   - Summer camps
   - Partnerships

3. Sponsors
   - Sources of funding
   - Partnerships

4. Contact
   - Contact name
   - Contact email
   - Size (staff)

Note. The Phase 1 data extraction process included looking through four sections on the website to start generating organizational profiles.

A final pass through the websites was done to obtain any additional or missing information from the categories. If/when any data within a category was missing or unable to be extracted, it was labeled as “not on the website.” All extracted data was imported and coded into Microsoft Excel where it was used to aid quantitative descriptive statistical data analysis.

Once the data was extracted from the 15 different categories, each SOUs’ website was assigned a checklist score (out of a possible 15 points) to summarize how many of the categories were represented. For example, if an organization’s website mentioned their funders and that they partnered with a local school, it would mean that two of the fifteen checklist categories would get
a point. Although the websites are used as a data source, it is important to note that this study and the checklist score are not assessing the quality or completeness of the websites.

The findings from the website analysis served as a starting point for exploring the role of SOUs within K-12 STEM learning ecosystems (the quintain) across Canada by starting to generate organizational profiles of the university-based SOUs as individual cases. These profiles were used to generate a geographical representation to illustrate the Canadian K-12 STEM outreach landscape within and across each province. Phases two and three followed up with specific university-based SOUs (cases) by investigating their role in a STEM learning ecosystem.

**Phase 2 – Online Survey**

An online survey allowed for expansion beyond the organizational profiles developed in Phase 1. The survey was structured to incorporate a mixture of closed (quantitative) and open-ended (qualitative) questions, divided into the following three sections: STEM outreach demographics, STEM outreach organizational features, and K-12 STEM learning ecosystems. Whenever possible, qualitative open-ended questions within each section created an opportunity for the participants to express themselves without the influence of pre-determined categories (Patton, 2002). The order of the questions was also purposefully designed to allow participants to answer the broad open-ended questions before any closed questions to minimize imposed bias. An overview of the components, questions, the rationale for each of the three sections, as well as the complete survey can be found in Appendix A4.

**Phase 3 – Semi-Structured Interviews**

The purpose of the semi-structured interviews was to gain further insight into how the decision-makers (such as managers or directors) of the SOUs view their organizational role related to knowledge brokers, and to explore the perceived benefits, drawbacks, and essential components of a multi-stakeholder collaborative K-12 STEM learning ecosystem. When conducting the interviews, an interview protocol was used (included in Appendix A5) containing
a pre-determined set of questions that allowed for flexibility and exploration of responses in detail. A copy of the interview questions can be found in Appendix A5.

All interviews were conducted by the sole researcher and each interview lasted between 60 and 75 minutes. With the consent of participants, each interview was audio-recorded and transcribed verbatim. Once the interview was transcribed, a copy was emailed to each participant inviting them to member-check (Merriam, 2009) for accuracy (credibility/internal validity) and to make any revisions or omissions as they deemed necessary.

**Data Analysis**

Merriam (1998) indicated that six analytical strategies can be used for case studies: ethnographic, narrative, phenomenological, content analysis, constant comparative, and analytic induction. In addition, Patton (2002), as outlined in Figure 8, suggests that within a naturalistic inquiry, data analysis might require a mixture of content analysis and statistical analysis. Depending on the phase of this dissertation, a combination of descriptive statistical analysis, content analysis, and inductive thematic analysis (Bowen, 2009; Patton, 2002; Thomas, 2006) is used. Descriptive statistics analysis for this study refers to using quantitative data such as frequencies and percentages to summarize, organize, and display the finding. Content analysis is the process of identifying meaningful and relevant passages of text and organizing the information into categories. According to Thomas (2006), the purpose of an inductive analysis is threefold: 1) to condense raw text data into a summary format, 2) to establish clear links between research objectives and findings derived from the raw data while ensuring transparency, and 3) to develop a framework of the underlying structure as evident in the raw data. Although the general inductive approach is not as strong as other analytic strategies that are used for theory or model development, it provides a systematic procedure for exploring and analyzing naturalistic data that produces reliable and valid findings (Thomas, 2006), which give insights into how individuals experience a particular phenomenon (Rowan & Huston, 1997).
Phase 1 – Website Analysis

Patton (2002) identifies the first step of naturalistic qualitative content analysis as developing a manageable classification or coding scheme. The content analysis component for Phase 1 of each STEM outreach website involved multiple rounds of reading (thorough examination) and interpretation (meaning-making) (Bowen, 2009). In the first round of reading, the organizational features component of the conceptual framework was used as predefined categories to extract relevant data from the website and assign preliminary codes to the units of text. Coding is the process of identifying important/meaningful stand-alone ideas that emerge from the data and then categorizing them (Patton, 2002). The next step was to examine all the codes to see if the extracted data fit within the properties of a certain category. If not, an additional category was created. Finally, all categories were holistically compared to see if any overlap or relationships existed. To consolidate the data, the predefined codes were used to generate a matrix/summary table using Microsoft Excel to comment on commonalities and variations of the SOUs. Once completed, the data from within the summary table was used to analyze descriptive statistics (frequencies and percentages) that further contributed towards data analysis. During this phase, the extracted data was reviewed, paying close attention to the language used to describe the SOU and its initiatives within their ecosystem.

Phase 2 – Online Survey

The data analysis of Phase 2’s online survey was analyzed using descriptive statistics (Patton, 2002) for the closed questions, and a combination of content analysis (Merriam, 1998) and inductive thematic analysis (Bowen, 2009) for the open-ended questions to allow for insights to emerge within and across a set of intentional questions and concepts to be explored.

Analysis in this phase began with performing statistical analysis using Microsoft Excel on the purposefully designed closed questions within the survey to generate frequency counts as well as percentages to help explore the research questions. Following, the content analysis component of the online survey for each SOU using the organizational features as a template to
organize the data for subsequent inductive analysis. Using the predefined categories and the emerging codes from Phase 2, a summary table was generated using Microsoft Excel to construct preliminary organizational profiles for each SOU. With these profiles, the inductive coding process continued, which involved a close reading of the data within the unit of analysis (which are the SOUs as individual cases), allowing for the discovery of patterns and themes to emerge. When analyzing the data, the goal was to keep the central ideas “close to the data” (Charmaz, 2006, p. 59) by using direct quotes from participants which were important given that the preliminary case descriptions would serve as partial data for subsequent analysis in Phase 3.

A key focus within Phase 2 was to describe the themes which inform how university-based SOUs approach building and maintaining partnerships with the other STEM education stakeholder groups within their local K-12 STEM learning ecosystem. Therefore, the last step involves making sense of the partnerships (Merriam, 2009). Based on the findings from Phase 1 and Phase 2, individual cases were identified that were best positioned to inform this study’s research questions in Phase 3.

**Phase 3 - Semi-Structured Interviews**

The first part of the data analysis in Phase 3 includes the iterative process using inductive thematic analysis (Bowen, 2009) and content analysis (Merriam, 1998) and to support and/or supplement the broad themes that emerged from the previous phases. The second part of the analysis focused on analyzing the Phase 3 data (along with any relevant information from Phase 1 and 2), to construct complete SOU profiles as individual cases. Once the individual case descriptions had been completed and put into an integration table, data analysis continued by extracting key information to compare the similarities and differences across the included SOUs. To help with this, qualitative data analysis software (NVivo software – version 11.4.3, by QSR International) was used to annotate and code the dataset.

In the third round of data analysis, the Phase 3 data along with the case study descriptions were further analyzed based on the research questions that explored organizational features;
multi-stakeholder collaborative K-12 STEM learning ecosystem; and STEM outreach as knowledge brokers. Similar to Phase 2, the goal of the analysis was to annotate recurring themes as well as new emerging themes from Phase 3. In Phase 3, each code was checked for homogeneity, meaning that data assigned to the same code had a similar meaning. Eventually, the codes from Phase 3, including representative quotes from each of the themes, were cross-references and combined (when possible) with the Phase 1 and 2 findings to help answer the research questions.

The final step for data analysis in Phase 3 involved the combination of induction thematic analysis and the use of a constant comparison method (Glaser, 1992; Glaser & Strauss, 1967; Merriam, 2009). The constant comparative method involves comparing and contrasting ideas emerging within and across data sources to discover patterns of meaning (themes) in the extracted data (Glaser, 1992; Glaser & Strauss, 1967). According to Tesch (1990), a comparison is the central intellectual activity of the researcher as an instrument:

The method of comparing and contrasting is used for practically all intellectual tasks during analysis: forming categories, establishing the boundaries of categories, assigning the segments to categories, summarizing the content of each category, finding negative evidence, etc. The goal is to discern conceptual similarities, refine the categories, and discover patterns (p. 96).

A summary table of the individual cases used within Phase 3 served as a matrix to compare similarities and differences both within and across cases (i.e., within a column and across rows). The goal for doing this was to help understand the similarities and differences from what was described within cases; and establish those ideas that were mentioned consistently across several cases (Bowen, 2009). This last step has a particular focus on describing the themes that best answer the research questions and reporting on important lessons learned about the roles of SOUs within their K-12 STEM learning ecosystem (quintain).
Ensuring Trustworthiness and Credibility

For professionals in applied fields of research, such as education, where practitioners are intervening in people’s lives, it is vitally important for researchers to demonstrate trustworthiness in their approach to conducting the research, as well as in their research findings (Merriam, 2009). In rigorous naturalistic inquiry qualitative research, Guba (1981) suggests that trustworthiness involves conducting investigations with credibility (internal validity), confirmability (objectivity), and transferability (external validity). To increase the overall trustworthiness of this study, all four of these factors were considered and addressed.

According to Patton (2002), credibility and internal validity “is dependent on training, experience, track record, status, and presentation of self” (p. 552), but it also involves “intellectual rigor, professional integrity, and methodological competence” (p. 570). Internal validity of research has to do with the credibility of the research process, and the soundness of the findings that are produced. According to Merriam (2009), there are six strategies towards enhancing the internal validity of research: triangulation, member checks, long-term observation, peer examination, participatory research, and disclosure of researcher bias. To improve the internal validity of the findings from this research, triangulation occurred across all 3 phases and data sources. Data triangulation can simply be viewed as using different approaches in support of one another, such as the Phase 2 survey and the Phase 3 interviews, to respond to and build a progressive understanding of the same research questions. Triangulation also occurred when comparing emergent themes within and across data sources, thereby allowing for categories of meaning to emerge, be negotiated, and potentially consolidated into more robust themes.

As the primary investigator, credibility was demonstrated by being thoughtful in the approach to building professional relationships with those who were interviewed by making sure that the purpose of the research, the methods of inquiry, and the level of participation required were thoroughly explained. Finally, researcher transparency was increased by articulating
personal views through the autobiographical statement at the beginning of this study that outlines
the personal background, experiences, and lenses brought to this research.

Transferability in an applied context relates to the responsibility of the researcher to provide enough contextual information about the process and findings to enable the reader to infer and consider what this might look like and mean in their own professional or practice context (Merriam, 2009). Merriam (2009) identifies three techniques to enhance transferability (external validity): use of thick description, typicality or modal categories, and multi-site designs. While the goal of qualitative research is never generalizability (Merriam, 2009; Patton, 2002), the external validity and internal rigor of this dissertation research was improved by producing rich, thick descriptions that illuminate key concepts and relationships amongst concepts that external readers can then use make sense of their own experiences. Finally, reliability, as a concept, describes the extent to which there is consistency within the findings of my studies, and with the findings of related published research. By describing, in detail, how this research was conducted, and relating the approach and insights to the published literature, transparency in the assumptions and decision-making was provided.
Chapter 4

Findings – Phase 1: Environmental Scan and Website Analysis

The purpose of this research is to identify the organizational features of university-based SOUs within Canada and to explore their conceptual position within a K-12 STEM learning ecosystem and their conceptual role as knowledge brokers. Three overarching research questions that guide this study are: 1) What are the organizational features of university-based STEM outreach units in Canada, 2) What approaches to collaborative partnerships do university-based SOUs have within a K-12 STEM learning ecosystem, and 3) To what extent do university-based SOUs have the capacity to act as knowledge brokers within K-12 STEM learning ecosystems? Chapters 4 presents the combined findings from Phase 1 according to the research questions and related concepts from the conceptual framework.

The objective of Phase 1 was to serve as a starting point for exploring the first research question by helping to generate an environmental scan of university-based STEM outreach units across Canada. According to Universities Canada (2020), there are 96 universities listed on their website, of which, 82 are publicly funded universities distributed across Canada. The inclusion criterion for Phase 1 included only those universities providing K-12 STEM outreach to the greater public, thereby removing nearly a third of the universities, resulting in a total of 57. That said, within a single institution, it is possible to host more than one K-12 SOU, whereby, different faculties may offer their own organized form of outreach that is independent of another faculty and operates to reach different targets. Hence the sample size is potentially larger than 57 as each university is possibly home to one or more SOU. Based on the results from the Phase 1 search strategy, there are 124 K-12 SOUs identified across the 57 different universities.
When exploring university-based SOUs, it is important to acknowledge two groups: Let’s Talk Science and Technoscience. Let’s Talk Science (LTS) is a national charitable organization that provides engaging, evidence-based STEM programming to Canadian youth and educators. As a national organization, LTS is unique in that it partners with post-secondary institutions to establish a chapter that usually consists of STEM post-secondary student volunteers and a supervising faculty member. Embedded within the institution, LTS can provide STEM learning opportunities to educators and students as part of the larger organizational mandate. Of the 124 SOUs identified in the initial search strategy, 40 of them are host to an LTS chapter. Similarly, Technoscience, a provincial organization operating out of higher education institutions across Quebec, acts in the same way as LTS, whereby each institution is an individual chapter of a larger organization. Technoscience is hosted at 3 of the universities within the current sample. The contributions of these two specific STEM outreach organizations have relevance for K-12 STEM learning ecosystems, but since they are more aligned with a non-profit/charitable type of STEM outreach organization (as described in Chapter 1), further detail into them is beyond the scope of this study which focuses on university-based STEM outreach organizations.

This means that LTS chapters and Technoscience chapters, although providing a valuable contribution to the STEM learning ecosystem, have been purposefully excluded due to their organizational structure of volunteer-led chapters that are connected to a university but not directly linked to its operations. Excluding LTS and Technoscience, the number of university-based SOUs for Phase 1 was 80. Figure 10 illustrates the distribution of the 80 SOUs across 52 public universities in Canada.
RQ 1 - What are the Organizational Features of STEM Outreach Units in Canada?

The following sections combine results from Phase 1 of this study to answer the first research question: providing details about the various types of university-based SOUs in Canada and their organizational features. A series of sub-questions, Figures, and Tables are used to provide well-rounded insight to research question one.

STEM Outreach Units' Mission Statements or Objectives

An initial scan of the outreach units' websites in Phase 1 revealed that 15 of the 80 SOUs had explicit mission statements, meaning the SOU specifically identifies their mission statement on their websites. One example of a formal/explicit mission statement is:

“to provide experiential opportunities for pre-university students to learn about engineering, with an additional focus on increasing diversity within the engineering profession; [to] develop and share quality engineering education tasks that align with the
Ontario K-12 Curriculum; [to] provide support and professional development opportunities for educators looking to integrate engineering and 21st-century skills into their practice; [and to] develop positive relationships between the FEAS and the community” (SOU # 27).

Twenty of the SOUs' websites (25%) did not explicitly describe a mission statement but did provide their general purposes, such as: “We envision the youth of Manitoba inspired and empowered by the possibilities of science, engineering, and technology. We envision a Manitoba where all youth, regardless of background, gender, or socioeconomic status are enriched in their science, math, and technology education” (SOU # 25). The remaining 34 SOUs (43%) had non-explicit mission statements but revealed information regarding their objectives, role, initiatives, target audience, reach, and more in sections such as the About Us, or similar (Objectives, Program Goals, or Overview). Overall, Figure 11 displays the most used words based on frequency count for all statements in Phase 1.

Figure 11

Common Words describing STEM Outreach Units Mission Statements

With the purpose of this study being to explore K-12 STEM learning ecosystems, only 20 of the included SOUs mission statements in Phase 1 (25%) mentioned any sort of partnership. Of
the 17 (85%) that did, these SOUs mention partnerships with a specific school, community, or their host university. It should be noted, however, that many of these organizations take on the name of their hosting university (e.g., Science Outreach [University X]), and it is therefore implied they are representing the university. Additionally, in looking at the types of initiatives offered within the Phase 1 data, 45 of SOUs (56%) offer in-class workshops to a K-12 student body, which implies a partnership with specific schools, collection of schools, or larger, a school board, hence it may not be explicitly stated in the mission.

**Intended Target Audiences of STEM Outreach**

The websites of the SOUs alluded to a variety of target audiences either by directly stating them or implying them in the descriptions of their initiatives. The target audience descriptors found on the websites were then grouped into the following categories: K-12 students, educators, the public, parents, and specific target audiences such as girls, Indigenous youth, and at-risk youth. Each SOU may target different groups at the same time, for example, K-12 students and educators, meaning the total number of audiences will exceed the 80 SOUs that were studied. Table 9 provides a summary of the target audiences for the 80 SOUs in Phase 1.
Table 9

The Distribution of Phase 1 Target Audiences of the STEM Outreach Units

<table>
<thead>
<tr>
<th>Target Audience</th>
<th>Frequency (n = 80)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-12 students</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elementary (K – Gr. 8)</td>
<td>16</td>
<td>20%</td>
</tr>
<tr>
<td>Secondary (Gr 9. – Gr. 12)</td>
<td>7</td>
<td>9%</td>
</tr>
<tr>
<td>Elementary &amp; Secondary (K – Gr. 12)</td>
<td>40</td>
<td>50%</td>
</tr>
<tr>
<td>Educators</td>
<td>16</td>
<td>20%</td>
</tr>
<tr>
<td>Greater Public (adults + children, families)</td>
<td>13</td>
<td>16%</td>
</tr>
<tr>
<td>Parents</td>
<td>3</td>
<td>4%</td>
</tr>
<tr>
<td>Specific Target Audiences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At-risk Youth/ Low SES Youth</td>
<td>4</td>
<td>5%</td>
</tr>
<tr>
<td>Indigenous Youth</td>
<td>9</td>
<td>11%</td>
</tr>
<tr>
<td>Girls</td>
<td>7</td>
<td>9%</td>
</tr>
<tr>
<td>Not available on the website</td>
<td>5</td>
<td>5%</td>
</tr>
</tbody>
</table>

Types of Initiatives STEM Outreach Units Offer

To achieve their mission, STEM outreach units are engaged in a range of activities such as in-class workshops, after-school programs, professional development opportunities, school-break camps, community events, and others. Based on the results from Phase 1 (Table 10), outreach units hosted, on average, three different types of initiatives. Again, knowing the overall aim of SOUs the majority of the 80 SOUs in Phase 1 offer school break programs (63%), in-class workshops (56%), as well as after-school programs (41%), and community events (43%).
### Table 10

**Phase 1 Types of Initiatives and their Frequency in STEM Outreach Units**

<table>
<thead>
<tr>
<th>Type of Initiative</th>
<th>Frequency (n = 80)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Camps/ Holiday Camps/ PD Workshops</td>
<td>50</td>
<td>63%</td>
</tr>
<tr>
<td>Workshops (Formal in-class experiences)</td>
<td>45</td>
<td>56%</td>
</tr>
<tr>
<td>After-School Programs (Weekdays/Weekends/Girl Guides/Boy Scouts [&amp; similar])</td>
<td>33</td>
<td>41%</td>
</tr>
<tr>
<td>Community Events/ Demonstrations</td>
<td>34</td>
<td>43%</td>
</tr>
<tr>
<td>Conferences/ Public Lectures/ Conventions/ Fairs/ Open Houses/ Seminars/ Forums/ Podcasts</td>
<td>19</td>
<td>24%</td>
</tr>
<tr>
<td>Competitions</td>
<td>16</td>
<td>20%</td>
</tr>
<tr>
<td>Professional Development (for Educators)</td>
<td>8</td>
<td>10%</td>
</tr>
<tr>
<td>Other (Birthdays/ Volunteer /Summer Jobs/School Co-Op)</td>
<td>9</td>
<td>11%</td>
</tr>
<tr>
<td>Tutoring/ Mentoring/ Leadership Training</td>
<td>4</td>
<td>5%</td>
</tr>
</tbody>
</table>

The identified types of initiatives offered by SOUs are unique in the sense that outreach units are the primary group to deliver such services, meaning that it is not common for schools to run their summer camps or after-school programs employing their staff. It is also worth noting that these initiatives may range in their formality, which is often tied to how closely an activity is related to the overall expectations and goals of a provincial curriculum. In this study, in-class workshops, whereby the STEM outreach unit visits a school, or the class visits the university on-site, were considered formal initiatives, whereas school-break camps and after-school programs were considered informal. In-class workshops are offered through the school year, in which teachers are looking to fulfill curriculum expectations that can be met through certain outreach programming, whereas in the summer months, summer camps are not monitored by a larger educational expectation and can be flexible in their content delivery making them more informal.
These informal initiatives, such as camps and after-school clubs, also vary in the types of staff that are facilitating the activity.

After-school programs are unique because some programs already presented themselves as having some sort of partnership outside of the SOU. For example, 19 of the 80 Phase 1 SOUs (or 25%) are partnered with the Ontario Network for Women in Engineering (ONWiE) to deliver one or all partner events or other community partners such as Boy Scouts, the Boys and Girls Club of Canada, or First Lego Leagues. Only 10% of the Phase 1 SOUs offered professional development to educators, a ratio that is worth investigating further as teachers can have more of an ongoing influence on students’ perceptions and motivation regarding STEM subjects and careers than a one-time in-class workshop.

**STEM Outreach Units’ Staffing Capacity**

The capacity, represented by the number of staff personnel and their roles, of an outreach organization was determined by investigating the “About Us,” “Our Team,” or tabs of similar information in Phase 1. Upon investigation, it was found that 23 of the Phase 1 SOUs (28%) listed both full-time staff and students working for the SOU but did not provide information on their roles. Eleven of the SOUs (14%) did not specifically mention staffing capacity but provided at least one contact person which could indicate they were a staff member. Forty-six of SOUs (58%) did not list any staff employees on their websites.

**STEM Outreach Units Financial Resources**

The sources of funding for SOUs were challenging to collect and analyze from publicly available information featured on the SOU websites. It should be noted that each SOU may have multiple sources of funding; for example, an SOU can have self-generated revenue, and university support, while also receiving grants from the government or foundations.

SOUs in Phase 1 provide school-break camps or formal in-class workshops that follow a provincial curriculum, and as such were assumed to have self-generated funds as a source of funding (76%). Interestingly, 29 of the SOUs (36%) specifically acknowledged their host
university or department as a source of funding but it is unknown if this includes any in-kind contributions such as office space or administrative help. Another source of widely used funding for 26 SOUs (33%) was Actua, a national leader in STEM education outreach, who acts as a funder to many STEM outreach units across the country.

Based on the analysis of universities that have more than one SOU within a given institution, it appears from the website analysis that Actua is a funder with only one SOU for a given university, implying that it does not fund multiple units at the same institution. Adding to the complexity of funders are the various STEM-related industries and businesses. For those SOUs that were identified as being funded by Actua, it appears that several STEM-related industries/businesses are funders of Actua, to which Actua brokers these funds to its members, and are therefore indirect funders of 26 SOUs (or 33%). Separate to the industries and businesses that are linked to Actua, an additional 26 SOUs in Phase 1 (33%) appear to have at least one other STEM-related business or industry partner as a funder. Federal grants from the Natural Science and Engineering Research Council (NSERC) were also found to contribute to 19% of the Phase 1 SOUs funding. On the other hand, provincial funding was not as widely available. It is worth noting, however, as will be discussed within partnerships, the extent to which funding is provided will vary on a case-by-case basis and is influenced by other factors such as the scope, geographical location, the complexity of initiatives offered, size, and quality of employees, STEM industry/business return on financial support, etc.

**Evaluating STEM Outreach Units’ Programs and Overall Impact**

As a reminder, evaluation in the context of this study refers to the systematic assessment of the design, implementation, or results of an SOU initiative for learning or decision-making (Canadian Evaluation Society, 2015), and impact refers to the intended and unintended, direct, and indirect outcomes produced by the SOU initiative. Typically, outcomes are classified as short or medium-term and could include changes to students’ STEM knowledge, skills, and capacities because they participate in the outreach initiative. The data around program evaluation or impact
was difficult to extract from the publicly available SOUs websites in Phase 1, as some of them offered testimonial statements from target audiences but no annual impact report. After an initial scan, it was decided that exploring this organizational feature should be done through semi-structured discussion in Phase 3.

**RQ 2 - How are STEM Outreach Units Involved in a K-12 Learning Ecosystem?**

The concept of a K-12 STEM learning ecosystem refers to harnessing the unique contributions of both formal (in-school) and informal (out-of-school) learning opportunities, provided in collaboration by various groups, in multiple settings, to enable young people to become engaged, knowledgeable, and skilled in STEM. This section combines the findings from Phases 1 to answer the second research question exploring the conceptualization of STEM learning ecosystems from the perspective of university-based SOUs, and their potential role as knowledge brokers within them.

**Partners of STEM Outreach Units within a STEM Learning Ecosystem**

Partnerships refer to the groups within a K-12 STEM learning ecosystem who collaborate with SOUs to deliver in-person STEM learning opportunities and have a direct influence on the ecosystem. The groups identified as potential partners within a K-12 STEM learning ecosystem have been previously presented in the conceptual framework (Figure 7). SOU partnerships were difficult to capture from publicly available information from the Phase 1 SOUs websites. One of the main reasons was the overlap in other organizational feature categories such as stakeholders.

The website analysis of the 80 SOUs revealed the most common partnership is with schools, which is not surprising, as many of the SOUs provided formal in-class workshops (53%). The second most common partnership was with the charity/non-profit STEM business category including foundations, as this includes partnerships with businesses such as Actua or Let’s Talk Science (40%), both appearing to have a role within the larger K-12 STEM learning ecosystem. STEM industry was the third-highest partnership grouping (35%), but, as previously mentioned
and similarly to the government partnerships identified (19%), it was unclear from the websites as to whether industry partners are better described as a funder without any involvement with the SOU. Regardless, 28 of SOUs (or 35%) appear to be connected to STEM-related industries from within their local ecosystem, as well as government funders. The next most frequent grouping of partnerships is between the identified SOUs and other STEM units within their institution, to share knowledge, resources, personnel, and more. In this case, it was found that 22 SOUs (or 28%) had formed partnerships with other STEM units in their institution such as the Women in Science and Engineering (WiSE), Let’s Talk Science, and Engineers without Borders.

According to the websites explored in Phase 1, the least common types of partnerships for SOUs within a K-12 STEM learning ecosystem include community-based organizations, partnerships with educators, and partnerships with parents. The breakdown of SOUs partnerships for each respective grouping are as follows: community-based organizations such as the Boys and Girls Club and Girl Guides (13%), museum/science center (10%), and public libraries (1%). It is worth noting that both educators and parents were not identified as partners. These partnerships, although less frequent, based on the website data extraction, might be of high importance for understanding the K-12 STEM learning ecosystem approach. This is because educators and parents are identified as target audiences, whereas community settings are most often accessible and low-cost services used by a diverse group of community members. At this point, it is important to remember that this partnership data describes only the information available on the website as 16 SOUs (20%) did not provide any information about partners. The website data was a good starting point for mapping the landscape of SOU STEM outreach. Depth and detail, and perhaps further clarification come from the data obtained in phases 2 and 3.
Chapter 5

Findings – Phase 2: Online Survey

Phase 2 built on information obtained in Phase 1, with the intent of further exploring the landscape of university-based STEM outreach units across Canada to provide preliminary insight on the conceptualization of K-12 STEM learning ecosystems and SOUs as knowledge brokers within them. Two inclusion criteria were implemented in Phase 2: Only the 80 university-based K-12 SOUs that were included in Phase 1, and of those, only those SOUs which appear from their website analysis to partner with at least two other STEM education stakeholder groups within their local ecosystem. After applying these two inclusion criteria, the maximum number of university-based SOUs included for further analysis in Phase 2 was 70.

Of the possible SOUs who met these inclusion criteria, 34 (49%) responded to the recruitment email, signed the consent forms, and initiated the online survey. Of those, 25 (36% of the possible 70) were selected for further analysis in Phase 2 as nine of the survey responses were removed from the sample due to incompletion as the participants had responded to less than 30% of the survey questions. It is also important to note that the SOU directly linked to the researcher was included in this sample, but the outreach lead completed the survey on behalf of the SOU. Within the final Phase 2 sample of 25 SOUs, there was a geographical representation from most provinces in Canada as shown in Table 11.
Table 11

Geographical distribution of the number of SOU participants in Phase 2

<table>
<thead>
<tr>
<th>Province</th>
<th>SOUs in Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>5</td>
</tr>
<tr>
<td>Alberta</td>
<td>3</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>2</td>
</tr>
<tr>
<td>Manitoba</td>
<td>2</td>
</tr>
<tr>
<td>Ontario</td>
<td>7</td>
</tr>
<tr>
<td>Quebec</td>
<td>2</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>1</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>2</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>0</td>
</tr>
<tr>
<td>Nfld. &amp; Labrador</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25</strong></td>
</tr>
</tbody>
</table>

The following sections combine results from Phase 2 of this study to explore the research questions, providing details about the organizational features of university-based SOUs in Canada, their partners within an ecosystem, and preliminary views on knowledge brokering.

RQ 1 - What are the Organizational Features of STEM Outreach Units in Canada?

A series of sub-questions, Figures, Tables, descriptive statistics, and qualitative quotes are used to provide well-rounded insight to unpack each research question.

**STEM Outreach Units' Mission Statements or Objectives**

In Phase 2, 11 of the 25 (44%) SOUs provided formal/explicit mission statements that matched the statements found on their websites. The remaining 14 SOUs (56%) provided either a
formal/explicit statement or a general objectives statement that was not included or different from what was on their website. It must be noted that all 25 statements, regardless of whether they were formal mission statements or not, were analyzed for their meaning. Moving forward, these statements, again, formal, or informal will be identified as mission statements. Following a review of all the mission statements, Table 12 describes the broad categories identified in Phase 2 to describe the various goals of an organization.

**Table 12**

*Phase 2 - STEM Outreach Mission Statement Categories*

<table>
<thead>
<tr>
<th>Mission Category</th>
<th>Description</th>
<th>Frequency (/25)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEM Enrichment/Spark STEM Curiosity</td>
<td>Encourage STEM curiosity/excitement or enrich STEM content</td>
<td>21</td>
<td>84%</td>
</tr>
<tr>
<td>Support Equity, Diversity, and Inclusivity</td>
<td>Areas of equality, diversity, inclusion, Indigeneity (EDI)</td>
<td>10</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>with target groups such as girls, at-risk youth, low-socioeconomic youth, and people of color</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involve the Community</td>
<td>Whether a community approach or initiative was taken by the organization, listed again either specifically (e.g. city, region, etc.), or in general</td>
<td>10</td>
<td>40%</td>
</tr>
<tr>
<td>Develop Learning Skills and Work Habits</td>
<td>Developed non-subject bound skills, such as creativity, communication, and collaboration that are often described as 21st-century competencies</td>
<td>9</td>
<td>36%</td>
</tr>
<tr>
<td>Promote STEM Careers &amp; Real-World Applications</td>
<td>Organizations develop connections to society (e.g. careers within STEM fields) or applications to life outside of school</td>
<td>7</td>
<td>28%</td>
</tr>
<tr>
<td>Mental Health</td>
<td>Wellness and mental health considerations</td>
<td>2</td>
<td>8%</td>
</tr>
</tbody>
</table>
Recruit to Affiliate University
Recruitment (i.e. seeking students for admissions into the affiliated university) 2 8%

Develop Partnerships
Partnerships, particularly if any partners were mentioned by name (e.g. Actua) or in general 2 8%

Other
Other areas include revenue-generating operations, global issues, or environmental issues 2 8%

In addition to their mission statements, SOUs in Phase 2 were asked to identify other priority areas. Once again, responses were reviewed to establish broad categories. Categories included the same ones listed above for mission statements, but with the addition of informing policy, engaging parents and educators, providing access to STEM activities and knowledge, and providing employment opportunities. The most common secondary focus of STEM outreach organizations, as indicated by 9 Phase 2 SOUs (36%), was to increase the accessibility of STEM education to underrepresented youth, specifically Indigenous, at-risk youth, girls, and women.

In looking for alignment between the Phase 1 website data and the Phase 2 survey data in terms of SOUs’ mission statements, the general SOU mission was determined to be: to promote the field of science and technology to the youth of a particular community. Many of the SOUs aims to promote, provide, engage, or make accessible, various aspects relating to STEM. The acronym STEAM, which adds the Arts discipline, into STEM was not found amongst mission or descriptive statements. Likewise, the acronym STEM, however, is scarcely used in mission statements and is instead replaced by listing one or two of the four interrelated fields. This is perhaps because STEM, for those audiences such as students and parents that are not working or experienced in the field of STEM or education, is likely not a commonly used acronym and therefore is omitted from mission or descriptive statements. Some organizations also make
explicit the development of foundational intra- and interpersonal competencies/ 21st Century skills, including teamwork, leadership, lifelong learning, critical thinking, and science literacy.

**Intended Target Audiences of STEM Outreach**

In Phase 2, participants identified their target audiences and ranked them based on their level of influence (Table 13).

**Table 13**

*Phase 2 Target Audience Frequency and their Influential Ranking*

<table>
<thead>
<tr>
<th>Target Audience</th>
<th>Frequency (25)</th>
<th>Percentage (%)</th>
<th>Ranking Based on Frequency</th>
<th>Ranking Based on Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-12 Students</td>
<td>24</td>
<td>96%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Underrepresented Youth</td>
<td>22</td>
<td>88%</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Community Groups</td>
<td>18</td>
<td>72%</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>In-service Teachers</td>
<td>16</td>
<td>64%</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>K-12 Schools</td>
<td>16</td>
<td>64%</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Pre-service Teachers</td>
<td>16</td>
<td>64%</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Parents &amp; Guardians</td>
<td>13</td>
<td>52%</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>School Boards</td>
<td>5</td>
<td>20%</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Administrators</td>
<td>4</td>
<td>16%</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>12%</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Overall, SOUs targeted on average five-six diverse audience groups. Twenty-four SOUs (96%) indicated that the K-12 student population was both the most prominent target audience, as well as the audience with the highest influence. Following K-12 students, the next grouping of four target audiences indicated by the 25 SOUs in Phase 2 included the community (72%), followed by both in-service and pre-service teachers, and K-12 schools, all of which had the same frequency (64%). The ranked order of influence within these four target audiences indicates that in-service teachers were found to be most influential compared to pre-service teachers, but the
difference between the groupings was minor. Finally, the target audiences that received the least amount of attention from the Phase 2 SOUs included parents and guardians (52%), school boards (20%), and then the individuals of senior leadership at schools (16%). There is a displacement of parents and guardians when comparing their role as stakeholders versus target audiences that requires further analysis given that parents and guardians are often considered to have a large influence on their child’s life, and in part, their child’s academic and career choices.

**Important Stakeholders of STEM Outreach Units**

Stakeholders refer to the groups or individuals that have a vested interest in the program and can directly or indirectly influence the overall K-12 STEM learning ecosystem (Alkin, 2011). For the SOUs in this study, the various groups included within a K-12 STEM learning ecosystem (Figure 7) could be primary, secondary, and tertiary levels of stakeholders. Within Phase 1, it was challenging for the websites to determine which groups are stakeholders, which are partners, and which are both. Due to the ambiguous nature of information found on stakeholders solely from SOUs websites, SOU stakeholders were further explored in Phase 2.

In Phase 2, the survey respondents were asked to identify stakeholders of their SOU based on the list of possible stakeholders mentioned above. A summary of the stakeholder frequency, ranking based on that frequency, and ranking based on the overall influence of the SOU is shown in Table 14.
Table 14

*Summary of Phase 2 Stakeholder Frequency and their Influential Ranking*

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Frequency of Stakeholders (/25)</th>
<th>Percentage (%)</th>
<th>Ranking of Stakeholders by Frequency</th>
<th>Ranking of Stakeholders by Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affiliate University</td>
<td>24</td>
<td>96%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>K-12 Students</td>
<td>20</td>
<td>80%</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>K-12 Schools</td>
<td>19</td>
<td>76%</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Community Groups</td>
<td>19</td>
<td>76%</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Parents/Guardians</td>
<td>18</td>
<td>72%</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>K-12 Educators</td>
<td>15</td>
<td>60%</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Fed. Government</td>
<td>14</td>
<td>56%</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>STEM Businesses &amp; Industries</td>
<td>11</td>
<td>44%</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Prov. Government</td>
<td>8</td>
<td>32%</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>16%</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Overall, the average number of stakeholders per SOU was approximately six. Although the stakeholder ranking based on SOU influence does not explicitly ask if each stakeholder is primary, one could suggest that the affiliated university, K-12 students, and their parents are primary stakeholders. One area that is worth investigating further is the distinction among stakeholders and funders and reasons why the government and STEM-related business/industry are not being identified as prominent stakeholders despite being key players in acquiring funding for initiatives (e.g., Actua, Google, RBC, Shopify, and Shell) and contributing towards the growth of SOUs over the last five years.

Participants ranked their stakeholders based on the level of influence each group had on the organization. For example, if an organization identified five stakeholders, they would then assign rankings using the numbers one through five for each stakeholder, whereby the number one indicated that this stakeholder had the most influence. The top two most influential
stakeholders were identified as the affiliated university or faculty/department, followed by K-12 students. In this case, parents/guardians were ranked the third highest in terms of stakeholder influence which is interesting given that they were ranked fifth in terms of frequency, meaning that their opinion is valued much higher despite their low presence. On the contrary, community groups, identified as the third most common stakeholder dropped to sixth place in terms of the level of influence despite their larger involvement, suggesting they are secondary or tertiary stakeholders. Groups that were determined to have the least amount of influence were the federal government, the provincial government, and STEM-related businesses. This result suggests that SOUs consider these groups as tertiary funding stakeholders and are less involved in the operations of the SOU.

**STEM outreach units' staffing capacity**

Within Phase 2, the staffing density of the 25 SOUs was determined by the number of staff, the roles they have within the organization, and their SOUs' financial resources. Staff members were grouped into four broad categories including full-time staff working 35-40 hours/week, part-time staff working 10-20 hours/week, casual staff working less than 10 hours/week, and summer students working 35-40 hours/week throughout the university summer break (Table 15).
Table 15

Summary of Frequency of Staffing Types versus STEM Outreach Units Size

<table>
<thead>
<tr>
<th></th>
<th>Full-time (35-40 hours/week)</th>
<th>Part-time (10-20 hours/week)</th>
<th>Casual (less than 10 hours/week)</th>
<th>Summer students (35-40 hours/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don’t have staff within the role type (0 people)</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Small (1-3 people)</td>
<td>16</td>
<td>10</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Mid-sized (4-7 people)</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Large (8+people)</td>
<td>1</td>
<td>7</td>
<td>9</td>
<td>18</td>
</tr>
</tbody>
</table>

Sixteen of the Phase 2 SOUs (64%) were small, with few full-time professional staff. Only 1 of 25 organizations in Phase 2 had eight or more full-time staff members. When looking at staffing altogether, university students make up the bulk of the team. Perhaps this is because the SOUs operate from within the affiliated university and in turn have access to a diverse student body who are seeking employment both during and outside their academic year. This staffing format may suggest there are transient workers within the SOU.

Full-time staff described their various roles and responsibilities. Of the roles described by the Phase 2 participants, the most common role is a director or manager (60%). After hiring a director or manager, a secondary common position was to hire delivery coordinator(s) (56%) and/or a programming manager(s) (48%). Within these roles, the job descriptions appear to be similar or even equivalent to each other, but the terminology used may vary based on the university. For example, a program coordinator at one institution might have similar responsibilities to a program manager at another institution. After the top three roles, all other positions' job descriptions became more specific and were much less common across SOUs. Examples of positions as described by the 25 Phase 2 SOUs include a logistics and administrative assistants to help with workshop bookings and finances (32%), team lead (32%), a community
relation to help with engaging community groups (32%), and a communications specialist to help
with social media and marketing (12%). Overall, SOUs employed, on average, about 2-3 different
full-time and professional staff. Within each SOU, there may be multiple staff in the same role
but working on separate projects.

**STEM Outreach Units Financial Resources**

In Phase 2, the 25 SOUs were asked to identify the sources of funding that contribute to
their annual operating budget. Table 16 illustrates the various sources of SOU funding, the
frequency of the source, as well as the percent of SOUs that indicated this revenue source.

**Table 16**

*Phase 2 STEM Outreach Units Sources of Funding*

<table>
<thead>
<tr>
<th>Sources of Funding</th>
<th>Frequency Count (/25)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-generated</td>
<td>22</td>
<td>88%</td>
</tr>
<tr>
<td>Federal Government</td>
<td>20</td>
<td>80%</td>
</tr>
<tr>
<td>Foundations</td>
<td>20</td>
<td>80%</td>
</tr>
<tr>
<td>Affiliate University/ Faculty/ Department</td>
<td>18</td>
<td>72%</td>
</tr>
<tr>
<td>STEM-related Businesses &amp; Industries</td>
<td>15</td>
<td>60%</td>
</tr>
<tr>
<td>Provincial Government</td>
<td>12</td>
<td>48%</td>
</tr>
<tr>
<td>Private Donations</td>
<td>12</td>
<td>48%</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>12%</td>
</tr>
</tbody>
</table>

On average, the SOUs have approximately five different types of funding sources. Based
on the weighting of these funding sources, 22 of the SOUs highlighted that self-generated funding
accounts for on average 44% of their annual operating budget. However, taking the average of all
the SOU percent distributions per funding source potentially leads to a false representation as
some SOUs are 90 - 100% self-generating, whereas others are 20% self-generating. This implies
that some SOUs rely heavily on external sources of funding such as foundations, grants, and
donations. On average, foundations contributed approximately 15% and federal government
grants contributed approximately 10% to SOUs budget. Less prominent sources included private donations (5%), provincial government (6%), and other (5%).

**Annual Operating Budgets of STEM Outreach Units**

In Phase 2, the 25 SOUs identified which binned category most closely represented their SOUs' annual operating budget. The binned categories ranged from under $150,000 to over $1,000,000, grouping them into $150,000 increments (Figure 12).

**Figure 12**

*STEM Outreach Units in Phase 2 Annual Operating Budget*

![Bar chart showing distribution of operating budgets across 25 SOUs in Phase 2, binned into $150,000 increments.]

*Note.* This figure illustrates the distribution of the operating budgets across 25 SOUs in Phase 2, binned into $150,000 increments.

When further grouping the binned categories into three regions (low represents $0-$300,000, mid-level represented $300,000-$750,000, and high represented $750,000 and above) it is clear the bulk of these SOUs have the mid-level budget (48%), followed by low-level budget (36%), and most rare, high budget (16%). SOUs that operated with the highest budget is also located within a large university-based student population and are within a large urban center.

Furthermore, these four highly funded SOUs have more potential capacity for outreach due to having multiple full-time and professional staff roles including a director/manager, program
delivery coordinator, programming manager, administrative assistant, team lead, and volunteer supervisor, as well as large numbers of staff in part-time, casual, and summer staff positions.

**Growth of STEM Outreach Units Over Five Years**

As a follow-up to the SOUs operating budget and to complete the staffing capacity section, the participants described if/how their SOU staffing has changed over the past five years. Twenty-two of 25 of the Phase 2 SOUs (88%) identified there was an increase in their efforts whereas two identified a decrease, and one identified no change. The SOUs were then encouraged to attribute their described change to a single or variety of factors. The four most common changes were the hiring of full-time staff (52%), hiring more student staff (40%), an increase in quality outreach program offerings (40%), and an increase in funding (36%). The increase of funding supports the Phase 2 data, which suggests the growth of the SOUs' staff capacity.

In Phase 2, the SOUs recognized the value of having full-time staff members who are both dedicated to outreach and committed to the team for several years. For example, SOU #1 stated that “adding full-time position dedicated solely to outreach has been the driving force [in the growth of the program].” Similarly, another SOU (#73) suggested: “careful financial management has allowed for hiring [of] more full-time, year-round staff for sustainable delivery.” With more full-time staff members, operations can run throughout the year, extending beyond the popular summer break programming or after-school programming. When it came to providing quality programming, one SOU in Saskatchewan stated they “review all of [their] camps and have made significant changes in response to changing market conditions” (SOU #22). Some organizations touched on the ability to target and engage with new audiences, such as educators or Indigenous communities. Finally, some organizations attributed their growth to new funding opportunities from larger grants provided by Actua, CanCode, or PromoScience. Ultimately, it is likely that from the funding, SOUs were able to target other aspects within their organization such as staff, hiring, programming, space, and marketing.

**Facilitators and Challenges of Delivering STEM Outreach**
Participants in Phase 2 were asked the open-ended question to identify three facilitators and barriers when delivering STEM outreach, which was coded into a broad set of categories. Of the outreach facilitators provided in the responses, the most common was the ability to provide varied, engaging, and accessible STEM outreach initiatives (44%). Second, SOUs shared that they have been recognized by providing such initiatives to students, parents, and community members and that it allowed for relationships (40%) to be fostered between partners. For example, SOU # 4 stated that by providing “multiple ways of presenting content such as in-school clubs, summer camps, Saturday camps, special events, you can reach the children where they are.” Similarly, SOU # 20 stated that “being extraordinarily flexible in [their] delivery modeling, allowing [them] to build programming that fills needs in the community.” Many of these partnerships were with schools and community groups or members within which initiatives were nested. For example, SOU # 73 suggested that “establishing personal relationships with community leaders and organizers is very important. It means that you have a point of contact who knows the value of the program. Meeting these contacts in person if possible is a great strategy.” The third facilitator was attributed to the supportive and talented staff, full-time and student staff, who provided outreach initiatives (32%). Some groups emphasized the role of having long-term full-time staff acting as a facilitator. For example, SOU # 39 stated that they have a “really strong team that has been with the organization for several years”; which is supported by SOU # 73 that recognized the value of full-time staff members saying that “having a great team who are aware of the roles and responsibilities of delivering outreach is key. It means that they can organize and deal with anything that comes up that could potentially be a barrier to delivery.” The remaining categories of facilitators to STEM outreach included a low cost to the target audience (16%), established logistics and operations (12%), and being the only STEM outreach group in the community (12%).

When identifying three barriers in delivering STEM outreach, the broad barriers included: funding, time, staffing and hiring, demand, operations and logistics, space, language,
marketing, transportation, and community partnership development. The most common barrier identified by the 25 Phase 2 SOUs was funding (68%). A lack of funding seemed to be the gateway for other limitations including staffing, resources, to decision-making between free programming and paid programming. For example, one SOU spoke about doing their “best to offer as many programs as possible for free, but [that] schools find even [their] low workshop rates [...] challenging” (SOU # 73). This same SOU hopes that more funding will be able to increase the chances of offering free in-class workshops. On the other hand, SOU # 24 stated that cost affects “the ability of staff training to do outreach,” which is supported by SOU # 4 who mentioned that there is “uncertainty related to budget due to government changes and government priorities, [that] if there is no money to cover costs, there is no programming.” Other organizations also mentioned the idea of minimal funding at the provincial level to support individual schools and school boards, which limits their access to STEM outreach opportunities.

The second most common barrier was staffing (48%). Within this barrier, SOUs mentioned the difficulty in depending on student staff. For example, SOU # 1 states that “using student staff for delivery is challenging during the academic year.” One SOU highlighted that despite their use of students as staff members, that students “do not speak French and [that] this is a definite barrier in [their] city as it limits the reach to English schools or French schools specifically requesting an English presentation. Being an English university, [...] students are not fluent in French while the local community and especially the population in under-served communities are French-speaking Canadians” (SOU # 65). Other SOUs spoke of the unique position they have within the institution in that it can be difficult to find staff with educational, outreach, technical STEM knowledge, and experience to fill the roles. SOU # 39 stated that:

*It is difficult to find people with the right set of skills to manage and coordinate outreach programs. The size of most outreach organizations is small, which often requires people who have very general experience. On top of this, the content being delivered is STEM-based and requires people who have a background in education and/or STEM to oversee those programs to ensure innovative and impactful content. The pool of potential candidates is often small, and for our organization, we also need to add bilingualism.*
The third most common barrier involved transportation (24%). Many of the SOUs deliver programs to target audiences outside of the campus and therefore depend on renting cars, and in some cases traveling by plane to reach specific target audiences. This was an issue for remote outreach organizations. SOU # 15 mentioned that “[they] run extensive after-school clubs within an hour drive of the University. We are dependent on staff who can drive and/or have access to a vehicle.” The remaining categories of barriers to STEM outreach delivery included space on campus to run events (20%), established logistics and operations (20%), marketing and communication (20%), and time to deliver workshops (12%).

RQ 2 - How are STEM Outreach Units Involved in a K-12 Learning Ecosystem?

The concept of a K-12 STEM learning ecosystem refers to harnessing the unique contributions of both formal (in-school) and informal (out-of-school) learning opportunities, provided in collaboration by various groups, in multiple settings, to enable young people to become engaged, knowledgeable, and skilled in STEM. The following sub-sections combine the findings from Phases 2 to explore the conceptualization of STEM learning ecosystems from the perspective of university-based SOUs.

Partners of STEM Outreach Units within a STEM Learning Ecosystem

Partnerships refer to the groups within a K-12 STEM learning ecosystem who collaborate with SOUs to deliver in-person STEM learning opportunities and have a direct influence on the ecosystem. Using the same groupings of partnership categories from Phase 1, the survey participants in Phase 2 further indicated who they partner with (Table 17).
Table 17

Phase 2 K-12 STEM Learning Ecosystem Partners

<table>
<thead>
<tr>
<th>Partner</th>
<th>Frequency Count (/25)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-12 Schools/Teachers</td>
<td>21</td>
<td>84%</td>
</tr>
<tr>
<td>Community Groups</td>
<td>20</td>
<td>80%</td>
</tr>
<tr>
<td>Libraries</td>
<td>16</td>
<td>64%</td>
</tr>
<tr>
<td>Internal STEM Outreach Organizations</td>
<td>15</td>
<td>60%</td>
</tr>
<tr>
<td>After School Programs</td>
<td>11</td>
<td>44%</td>
</tr>
<tr>
<td>Industries &amp; Businesses</td>
<td>10</td>
<td>40%</td>
</tr>
<tr>
<td>External STEM Outreach Organizations</td>
<td>9</td>
<td>36%</td>
</tr>
<tr>
<td>Science Centers</td>
<td>8</td>
<td>32%</td>
</tr>
<tr>
<td>Parents &amp; Guardians</td>
<td>8</td>
<td>32%</td>
</tr>
<tr>
<td>Museums</td>
<td>6</td>
<td>24%</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>20%</td>
</tr>
</tbody>
</table>

Similar to Phase 1, the most frequent partnership reported in the 25 Phase 2 survey responses, was between the SOUs and K-12 schools/teachers for in-class initiatives (84%). This is supported by one SOU (# 39), who suggested “partners have been instrumental in making things happen. School boards have been good because they are already connected to their educators and their students. If you get them on board, they can do a lot of the work for you that, historically, you’d be doing yourself.” Similarly, another SOU (# 25) expanded on the importance of partnership with schools by saying “I think school partnerships may honestly be one of the most important things because it doesn’t matter how much we create or fine-tune things on our end, if we don’t have those relationships established then we just don’t have a way of accessing the youth.”

One difference between Phase 1 and Phase 2 is the percentage of SOUs who have partnerships with community groups/settings. In Phase 1, very few SOUs websites indicated partnerships with these categories; however, in Phase 2, 80% of SOUs indicated partnerships with community groups, and 64% partner with libraries. In partnering with these community groups,
SOUs reported having greater access to their prominent target audiences. The importance of partnerships with the community was very clear in Phase 3, as 9 SOUs (75%) mentioned how partnerships help achieve their mission.

**Multiple STEM Outreach Units in the Same K-12 STEM Learning Ecosystem**

Of the 25 STEM outreach organizations included in Phase 2, 20 of them (80%) identified that other STEM outreach groups exist within their local ecosystem and that they have the same target audiences. A total of 51 additional STEM-like outreach organizations (e.g., not the SOUs included within this sample) were identified by name. The most common STEM outreach organization type existing within the same ecosystem were non-profits (40%), followed by other groups within the same affiliate university (21%), and finally paid-entry services (17%). All remaining categories were less common.

Within the online survey in Phase 2, participants were asked if they have previously tried to partner with these organizations, and if so, why and to what extent. Some SOUs describe their collaboration efforts as a tool to avoid overlap in programming. For example, SOU #71 stated that “We have met with [other organizations] to collaborate and coordinate. We are a small community, so we want to make sure that we are working together or in parallel to avoid conflict and getting into each other's territories.” Similarly, SOU # 25 stated that “we sometimes meet with Let's Talk Science to discuss where their organization and ours will be delivering programs in the spring/summer, so that we avoid overlap.” In general, SOUs explained how “[they] work together with other STEM outreach organizations very well” and often take on a leadership role with these other groups:

*We have taken on the leadership role in organizing many of the inter-departmental events that bring different outreach programs together. Other groups have offered up student hours to help develop a website that will showcase outreach works across campus and not limited to the faculty of science. This is an ongoing effort. The challenge is not having one person that is dedicated to managing collaborations. Most of us are doing collaborative work off the side of our desks while trying to maintain the existing activities our outreach programs host (SOU # 9).*
Some SOUs highlighted the difficulties faced when trying to collaborate. For example, SOU # 65 emphasized that collaborating with organizations outside of the affiliated university becomes more challenging as there is not enough time or resources to expand beyond the activities they are already running. This statement is supported by another SOU, who indicated they “have made attempts, but find that the other programs that are already happening do not require assistance from us” (SOU # 24). Whereas SOU # 22 does not have partnerships because they are completely self-funded, have a small population base, and are in direct competition with other organizations chasing the same audience and funding.

RQ 3 – To what extent are STEM Outreach Units Knowledge Brokers within an Ecosystem?

The following sections combine results from Phase 2 to answer the third research question: providing details about the conceptualization of university-based SOUs as potential knowledge brokers within K-12 STEM learning ecosystems.

Similarities and Differences between STEM Outreach Units and Knowledge Brokers

In Phase 2, participants were provided with a description of a knowledge brokering process as a person or organization that facilitates the creation and sharing of knowledge and helps address knowledge gaps between at least two other parties, providing value beyond what the individual parties can do alone. SOUs were asked to identify if/how the description of a knowledge broker compares to the role of their STEM outreach unit within their K-12 STEM learning ecosystem. After reading the description, 17 of the SOUs in Phase 2 (68%) suggested that their role within the K-12 STEM ecosystem has similarities to that of a knowledge broker. One SOU stated that the concept of knowledge brokering is:

Exactly what we do and is a large part of our mandate. We actively identify and fill in some STEM education gaps in schools and with teachers by creating and sharing STEM content knowledge. With community groups, they reach out to us because they are looking for something they can’t provide themselves, so we supplement their STEM activities. This is how I see us being like a knowledge broker (SOU # 20).
**Knowledge Brokering Functions Being Used by STEM Outreach Units**

Diving deeper into the concept of STEM outreach units as knowledge brokers, Phase 2 participants were asked to identify the extent to which they use the KMb functions within their SOU. The descriptions, as well as example strategies for each of the KMb functions, were provided exactly as described in Chapter 2 (Table 7).

Overall, the Phase 2 survey results suggest that SOUs are not currently using many of the brokering functions, based on the description that was provided in the online survey (Figure 13).

**Figure 13**

*KMb Knowledge Brokering Functions used by Phase 2 SOUs*

One thing to note about the brokering descriptions used in Phase 2, which may have adversely impacted the results, were the definitions and sample strategies shared, which emphasize ‘research’ knowledge and perhaps preclude a broader definition of knowledge brokering. Also, if the concept of KMb and the terms used to describe brokering functions were new to the participants, they may not have had the time or space to consider how this concept is or is not relevant to the work they are doing. Using the Phase 2 results to inform Phase 3 and thinking about the brokering functions more broadly, it was best to remove the specific language
that highlighted research, as well as the example strategies. By doing so, the intent was that SOUs could describe if/how they use the brokering function and provide their examples.

As discussed in Chapter 3, the first unit analysis was an environmental scan of the organizational features of SOUs, followed by exploring the concept of K-12 STEM learning ecosystems and the role of SOUs as knowledge brokers within them. Chapter 4 and Chapter 5 have presented the integrated findings across Phase 1 and Phase 2 as one approach to answering the research questions. Chapter 3 also discusses a multi-case study approach, that uses individual cases as a different unit of analysis (not analyzing the results categorized by RQ’s), but still explores the research questions. Chapter 6 presents the individual case study descriptions of the SOUs in Phase 3 and Chapter 7 analyzes the findings within and across the cases, focusing on the relationships between SOUs, ecosystem partners, and knowledge brokering of twelve SOUs as individual case studies.
Chapter 6

Phase 3 – Case Study Descriptions

As a reminder, a multi-case study starts with the quintain, but to understand the phenomenon better, it is important to study some of the individual cases to understand the differences and the similarities between the cases by analyzing the data within cases and across cases (Baxter & Jack, 2008; Stake, 1995; Yin, 2003). In the context of this dissertation, the quintain is university-based SOUs within their respective K-12 STEM learning ecosystem and the potential role they may have as knowledge brokers. To explore this quintain in more detail, this chapter starts with individual case study descriptions for the SOUs in Phase 3 to provide context as to their organizational features, how they conceptualize their position within a K-12 STEM learning ecosystem, and their conceptual role as knowledge brokers. Each case includes website analysis from Phase 1, survey data from Phase 2, and interview data from Phase 3.

The only inclusion criteria for an SOU to be included in Phase 3 as a case study was, they needed to have completed the Phase 2 survey. Of the 25 SOUs in Phase 2, 12 (or 48%) directors/managers of the individual SOUs responded to the recruitment email, signed the consent forms, and completed the semi-structured interview. Within the Phase 3 sample of twelve SOUs, two were from the following provinces: British Columbia, Alberta, Saskatchewan, and Manitoba; and one from each of the following provinces: Ontario, Quebec, New Brunswick, and Nova Scotia. There was no geographical representation from Prince Edward Island or Newfound Land. Following the individual case study descriptions, this chapter provides an integration table containing extracted key information from the case study descriptions themselves as well as the Phase 3 interview data, to compare the similarities and differences across the twelve cases.
Individual Case Study Descriptions

To provide structure for each SOU case study description, a template approach (Crabtree & Miller, 1999) was used to organize the data within each case using the same four categories: 1) mission, 2) organizational capacity, 3) views on partnerships within an ecosystem, and 4) views on SOUs as knowledge brokers. When using the findings to write the descriptions, it was also important to use direct quotes from participants, whenever possible. Lastly, to maintain the anonymity of the participants as well as to have continuity from Chapter 4, the cases will be numbered based on the order as to which they were included in Phases 1 and Phase 2.

Case Study 1 (SOU # 1)

The broad mission statement for SOU # 1 is to provide youth with positive, interactive, educational, and social learning experiences that promote science, technology, teamwork, and leadership. In terms of organizational capacity, SOU # 1 operates with an annual budget in the range of $150,000 - $300,000, that is used to employ a small team of full-time staff (1 – 3 people), but a large number of casual staff (8+) during September – April, as well as a large summer student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU engages approximately 4,500 youth per year, of which, 500 can be classified as under-represented or under-serviced in STEM.

SOU # 1’s views partnerships as being important in terms of having a broader reach in trying to roll out their mission, to reach their goals, while using different resources and different strengths within their community. The director of SOU # 1 expanded on the approach to forming partnerships by suggesting they are “very relationship-based and requires a lot of time getting to know people, learn about their institutional culture or just culture in general. For us, our mission is to focus on how science is fun, taking that away from that level of fear and intimidation from STEM learning. Various partnerships may look a little bit different, but they help us to reach our goal.” Since SOU # 1 is based within a small community with not a lot of other STEM outreach
organizations and resources, they have organically formed partnerships over time with schools, students, and community groups, without realizing they have done so. Thinking more broadly about a formalized STEM learning ecosystem, the director of SOU # 1 suggested that “because we know the power of partnerships, relationships and working together, which gets us much further, a formal STEM learning ecosystem will achieve greater results and have buy-in from all partners. That said, I don't know how much different it would look on the ground.” These quotes from SOU # 1 provide evidence to suggest that they have an active approach to collaborative K-12 STEM learning ecosystems, which includes mutually beneficial partnerships with all stakeholders.

In terms of SOU # 1’s views on the conception of SOUs as knowledge brokers within an ecosystem, the director had mixed views. The director of SOU # 1 viewed the concept of knowledge brokering being similar to the role of their SOU has within their ecosystem in the following ways: 1) gaining knowledge from partner groups within the ecosystem and then sharing that knowledge over other partners, including students, 2) they fill gaps in the schools and STEM education by having their knowledge or taking knowledge from one area and providing it back to another area, 3) with teacher professional development, we can take knowledge and build confidence and skill set that they can take that into their classroom. Even though the director of SOU # 1 acknowledged similarities between SOUs and the concepts of knowledge brokering, they also mentioned that “the terminology of knowledge brokering is a bit of a weird term and it's a concept that we have never really applied to STEM before. Because K-12 STEM education has a little more fluidity and a little more of a sense of going with the flow, brokering just sounds a little bit rough.” Finally, SOU # 1 highlights the potential regarding SOUs as knowledge brokers since they actively look to gain knowledge and then pass it along to others, but the brokering term is not a word they would “instinctively gravitate towards when describing my organization.”

Case Study 2 (SOU # 4)

SOU # 4 is a student-delivered initiative of the University of [X] Faculty of Engineering
that focused on STEM fun, accessibility, and mentorship. The core objective of this SOU is to serve youth, our future leaders, by inspiring and engaging them through fun, meaningful, and accessible science, technology, engineering, and math (STEM) programs that help them overcome barriers, maximize their potential, and achieve positive life outcomes. In addition, SOU # 4 seeks to offer programs targeted at underrepresented populations in STEM, including girls and First Nations, Métis, and Inuit (FNMI) students.

In terms of organizational capacity, SOU # 4 operates with an annual budget greater than $1,000,000, which is used to employ a small team of full-time staff (1 – 3 people), 8+ part-time staff, a large number of casual staff (8+) during September – April, as well as a large summer student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU engages approximately 20 900 youth per year, of which, 10 000 can be classified as under-represented or under-serviced in STEM.

Within SOU # 4’s local ecosystem, the director disclosed that they “quite value partnerships because we understand that we are not experts in everything. Having specific partnerships, such as a contact within an Indigenous community, is super important to us as it helps with the type of stuff we want to present, but we might not necessarily be the expert in. We always look for a win-win situation in what we do.” In some instances, SOU # 4 actively seeks out partnership opportunities, but most of the time, community groups and schools typically reach out to them with the request for supplementing STEM learning opportunities. The idea of SOU # 4 ‘supplementing’ what other groups within the ecosystem are offering was highlighted several times in terms of their role, suggesting that they provide a service to others.

In terms of SOU # 4’s views on the conception of SOUs as knowledge brokers within an ecosystem, the director had positive views. “I would say that knowledge brokering defines what we do because we are supposed to be these people that come in and supplement on very specific STEM topics for these different groups. The reason why people reach out to us is that they're
looking for something specific that they can't necessarily provide themselves. So, I think that would be like the knowledge brokering idea.” Although the director of SOU # 4 expressed some relevance, they also provided some concerns with the definition and concept. For example, SOU # 4 felt that the role of a knowledge broker is to be an integrated part of the ecosystem who actively fills the knowledge gaps, whereas “since we have a financial bottom line and we need to be cost recoverable, we can’t fill all the gaps. We only work with others in the ecosystem when they approach us.” This positionality of SOU # 4 towards knowledge brokering aligns with their views on partnerships in that they look to disseminate STEM knowledge when asked for it.

**Case Study 3 (SOU # 14)**

SOU # 14 is unique in that is primarily a student-run organization but during the time of this research, was in the process of breaking away from a student group and being formally supported by its faculty who hired an outreach manager.

The broad mission statement for SOU # 14 is to spark interest and dispel stereotypes in the fields of science, engineering, and technology. We make our programs accessible to all youth regardless of gender, culture, or financial background by offering special programs and bursaries. In addition to the broad mission statement, SOU # 14 also specifies that they focus on educator professional development as well parent participation to help support STEM integration into student home life.

In terms of organizational capacity, SOU # 14 operates with an annual budget in the range of $300,000 - $450,000, that is used to employ a small team of full-time staff (1 – 3 people), but a large number of casual staff (8+) during September – April, as well as a large summer student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU engages approximately 16 800 youth per year, of which, 1 800 can be classified as under-represented or under-serviced in STEM.

The manager of SOU # 14 described partnerships as being a “central part of
accomplishing their mission. Without the help of partnerships and the relationships that we have, we probably wouldn't reach the audience that we do. We work a lot with outside organizations to identify specifically the populations that we're trying to target. When we are trying to reach indigenous populations or low-income situations, we seek out specific partnerships for that to make sure that we're reaching the right people.” The manager also admitted that since SOU # 14 has traditionally been student-run, there was not enough time or energy to put into individual partnerships, or there was just so much red tape involved with having a student-run organization working with community groups. With the transition from student-run to an embedded outreach unit with the faculty, the manager of SOU # 14 is hoping to support both the student groups and the ecosystem. For example, “a student-group could pitch us the idea and then we will give them the support to run those programs within the school or in the community. We also hope to get to a point where the community understands or recognizes the STEM programming services, we offer and that different groups can come to us with their ideas.” In summary, SOU # 14 sees the value in ecosystem partnerships as it leverages the larger audience to broaden their reach, which is important for their faculty who is “trying to provide STEM outreach programming to Indigenous students who would benefit from the learning opportunity, and support them through their education journey, and eventually help them into university.”

In terms of SOU # 14’s views on the conception of SOUs as knowledge brokers within an ecosystem, the manager suggested it is “something that we utilize a lot because they leverage the people that we know that have extensive content knowledge in specific areas such as coding, to help us facilitate or create our programming to appeal to the community that we're trying to reach.” In addition to content appealing to the community, SOU # 14 brokered knowledge by using the ‘relationships we have with different organizations to come into our summer camps to deliver programming because they're the experts in it and it would be better for students to learn from the experts.” This viewpoint on reaching out to partners and utilizing their knowledge is a big piece of what they do, recognizing that they don’t have all the educational knowledge to
develop and deliver their STEM learning opportunities. For us, “especially with the goals we have, knowledge brokering will be a key aspect to developing our new programming. The aspect of knowledge brokering is just making sure we’re correctly delivering the information while using experts in the field to make sure the knowledge is correct.”

Case Study 4 (SOU # 15)

The broad mission statement for SOU # 15 is to inspire all [geographic region] youth to explore their potential and discover their vital role in the world through life-changing science, technology, engineering, and math experiences. In addition to the broad mission statement, SOU # 15 also specifies six sub-objectives for their organization: 1) inform youth about STEM as career choices, 2) provide positive role models and dispel stereotypes associated with STEM, 3) ensure that socio-economic backgrounds do not limit youth who may participate in our programs, 4) contribute to the university's Indigenous plan, 5) introduce youth to the university environment in a non-threatening and fun manner, and 6) support teacher training for pre-service teachers.

In terms of organizational capacity, SOU # 15 operates with an annual budget in the range of $600,000 - $750,000, that is used to employ a small team of full-time staff (1 – 3 people), but a large number of casual staff (8+) during September – April, as well as a large summer student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU engages approximately 23,200 youth per year, of which, 3,700 can be classified as under-represented or under-serviced in STEM.

Within SOU # 15’s local ecosystem, the director is an active member of an advisory committee that has been working since 2019 on establishing a formalized STEM ecosystem hub that is driven by the community. As such, the director’s involvement within an emerging local ecosystem provides insight into SOU # 15’s views on partnerships. Community partners are “paramount because it’s actually what drives what we do, as our work is community-driven. Without those relationships, you really can't do that deeper type of programming, especially
when you're working with target audience groups. So, for us, those relationships that we have within the community are the only way that we really couldn't reach our mission of inspiring all youth to reach their potential.” Not only is SOU # 15 engaged in a partnership, but the director also expanded on the established positive relationships with other STEM outreach units and suggested they “look for opportunities to co-apply for funding as we have carved out a unique niche of hands-on activities delivered through barrier-breaking programs to underrepresented youth.” These quotes from SOU # 15 provide evidence to suggest that they have an active approach to collaborative K-12 STEM learning ecosystems, which includes mutually beneficial partnerships with all stakeholders.

In terms of SOU # 15’s views on the conception of SOUs as knowledge brokers within an ecosystem, the director had mixed views. Within their institution, SOU # 15 already plays a leadership role in facilitating the collaborative science outreach events and is “well-positioned to do this because we have direct contacts with principals and teachers in the community because of our in-school programming. We also work with local non-profit (girl guides, science rendezvous, Let's Talk Science) organizations in planning and development STEM activities, and we have working relationships with community groups that engage under-serviced students.” This positionality of SOU # 15 aligns with their previous views on partnerships while suggesting that they have working relationships with multiple stakeholders within their ecosystems, similar to the description of a knowledge broker. However, careful consideration is needed when trying to overlap the concept of knowledge brokering onto the work of SOUs, so it is not forced. As an example, the director further explained that “Yes, we are gaining and sharing knowledge, yes, the brokering functions or concepts are there, but the brokering terminology just doesn’t seem right. It almost seems like a position of power. Based on my own biases of what a broker does, I suggest softer language like knowledge facilitator. When I think about my organization as a knowledge facilitator, it means we are bringing together all these collective ways to have an impact on youth through STEM education outreach.”
Case Study 5 (SOU # 20)

The broad mission statement for SOU # 20 is to spark curiosity and develop a lasting interest and enthusiasm in science, engineering, and technology in children grades two through nine by engaging them in hands-on, fun-filled activities. In addition to the broad mission statement, SOU # 20 also specified that they have four specific objectives: 1) provide outreach for targeted underserved communities and areas in [our region] which includes girls, Indigenous youth, and new immigrants, 2) offer professional development for educators, 3) act as recruitment for the sciences at our university, and 4) provide activities for engineering recruitment events.

In terms of organizational capacity, SOU # 20 operates with an annual budget in the range of $600,000 - $750,000, that is used to employ a small team of full-time staff (1 – 3 people), a small number of part-time staff (1 – 3 people), but a large number of casual staff (8+) during September – April, and large student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU # 20 engages approximately 37 100 youth per year, of which, 8 100 can be classified as under-represented or under-serviced in STEM.

SOU # 20 is situated within an ecosystem that doesn’t have a dense population, which from the perspective of it’d director, partnerships are “critical as we depend on working with like-minded organizations to meet our outreach goals, and to kind of expand into any sort of underserved or critical-need community.” This SOU also disclosed their positive views towards partnerships in that they help with funding, co-developing STEM content, creating safe, accessible spaces for the kids to learn, and help diversify delivery with high priority audiences such as Indigenous youth or girls, underserved youth in the community, or educators. Overall, SOU # 20 couldn’t operate at the capacity we do without partners. In terms of the broader ecosystem perspective, the director of SOU # 20 thinks that “as a STEM outreach organization, we can’t exist in a vacuum. Our work primarily is face-to-face with kids, but it needs to also include educators, members of government, parents, guardians, businesses. By only teaching the
youth, what we're doing is saying that everything else is okay and can continue to operate as normal when we know what exists now for creating safe and engaging STEM spaces isn't working. The ecosystem aspect is so important for the work that we do in engaging youth and getting them through to a STEM career."

In terms of SOU # 20's views on the conception of SOUs as knowledge brokers within an ecosystem, the director indicated that at first glance, brokering is “98% what they do as we look to actively fill knowledge gaps. For example, we support undergraduate students in taking some time to teach younger students to code, we are involved in conversations with ministry officials about why investing in Indigenous community education and STEM education is what results in success, we talk to parents about why it's important they have conversations about STEM, and we make all of our STEM content publicly available to educators.” This said, although the concept of knowledge brokering appears to be central to what they do, it is a new way of thinking about STEM outreach and is something the director would like to learn more about.

**Case Study 6 (SOU # 22)**

The broad mission statement for SOU # 22 is to increase the scientific literacy of [our province’s] youth through fun, engaging hands-on activities. To do so, SOU # 22 operates with an annual budget in the range of $600,000 - $750,000, that is used to employ a small team of full-time staff (1 – 3 people), a small team of part-time staff (1 – 3 people), but a large number of casual staff (8+) during September – April, as well as a large student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU engages approximately 29 000 youth per year, of which, 10 000 can be classified as under-represented or under-serviced in STEM.

A particular focus for SOU # 22 is to focus on underrepresented groups, including not just indigenous peoples but girls and rural as well. The geographic region of this SOUs ecosystem is large, and “we can only do so much on our own and if we want to make an impact in our communities that we seek to serve. Therefore, we must involve partners in our process. But that
can look very different, according to the community as with most of our partnerships, there is collaboration and other ones they just sort of bring us in and make space for us.” This SOU is heavily focused on providing summer enrichment learning opportunities for rural youth as this is a gap within the ecosystem as a youth might not have the opportunity to explore academics outside of school if the SOU didn’t provide programming. Within the ecosystem, the director of SOU # 22 acknowledges that they need support from the schools in the community, which should be at the center of the ecosystem and can help the SOU provide learning opportunities during the year as well as in the summer.

In terms of SOU # 22’s views on the conception of SOUs as knowledge brokers within an ecosystem, the director struggled to see the application with the concept for their SOU. For example, the director mentioned that “I know what we do in terms of outreach, I just haven’t thought about it as brokering. I think it is interesting because we do a lot of these things intuitively, but to shake it out is kind of interesting but some of it is forced.”

**Case Study 7 (SOU # 24)**

The mission statement for SOU # 24 is to encourage healthy living, creative expression, scientific curiosity, and life-long learning in children and youth through its summer day camp sessions. Although not an area of focus or priority, some ongoing work is to strengthen their engagement with teacher candidates in STEM and coding/robotics activities.

In terms of organizational capacity, SOU # 24 operates with an annual budget in the range of $300,000 - $450,000, that is used to employ a small team of full-time staff (1 – 3 people), 1 – 3 people on a part-time contract, 4 – 7 casual staff during September – April, as well as a large summer student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU # 24 engaging approximately 2 000 youth per year, of which, 500 can be classified as under-represented or under-serviced in STEM.

Within SOU # 24’s local ecosystem, the manager suggested that partnerships are
important as without them, it is difficult to achieve their mission. Further, the manager mentioned that their partnerships are either ones that involve a financial exchange or with high priority target populations. “When you’re talking about STEM outreach, there's a really strong push from within institutions to have relationships with indigenous organizations and that’s pushed almost as much as the funding relationships.” When further describing the SOUs’ view towards ecosystem and partnerships, the manager had a strong difference of opinion between themselves, and the directional guidance being provided by the institution. For example, the manager mentioned that “there's also a really big difference between the partnerships that are important at the community grassroots level and the partnerships that are important institutionally. Successful partnerships within the university are often very black and white, a budget line. Did it earn us money, or did it cost us money? When it comes to outreach, I feel that the university is only interested in recruitment to their university. For myself, I am interested in the health and overall well-being of the students. There is this institutional approach that goes on with partnerships that I don’t understand, and it gets in the way of indigenous partnerships a lot, where the focus is so much more financial.” This view on ecosystem partnerships is unique in that it highlights possible tensions between SOUs and how they support their affiliated university.

The manager of SOU # 24 did not offer many details about their views about the conception of SOUs as knowledge brokers except for it being similar. In further explanation, the manager said that “outreach organizations have both the STEM knowledge and the technology, which are unique within the community. We then broker out this knowledge to wherever else, whether it's students and youth or teacher development. I can't see any context that brokering is different from what we do. I think it's a really good fit.”

Case Study 8 (SOU # 25)

SOU # 25 envisions the youth of [our province] to be inspired and empowered by the possibilities of science, engineering, and technology. We envision [our province] where all youth, regardless of background, gender, or socio-economic status are enriched in their science, math,
and technology education. The young people today will become [our province’s] vibrant and diverse workforce of leaders tomorrow; these youth will be empowered by their knowledge and appreciation for science, engineering, and technology.

In terms of organizational capacity, SOU # 25 operates with an annual budget in the range of $600,000 - $750,000, that is used to employ a small team of full-time staff (1 – 3 people), a small number of part-time staff (1 – 3 people), a large number of casual staff (8+) during September – April, as well as a large summer student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU engages approximately 5 000 youth per year, of which, 2 000 can be classified as under-represented or under-serviced in STEM.

Within SOU # 25’s local ecosystem, the manager views partnerships as “one of the most important things because it doesn’t matter how much we create or produce or fine-tune things on our end if we don’t have those relationships established then we just don’t have a way of accessing the youth.” The importance on establishing relationships leading to partnerships was also a deemed important, especially when engaging “underrepresented, underserved, or First Nations communities because if you don’t have a relationship establish, it’s certainly not a place where you can just show up and like expect to be welcomed with open arms.” When describing the partnerships within the ecosystem, the manager of SOU # 25 continued to emphasize their focus on providing accessible STEM learning opportunities to low socio-economic communities, rural communities, or youth in general who don’t typically get receive STEM enrichment opportunities. SOU is also unique within its STEM learning ecosystem as being one of very view groups that focus on outreach, creating a large demand. For example, the manager suggested that they “we are almost in so much demand from different community groups like the libraries, like the Science Center, like the museums and Scouts or Girl Guides, that sometimes we just have to say no. In the past, we tried to be whatever people needed us to be but we’ve had to just start saying we just don’t have the people and the finances necessary to be able to help out.” This
quote suggests an increased need for SOU resources to match the demand within the ecosystem.

In terms of SOU #25’s views on the conception of SOUs as knowledge brokers within an ecosystem, the manager described it as being similar, especially in certain contexts. As described, this SOU has a large focus on engaging Indigenous youth and suggests the concept of knowledge brokering is relevant when they “work with our First Nations communities or Northern communities as they struggle every year to get enough trained teachers who feel confident in STEM. These schools within the communities rely on us to come in and to fill that gap for them. I think that’s common in First Nations communities so we kind of provide that STEM specialization that they’re missing.” In other contexts, such as when the STEM industry partner with SOU #25 to deliver outreach, the manager felt that they were used as a tool to help deliver ‘fun’ workshops that showcase the industry, and it wasn’t as much of a knowledge transfer. These two examples suggest the concept of knowledge brokering for SOU #25 has relevance in a certain context, but maybe not all elements of their role in the ecosystem.

Case Study 9 (SOU #39)

The broad mission statement for SOU #39 is to pilot & scale revenue-generating programs that help support faculty strategic goals such as fostering interest for engineering in the community, recruiting exceptional students & providing enriching educational experiences to students. In addition to the broad mission statement, SOU #39 also specifies nine sub-objectives for their organization: 1) to introduce science, engineering and technology to children of all abilities / backgrounds, in both official languages, with a special interest in the equal participation of young girls and boys, 2) to encourage the participation of children of low income families through the Bursary Program, 3) to provide positive female and male role models who share their experience and knowledge in a fun and accessible manner, 4) to introduce the university environment in a positive and non-threatening manner, 5) to provide children with the tools to discover science and engineering individually, and as part of a team, 6) to reach out to communities who do not have ready access to similar youth education programs, 7) to help
educators and parents show their children how science, engineering and technology can be challenging and exciting, 8) to offer summer employment to [our institution’s] students, and 9) to give students the opportunity to acquire entrepreneurial and leadership skills.

In terms of organizational capacity, SOU # 39 operates with an annual budget of more than $1,000,000, which is used to employ a large team of full-time staff (8+ people), a large team of part-time staff (8+ people), a large number of casual staff (8+) during September – April, as well as a large student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU # 39 engages approximately 75 000 youth per year, of which, 25 000 can be classified as under-represented or under-serviced in STEM.

SOU # 39 had strong opinions about partnerships, suggesting that they use them “strategically when we need something. I hate partnerships in general when they're not very focused and tailored to acquiring a certain resource or acquiring a certain marketing capability that you didn't have previously. I think a lot of organizations partner with all these other organizations, and it convolutes what you're trying to get done at the end of the day.” Even though the manager of this SOU approaches partnerships with a purposeful lens, they still acknowledge that when they need to reach a certain number of youths for targets, they think about which partners in their ecosystem, such as local school boards, can help them achieve the specific goal. In a closing statement, the manager of SOU # 39 said that “in general, partnerships if they are well focused and serve a very specific goal, are worthwhile. But in general, I'm very hesitant to jump in with a bunch of different partners if it's just for the fun of it or we feel we need to partner with others.” The manager of SOU # 39 also had passionate views concerning systematic and collaborative STEM learning ecosystems as they felt there is too much redundancy happening. For example, “when you look at the STEM content being generated, everybody's freaking reinventing the wheel all over the place. There's so much duplication and wasted money and time and effort in essentially developing content and curriculum. Some
organizations are developing content without a purpose in mind. There's a lot of content out there, but the synching up of measuring how effective that content is between different people that are using that content; that just doesn't happen. And I think that needs to happen within a STEM learning ecosystem because it's just so archaic and there's so much wasted resources.’’

In terms of SOU # 39’s views on the conception of SOUs as knowledge brokers within an ecosystem, the director did not see any real relevance. When describing the rationale, the manager said that “because brokering entails being a bridge to connect two parties, from what we do, we aren’t taking STEM knowledge from one place and trying to push it. I don’t see outreach organizations within the university’s taking the best research at the universities and education and transferring it down to the school boards. It is not happening.” This manager focused on the knowledge brokering concept from the perspective of mobilizing innovative STEM research that might be happening within their institution to the various groups within the ecosystem and that is why they didn’t necessarily see their SOU as brokers. Although the manager of SOU # 39 did not view their SOU as a knowledge broker, they did suggest that their “role is to find knowledge out there, distill it into something that we think is awesome because of our so-called expertise, then push it out to the people that we think need it. I don't know if I would call it brokering as we are not trying to connect two parties, I think it's more like knowledge remixing.” Overall, SOU # 39 did not see much relevance for SOUs as knowledge brokers.

Case Study 10 (SOU # 65)

The broad mission statement for SOU # 65 is to create, implement and support enriched learning opportunities for [our institution’s] Science students that in turn help us serve the needs of the [geographic] community for varied, high-quality STEM programs. In addition, SOU # 65 has the objective of providing professional development opportunities for undergraduate students focusing on diversity and working with indigenous communities.

In terms of organizational capacity, SOU # 65 operates with an annual budget in the range of $150,000 - $300,000, that is used to employ a small team of full-time staff (1 – 3
people), zero part-time staff, a small number of casual staff (1 – 3 people) during September – April, and zero summer student staff. With the combined personnel and financial resources, SOU # 65 engages approximately 18 500 youth per year, of which, none of them were reported as being classified as under-represented or under-serviced in STEM.

SOU # 65 is unique in that the manager role within the university was established in 2019 as most of the outreach happening within the institution was student-based and student-driven groups, with no cohesion, there was little communication within groups, and everyone was working on their own and feeling quite isolated. By introducing a new manager’s role within the university, one goal was to create internal partnerships with student groups and the various departments to coordinate outreach efforts. Another unique element to SOU # 65 is a primary focus on developing skills and competencies obtained for undergraduate students by providing outreach. Within SOU # 65’s local external ecosystem, the manager of SOU # 65 suggested that community partnerships have been extremely important towards achieving this mission.

In terms of SOU # 65’s views on the conception of SOUs as knowledge brokers within an ecosystem, the manager had mixed views. First, the manager suggested that the university itself has a knowledge broker function in that the community respects us in terms of it being a known reliable source of accurate and rigorous STEM information. Thinking about the specific role of outreach units, this manager felt that they “definitely play a role in terms of sharing STEM research knowledge. For example, we have grad students who are sharing what they are studying, helping people understand concepts where they maybe need some support. Even at the elementary level, I think that there are different types of scientific knowledge being shared. It’s not the research knowledge; it’s more the basic understanding of science concepts, how does it work, and what kind of careers can you do.” Holistically, if knowledge brokering can be classified as sharing passion about science, getting kids interested in the whole concept of what the nature of science is and their role in it, including personal life experiences as a science professional, then the manager of SOU # 65 believes that “this is a huge part of outreach.”
Case Study 11 (SOU # 71)

The mandate of SOU # 71 is to increase the awareness of and interest in science, engineering, and technology in a fun and supportive environment through hands-on activities and mentorships. In addition to the broad mission statement, SOU # 15 also has six goals: 1) educate and enthuse youth of [our province] about STEM through the delivery of expanded hands-on clubs, events, and camps delivered both on-campus and in off-campus outreach locations across the province, 2) provide youth with much-needed positive role models who are passionate about STEM, 3) help youth build confidence in themselves and the belief that everyone can contribute to science, engineering and technology, 4) expose youth to the variety of career opportunities that are available in STEM and the educational paths to get there, 5) promote post-secondary education by exposing youth to post-secondary environments and role models, 6) engage parents, teachers, schools, community leaders, local community groups, and volunteers to enhance programming and meet the needs of the community, and 7) strive to break down barriers to under-served youth and increase diversity in the STEM fields by providing positive experiences on campus which will in turn increase the number of students enrolling in the engineering program (again, with a goal of increasing diversity).

In terms of organizational capacity, SOU # 71 operates with an annual budget in the range of $150,000 - $300,000, that is used to employ a small team of full-time staff (1 – 3 people), a small team of part-time staff (1 – 3 people), 4 – 7 casual staff during September – April, as well as a large summer student staff (8+) during the summer term months of May-August when undergraduate students are looking for employment. With the combined personnel and financial resources, SOU # 71 engages approximately 7,500 youth per year, of which, 500 can be classified as under-represented or under-serviced in STEM.

Within SOU # 71’s local ecosystem, the director views partnerships are very important and wouldn't be able to do a lot of what they do if they didn't have good relationships with other groups. For instance, “we partner a lot with Big Brothers, Big Sisters, Boys and Girls Clubs,
community groups, and I don’t know if we’d be able to reach the rural and indigenous groups if we didn’t have good relationships with those partners.” The significance of the partnerships towards the SOU as described by the director feels “selfish” as they use them to meet the goals of their missions while helping them “get funding in the future because we’re able to show a successful partnership and we’re able to add numbers. I hate saying that out loud because it sounds like we’re just doing it to get numbers so that we can get more money, but that’s how we’re able to provide outreach.”

In terms of SOU # 71’s views on the conception of SOUs as knowledge brokers within an ecosystem, the director first wanted additional clarity on the concept as it was “the first time that I’ve heard of this brokering terminology.” After reviewing the concept and definition of knowledge brokering, the manager suggested that it is “exactly what it is we do. We have a team of people that take their STEM knowledge, and they share their passion with this larger group of students. Sometimes we must impose some passion or even some specific STEM knowledge such as coding on the outreach instructors or classroom teachers. We share the knowledge with them and then they're passing that on to other people to build STEM knowledge.” In addition to the STEM knowledge, the manager of SOU # 71 also highlighted the important role their SOU has towards providing role models in STEM, especially for those who are underrepresented in the professions, which could be classified as a form of knowledge brokering. Overall, the manager of SOU # 71 believes that viewing SOUs as knowledge brokers is “really interesting as it sounds super smart. I think that’s a way of framing outreach in a way that doesn’t just sound like we’re a summer camp. We are trying to bring some new knowledge and some new excitement and passion behind the STEM fields and trying to transfer that to the students so that they can then pursue it.”

**Case Study 12 (SOU # 73)**

The broad mission statement for SOU # 73 is to provide [our geographic region’s] youth with opportunities to explore the importance of Science, Technology, Engineering, and Math (STEM) in their lives and develop critical skills and attitudes for lifelong learning. In addition,
the mission of SOU # 73 is currently evolving towards a more longitudinal model of engagement, not just youth programming, but support for current undergraduate students and educators.

In terms of organizational capacity, SOU # 73 operates with an annual budget in the range of $450,000 - $600,000, that is used to employ a team of 4 – 7 full-time staff, 1 – 3 part-time staff, 1 – 3 casual staff during September – April, but a large number of student staff (8+) during the summer term months of May-August when students are looking for employment. With the combined personnel and financial resources, SOU engages approximately 16,000 youth per year, of which, 6,000 can be classified as under-represented or under-serviced in STEM.

Within SOU # 73’s local ecosystem, personal connections and partnerships are crucial and it’s the primary way they can do any of their outreach work. The director of SOU # 73 also described how their approach to relationships to form partnerships, has led to a positive reputation which has opened new opportunities with Indigenous communities in the region. As described by the director of SOU # 73, it is important to view partnerships in the ecosystem as “important learning opportunities for our university student staff, but there’s a lot to be gained from us going there. Our organization can fulfill our commitments to our funders and our stakeholders and our mission, but we could also provide things that they need from us and the other way around, as well.” Speaking more about their position within the ecosystem, the director described that “there are a lot of people working in the STEM education sector who have a lot of similar ideas and similar goals. When everyone’s working in a silo, everyone’s trying to go after the same funding and getting small parts of it. Everyone’s reinventing the wheel, figuring out their projects and activities and best practices, but by working together we could create much better content with better resources for the youth in the communities. It’s sort of like the idea of having the superclusters and by working together, there is so much more that you could draw on in terms of resources.”

In terms of SOU # 73’s views on the conception of SOUs as knowledge brokers within an ecosystem, the director first described that they have “close ties to a lot of rural and remote
communities, which is a place where STEM industries, government, and even higher education does not have great ties. Our organization works with the educators and the people who are actually on the ground, so we are well-positioned to be able to facilitate conversations and help to bring some of these higher-level organizations to the communities.” This positionality within the ecosystem implies the similarities between brokering and the role of the SOU in terms of creating and sharing of knowledge, but as the director described, “it's sort of incomplete because we are still proprietary of the content that we create. Knowledge brokering seems to be more of a more universal thing. While we do create and share knowledge, it's not usually freely available to everyone in every circumstance. That said, if it's referring to the knowledge creation or sharing between two different groups of stakeholders, I would say that's, in that context, it's accurate. That's sort of our main mandate; is to communicate STEM education to as broad an audience as possible, which includes all of the various sectors in the ecosystem.”

**Case Study Summary and Cross-case Analysis**

The next step towards exploring the twelve SOU cases was to generate a summary integration table (within Appendix A6) that could be used to help unpack the similarities and differences from what was described within the case study descriptions as well as data from the Phase 3 interview; to establish ideas that were mentioned consistently across several cases (Bowen, 2009).

To further analyze the data from each case study, one approach was to explicitly look at SOUs annual budget, the number of two-way partnerships within an ecosystem, their views on the concepts of collaborative partnerships in an ecosystem, as well as their views about the relevance of knowledge brokering for SOUs. As an approach to cross-case analysis, multiple strategies were used towards grouping the SOUs to explore emerging themes. The first strategy was to group SOUs based on their annual operating budget to see if that had a direct relationship on SOUs approaches to partnerships and their views on ecosystems and knowledge brokering.
When doing so, there were mixed results from the twelve case studies, suggesting that the operating budget does not consistently have a direct influence on SOUs approaches to partnerships. When the twelve case studies were analyzed based on their views of knowledge brokering, the cross-case analysis yielded similar results in that SOUs views on brokering did not consistently have a direct influence on their operating budget or their approaches to partnerships.

To further explore the cross-case analysis of the twelve SOUs, it was decided to group the case studies based on the number of self-identified two-way partnerships they have within their K-12 STEM learning ecosystem, (as shown in Table 18), then compare any similarities and differences within and across cases.

Table 18

*Synthesis of Case Study Data Grouped by Number of Two-way Partnerships*

<table>
<thead>
<tr>
<th>SOU Number</th>
<th>Two-way Partnerships?</th>
<th>View of Ecosystem Partnerships</th>
<th>Annual Budget</th>
<th>View of Knowledge Brokering</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Very High</td>
<td>Very Important</td>
<td>Above Average</td>
<td>Mixed</td>
</tr>
<tr>
<td>15</td>
<td>Very High</td>
<td>Very Important</td>
<td>Above Average</td>
<td>Mixed</td>
</tr>
<tr>
<td>73</td>
<td>Above Average</td>
<td>Very Important</td>
<td>Average</td>
<td>Relevant</td>
</tr>
<tr>
<td>71</td>
<td>Above Average</td>
<td>Very Important</td>
<td>Very Low</td>
<td>Relevant</td>
</tr>
<tr>
<td>20</td>
<td>Average</td>
<td>Very Important</td>
<td>Above Average</td>
<td>Very Relevant</td>
</tr>
<tr>
<td>22</td>
<td>Average</td>
<td>Important</td>
<td>Above Average</td>
<td>Low relevance</td>
</tr>
<tr>
<td>14</td>
<td>Below Average</td>
<td>Very Important</td>
<td>Below Average</td>
<td>Relevant</td>
</tr>
<tr>
<td>24</td>
<td>Below Average</td>
<td>Neutral</td>
<td>Below Average</td>
<td>Relevant</td>
</tr>
<tr>
<td>1</td>
<td>Below Average</td>
<td>Important</td>
<td>Very Low</td>
<td>Mixed</td>
</tr>
<tr>
<td>65</td>
<td>Very Low</td>
<td>Important</td>
<td>Very Low</td>
<td>Relevant</td>
</tr>
<tr>
<td>4</td>
<td>Very Low</td>
<td>Neutral</td>
<td>Very High</td>
<td>Mixed</td>
</tr>
<tr>
<td>39</td>
<td>Very Low</td>
<td>Neutral</td>
<td>Very High</td>
<td>Not relevant at all</td>
</tr>
</tbody>
</table>

Note: In terms of ecosystem two-way parents, the binned categories are: very Low = 0 - 2 partnerships, below average = 3 - 4 partnerships, average = 5 - 6 partnership, above Average = 7 -
8 partnerships, and Very High = 9+ partnership. In terms of operating budget, the binned categories are: very low = 0 - 300k, below average = 300k - 450k, average = 450k - 600k, above average = 600k - 750k, and very high = 750k+.

The first cross-case analysis was to explore the five SOU groups (based on the number of two-way partnerships) to see if any themes emerged in terms of their views on ecosystems. Across the five groupings, those SOUs that currently have very high or above-average two-way partnerships, view the concept of collaborative STEM learning ecosystems as being very important, whereas the SOUs on the lower end of two-way partnerships are more neutral. One other finding to acknowledge is that for some SOUs (such as SOU # 14 and # 65), the number of two-way partnerships is currently lower than their views on ecosystem partnerships.

When analyzing the case studies based on two-way partnerships and the SOUs annual operating budget, an indication of their available resources, the findings suggest a mixed relationship. For the group of SOUs with the highest number of ecosystem partnerships, their annual budget is above average, but the group of SOUs who are above average in partnerships, have an average budget or very low budget in comparison to the other cases. Interestingly, the two SOUs (#4 and #65) who have the largest operating budget of all SOUs in this study, are both very low in terms of two-way partnerships. This mixed finding across the cases would suggest that the number of partnerships does not have a strong direct link to the operating budget.

The final cross-case analysis explored the relationship between the number of two-way partnerships and the SOUs views on knowledge brokering. Within ten of the twelve cases, one theme that emerged was that the concept of knowledge brokering had relevance for the role of SOUs within their ecosystem. This said the specific knowledge brokering terminology caused concerns in the context of STEM outreach.

The cross-case analysis of the twelve SOUs and how they related to this study’s research questions are further explored in Chapter 7.
Chapter 7

Findings – Phase 3: Interviews

Phase 3 further explored SOUs’ views on K-12 STEM learning ecosystems as well as SOUs’ roles as knowledge brokers within a K-12 STEM learning ecosystem. To do so, the final step for data analysis involved the combination of induction thematic analysis and the use of a constant comparison method (Glaser, 1992; Glaser & Strauss, 1967; Merriam, 2009) of the twelve case studies who participated in the Phase 3 interviews to answer the research questions and when necessary, report on similarities and differences in case studies describing the roles of SOUs within their K-12 STEM learning ecosystem.

RQ 1 - What are the Organizational Features of STEM Outreach Units in Canada?

Phase 1 and Phase 2 of this dissertation have already explored most of the organizational features of SOUs that were outlined within this study’s conceptual framework, except for their views on program evaluation. It was determined that the Phase 3 interviews were most appropriate to explore this final organizational feature.

Evaluating STEM Outreach Units’ Programs and Overall Impact

As a reminder, evaluation in the context of this study refers to the systematic assessment of the design, implementation, or results of an SOU initiative for learning or decision-making (Canadian Evaluation Society, 2015), and impact refers to the intended and unintended, direct, and indirect outcomes produced by the SOU initiative. Typically, outcomes are classified as short or medium-term and could include changes to students’ STEM knowledge, skills, and capacities because they participate in the outreach initiative. Within Phase 3, the 12 SOUs case studies were asked to describe their current program evaluation efforts, including what information they are collecting, their rationale for collecting it, what they currently use the information for, and finally, what they might need to support their evaluation efforts to measure impact.
Currently, all twelve of the SOUs in Phase 3 report on program outputs, such as the number of target audiences participating in their programs, and when possible, collect basic demographic information as the main sources of evaluation data. Looking across the twelve cases, eight SOUs (identified within Appendix A6), indicated that they are not satisfied with current evaluation efforts, and a further two are not satisfied at all. Although all the SOUs identified that they collect the numbers of participants, five of the SOUs (#’s 1, 15, 25, 39, 71, and 73) described in-depth program evaluation has been identified as a weakness (50%) and something they hope to improve on. An example of an identified area of improvement, as described by SOUs, is focusing on depth instead of breadth in terms of student engagement in an outreach program. The mindset shift around increasing and reporting on the number of face-time hours with the participants as opposed to trying to engage as many students as possible is emerging within 25% of the SOUs, but the challenge is explaining and justifying the different approaches to stakeholders and funders that are used to seeing larger numbers. SOU # 73 described their approach as follows:

For a long time, our organization operated under a quantity over the quality model and always ramp up the number of kids reached so that you can show that to your stakeholders. Reaching more kids has traditionally been better, but I’ve been working hard to try and have better programs in general. Going to the board with my proposal to reach fewer kids was a hard sell at the beginning and a harder switch in mindset to get away from that numbers over impact.

In addition to measuring the output of SOU initiatives, such as the number of youth participants and the numbers and face-to-face hours, ten of the twelve case studies mentioned that the most used method of collecting evaluation data to assess their interventions is through pre and/or post surveys (83%) to participants. Reasons for conducting the surveys include: to attract funders (58%) through narrative stories/experiences; formative program development or improvement (50%); program satisfaction (33%) which can be classified at an output; and lastly, a self-reported program outcome (33%) to see if the program helps increase their
knowledge/interest in STEM. By collecting this survey data, one SOU suggests that it is important to identify and build upon what is working well, to achieve greater impact:

*If we can take the best activities and make a path that's hyper-engaging for all participants, we could make a difference in impacting whether people participate in more events. If you can improve and iterate on that experience and document that experience and you see the level of engagement is going up, then you can create a program that's super highly engaging to specific people and hopefully make an impact” (SOU # 39).*

Another metric of program evaluation focuses on repeat engagement and program retention. For example, six of the SOU case studies in Phase 3 (50%) use collected participant data to measure retention, meaning how many participants are returning. Other examples include how many communities have invited them back (25%), the level of engagement/interaction with community partners, and/or teachers (17%). Expanding on the concept of retention, 25% of SOUs (#’s 14, 25, and 39) suggested that retention is linked to recruitment to their institution. For example, “we want to track if students start in our programs young; what is their interest level and how have they improved over the years? What does that mean once they reach the end of high school and decide what they want to pursue further? Did our programs have an impact to encourage them to want to potentially pursue STEM at our university?” (SOU # 14). However, measuring the impact of programming on individual students’ experiences in an SOU program, and what that means for university-based recruitment has its challenges due to confidentiality and the tracking of minors. SOU # 39 also suggests “having the mandate of measuring impact on university recruitment is so long term that there's no real correlation. It's not going to happen. A kid attending one one-hour workshop and seeing if they get recruited in 10 years, how do you even measure that? There is no good way. I'm very skeptical when people are saying they're measuring overall impact.”

The identified challenges across the twelve individual case studies from Phase 3 face and need support with if they are to enhance program evaluation, include:
• developing evaluation capacity to move beyond surveys (58%),
• an increase in personnel and funding dedicated for evaluation (50%),
• help from an experienced program evaluator (25%),
• and the infrastructure to track participation and engagement in events (17%).

Overall, SOUs are collecting some quantitative and qualitative program evaluation data from target audiences and/or stakeholders for the primary purpose of reporting to stakeholders and improving initiatives. However, the participants from within Phase 3 suggested they are not maximizing their program evaluation potential, and that with support, they could systematically collect higher-quality evidence to assess the outcomes and impacts of their initiatives on their target audiences.

RQ 2 - How are STEM Outreach Units Involved in a K-12 Learning Ecosystem?

Similar to RQ1, Phase 1 and Phase 2 have already presented several results sections related to RQ2. The following sections provide findings from the Phase 3 case studies that contribute towards exploring how SOUs are involved within a K-12 STEM learning ecosystem.

Partners of STEM Outreach Units within a STEM Learning Ecosystem

In the semi-structured interviews of Phase 3, all twelve participants were asked to expand on the relationship they have with the various groups in an ecosystem. The individual responses for each case study are presented in Appendix A6, whereas Figure 14 illustrates the breakdown of relationship types identified across all twelve case studies and the groups within an ecosystem.
Figure 14

*Type of Relationship between SOU and Ecosystem Groups Identified by Phase 3 Participants*

Note. This figure illustrates the frequency count of relationship type (either two-directional, one-directional, or not-doing) between the twelve SOUs in Phase 3 and the K-12 STEM learning ecosystem groups.

When comparing the number of two-directional partnerships across each of the twelve SOU case study’s, there was no emerging trend in terms of how the SOUs could be grouped. For example, and supported by the data in Table 18, the two SOUs (#’s 15 and 25) who have over nine two-directional partnerships, SOU # 25 reach very low numbers, whereas SOU # 15 is average in comparison to the other SOUs. The lack of emerging trend when comparing the number of partnerships for SOUs to their annual budget and their number of youths reached per year, is an interesting finding itself, suggesting that partnerships are dependant on another factor.

Looking across the twelve cases, the two groups within the ecosystem with the highest two-way reciprocity with Phase 3 SOUs, as shown in Figure 14 are the community settings and the students themselves (75%). From the community settings perspective, nine SOUs (75%) suggested (as highlighted from SOU # 14) that the relationship is “*usually a two-way street as they typically come to us whether that be because of a pre-built relationship, or they have heard that we do this type of programming. We typically collaborate on some sort of programming.*”
Similarly, with students, 9 SOUs (75%) indicated that they offer programs and in return, students gain knowledge and provide feedback.

Figure 14 also indicates that SOUs have a two-way relationship with their affiliated university (66%). Expanding on the relationship between SOUs and their host institution, there are still mixed feelings as 5 SOUs (41%) indicated they are fully supported by their university; 3 SOUs (25%) indicated they are supported but the partnership is not as strong as it could be; and 4 SOUs (or 33%), as described by SOU # 14, suggested that “a lot of times because we were seen as, as an independent organization, we would often go to different faculties to see if they could help us. They would come to our programs and say a few words, but we did not collaborate. We do hire university staff and have access to facilities. I would say it’s pretty one-way.”

The relationship with K-12 schools, meaning individual teachers or senior leadership within the schools, is straightforward in that 7 of the Phase 3 SOUs (58%) feel the relationship is two-way as they deliver a STEM outreach initiative, and in return, the opportunity helps SOUs reach their target numbers and, in some cases, collect a fee-for-service. In terms of parental partnerships, 7/12 SOUs (or 58%) suggested that to support students in attending their outreach initiatives, they first share knowledge and obtain buy-in from parents, suggesting that this relationship is one-directional, but when connected with the students, it becomes a three-way relationship that can be beneficial for all. The identified partnerships with STEM business/industry are split as 50% of Phase 3 SOUs suggested the relationship is one-directional in that the business/industry provides funding for program delivery without being engaged, whereas some business/industry provide mentorship and are available as guest speakers.

Two ecosystem groups identified by Phase 3 SOUs with the lowest amount of two-way reciprocity include pre-service educators (25%) and in-service educators (17%). When looking at the pre-service educator results, 50% of the SOUs in Phase 3 do not currently have a relationship with this group. For those that do, 25% indicated that they are just getting started with a relationship whereas the other 25% are very well integrated into the professional development
opportunities for educators. As an example of both scenarios, SOU # 20 indicated that they are “starting to build capacity in pre-service educators within the Faculty of Education by doing some free training, supporting tech-lending, and all kinds of pieces along the digital literacy side. Unfortunately, we don’t talk frequently and so we’re trying to fill that gap.” where SOU # 15 indicated that they “do a lot of programming with pre-service teachers. Our office is in the Faculty of Education. So, we’ve got all access to pre-service teachers doing Pro-D.” With the in-service educators, seven of the SOUs (58%) described the relationship as one-way. One SOU expanded on the relationship by saying “we seek opportunities for educators within the schools to give feedback on our workshops, but for the most part, it’s us disseminating information to them” (SOU # 73). These two results are of particular interest and will be explored in more detail within the discussion chapter as educators have been identified as primary stakeholders and having important roles in terms of SOUs gaining access to students, but yet, the two-way reciprocity in terms of educator professional development opportunities was not identified in this section.

Finally, the last result from Figure 1 to discuss is the relationship between SOUs and the government. As mentioned, only 2 of the SOUs in Phase 3 (17%) indicated they have a two-way relationship with the government (either provincial or federal), as 58% view the relationship as one-directional where the SOUs receive funding and beyond reporting “there isn’t a whole lot going back from us” (SOU # 25). The specific result highlighting the one-way relationship with the government is worth noting as an area for further exploration as Chapter 1 described initiatives from the Federal government to increase financial resources for SOUs, which directly contributed to the identified growth of SOUs within the past 5 years. One possible explanation for this surprising result is that the SOUs are not seeing the longer-term impact of the partnership and how the work of SOUs contributes towards the economic growth of the country and a decrease in the projected STEM workforce gap.

Using the data collected from Phase 3 results (Figure 14) on ecosystem relationships as well as the case study data presented in Appendix A6 as well as Table 18, the original image
presented in Chapter 1 depicting the groups within a K-12 STEM learning ecosystem has been updated by adding directional arrows and repositioning circles to illustrate SOUs proximal interactions (Figure 15).

**Figure 15**

*Updated Conceptual Framework of K-12 STEM Learning Ecosystem Highlighting STEM Outreach Partnerships*

![Diagram](image)

**Note.** The partnership results from Phase 3 between university-based SOUs and the K-12 STEM learning ecosystem inform this updated conceptual framework as shown by the directional arrows. In addition to the arrows, the closer the STEM learning ecosystem group is to the center, the stronger the relationship they have with the SOU.

Within Figure 15, the placement of each group within the ecosystem has been adjusted in relation to the university-based SOUs depiction of how closely they support each other (i.e., proximity). For example, data indicated that schools and students should be placed close to the SOUs, whereas government and educators are further away. In addition to the physical placement of the group, Figure 15 now contains three different types of directional arrows with varying
thickness that represents the strength of the theme that emerged from the data, meaning that the thicker the arrow, the more supporting evidence.

**Why SOUs Engage in Partnerships?**

Ten of the twelve SOU case studies in Phase 3 identified partnerships as being important or very important to help them achieve their mission. SOU #20 described this as:

> Critical for multiple reasons. Our province is unique in that we don't have a very dense population, which means we're dependent on working with like-minded organizations to meet our outreach goals. This includes expanding into underserved or critical-need communities. We couldn't operate at the capacity we do without our partnerships. They help us diversify delivery, and then just meet youth that without them we wouldn't have been able to engage.

It was clear from Phase 3 results those partnerships within the community should be purposeful, as indicated by 83% of the SOUs. As described in Chapter 6, one case study (SOU #39) was unique in its approach to partnerships by saying:

> For us, we use partnerships strategically when we need something. I hate partnerships when they are not very focused and tailored to acquiring a certain resource or marketing capability that you didn't have previously. I think partnering with just anyone, convolutes what you are trying to get done. On my team, I try to be very strategic and suggest no partnerships unless we have a clear reason why we want a partner.

Purposeful partnerships that focused on specific target audiences were another important theme that emerged from eight case studies. For example, SOU #20 mentioned that they “only partner with organizations that match our mandate, whether that be working with Indigenous youth and communities, under-serviced and/or rural communities, girls, and/or underrepresented youth in STEM fields.” This link between partnerships and mission also aligns with these SOUs’ institutional goals around increasing diversity and reaching targeted underserved populations. To further illustrate this point, the case study description of SOU #25 described how:
Our organization is focused on strengthening our partnerships with First Nations communities because if you don't have a relationship established, it's not a place where you can just show up. A lot of the other people that we try to target are underrepresented or underserved, and possibly a little bit isolated. We are focused on those socio-economic neighborhoods where the average kid isn't necessarily going to be exposed to these extra-curricular STEM learning opportunities. We are always thinking about connections with those particular schools or organizations in those neighborhoods and communities.

Having partnerships is of significant interest to SOUs, especially when there is mutual benefit for all those involved. Within Phase 3, the SOUs expanded on what mutual benefit means to them and a synthesis of the themes presented in Table 19. The intention of Table 19 is to illustrate the three emerging themes across the twelve SOU case studies. In addition, the intent is to provide supporting examples of what SOUs contribute and receive within each theme. The examples provided are a synthesis of the reciprocated benefits from the Phase 3 participants.
Table 19

*Themes and description of what SOUs contribute and receive from partnerships.*

<table>
<thead>
<tr>
<th>Theme</th>
<th>SOUs</th>
<th>SOUs contribute</th>
<th>SOUs receive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link to the mission and high priority target audiences</td>
<td>n = 11/12</td>
<td>• Partners receive customized high-impact STEM learning experiences for under-serviced and under-represented groups in STEM that don’t traditionally have access. • Partner organizations fulfill their mission objectives to provide learning opportunities for youth.</td>
<td>• SOUs meet the goals of their mission by gaining access to a population of students. • SOUs report on the number of youth engaged to meet grant funding requirements. • SOUs can provide evidence of successful partnerships (program outputs) to secure additional external funds. • SOUs can leverage the opportunity to promote additional or future outreach events. • SOUs can learn about Indigenous, BIPOC, or other community cultures to integrate and enhance programs</td>
</tr>
<tr>
<td>STEM capacity-building</td>
<td>n = 10/12</td>
<td>- Free or minimal cost to support STEM education curriculum topics with fun activities and content.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- A large number of participants can be reported to stakeholders and used to leverage additional funding.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Professional development experiences from presenting to different audiences, learning teaching skills, gaining STEM confidence through receiving feedback from educators.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Opportunity to reflect on programs to expand the content to include relevance.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Bring something new and exciting to the community.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Exposure to STEM role models and careers.</td>
<td></td>
</tr>
</tbody>
</table>

| Resources (financial and facilities) | n = 6/12 | - Benefit from learning opportunities to build STEM knowledge. |
|                                    |          | - Money to cover the fees for services of a program or to send students to camp. |
|                                    |          | - Partners can spend resources assigned for specific purposes. |
|                                    |          | - SOUs also receive access to the venue such as schools or community centers to deliver the programs |
|                                    |          | - Access to new educational technologies such as robotics kits they might not have. |
|                                    |          | - Marketing opportunity to promote other outreach events. |
From the perspective of SOUs, they may be involved in several types of partnerships within their local ecosystem, all of which serve different purposes, connected to their overall mission. A representative quote capturing the essence of SOUs approaches to partnerships and STEM outreach more broadly was shared by SOU # 20 who views partnerships as very important:

*I can't speak for other communities, but I know for us, the only way we are going to be successful is if we do it together. If our organizational goal is to provide an engaging, positive, and healthy STEM experience for youth, this doesn't come through competition, it comes through working together. How cool is it to think that a student could come through our camp, a week of camp at the science center, and then a week of camp at the library, to have a well-rounded and diverse experience? That's what builds STEM confidence in these kids. There's so much research to support that the best way to engage them is through diverse positive experiences and mentorship. That doesn't come from attending one program that comes from attending multiple. This means we need to not compete with each other, and we need to lift each other.*

After compiling the results on SOU partnerships within a K-12 STEM learning ecosystem, the next step was to continue exploring the benefits, drawbacks, and barriers of a STEM learning ecosystem.

**Benefits of a STEM Learning Ecosystem**

An overarching theme that emerged from all participants in Phase 3 was that a collaborative STEM learning ecosystem could produce higher quality content, utilize individual strengths and knowledge sharing to provide more diverse learning experiences for students, contributing to a larger impact of K-12 STEM education. Focusing specifically on the sub-theme of higher quality content, 4 SOUs (33%) suggest the idea that:

*There are a lot of people working in STEM education, specifically STEM outreach, who have similar ideas and similar goals. Everyone's reinventing the wheel, figuring out their projects and activities, and best practices. There's so much duplication and wasted money, time, and effort in essentially developing the same content and curriculum. By working together, we could create better content with better resources for the community (SOU # 73).*

Utilizing the organizational/individual strengths such as subject/experiential knowledge and shifting the mindset towards embracing the idea of sharing that knowledge was another sub-
theme discussed by 4 SOUs in Phase 3 (or 33%) when thinking about educators/schools and community groups. If an ecosystem approach was to be adopted, a benefit could be that educators as well as community groups/settings, would “have people who have experience and expertise with the STEM subjects and the specific age level that they can count on to support them teaching STEM in the classroom” (SOU # 65). This increase in participation numbers and hopeful STEM education impact was supported by 5 SOUs in Phase 3 (42%), one of which summarized the benefits of a STEM learning ecosystem by saying “a collaborative ecosystem is going to make sure that the youth have several different experiences with STEM that aren't necessarily driven by us [the SOU]. We may be involved in it, but because there's interest at the libraries, the museums, or schools, then the kids are going to get this STEM exposure from all over the place, and ultimately it's going to increase our organizational mission and objectives” (SOU # 25).

**Drawbacks of a STEM Learning Ecosystem**

An important and salient drawback to the STEM learning ecosystem approach suggested by eight of the Phase 3 SOUs (67%) was a lack of resources. A lack of necessary resources to support university-based SOUs towards achieving their mission has been previously discussed, so the idea of sharing limited resources and/or redistributing efforts within the ecosystem is a drawback. The rationale provided by 4 of the SOUs (33%) relates to the awareness that they are already under-resourced and cannot afford to share in ways that benefit other organizations within the ecosystem. However, for an ecosystem model to work, a major challenge indicated by four SOUs (33%) would be obtaining and sustaining buy-in from the various groups that include some form of resource-sharing. Once buy-in has been achieved, 4 SOUs (33%) believed that each contributing group in an ecosystem would also benefit from having clear roles/niche responsibilities and expectations which could help to ensure the groups with the most expertise in one area can focus on that topic. Clear roles could reduce overlap and redundancies, contribute towards higher quality, and help to ensure all groups have a contributing and complementary role within the ecosystem. However, having the resources to coordinate the logistics of an ecosystem
approach was also identified by four SOUs (33%) as an important limitation to this approach to STEM outreach. For example, SOU #65 explained how they are already stretched thin with their current operations:

Would be concerned that people would see this [ecosystem] as being more work and yet another thing on their plate. There would have to be a convincing argument to say why this would be beneficial and why it’s needed. Right now, educators are exhausted, overworked, and underpaid, and asking them to start working with community groups who are in the same situation, is another layer of emotional labor and physical labor. Also, educating parents about why their involvement in STEM is important to add challenges, especially if they work a full-time job or don’t have STEM confidence themselves, and then have to come home and engage critically with their youth. The government has all its normal challenges. So, everyone in the ecosystem is at capacity.

A second drawback towards a systematic STEM learning ecosystem described by 7 of the Phase 3 SOUs (58%) derives from the misalignment of objectives and/or approaches as some components such as non-profit versus for-profit. Within this misalignment theme, the sub-categories of drawbacks identified by the twelve SOUs include questioning groups’ mutual or equitable contribution (42%), a lack of individual praise/recognition normally received that could dilute their contributions and brand recognition (33%), and larger groups within the ecosystem prioritizing their own specific needs above others, which could lead to partnership resistance (25%). Although there were several drawbacks highlighted, 25% of the SOUs suggested that overall, they didn’t see any major drawbacks and that with clear communication, all groups would provide value-add towards enhancing a K-12 STEM learning ecosystem.

The SOUs in Phase 3 also identified five drawbacks to be overcome for this ecosystem approach to be implemented. Of the five, three have previously been discussed, suggesting two new drawbacks. The first was the need for an unbiased and neutral facilitator or champion. Having a champion who can take the lead within the ecosystem could help mitigate some of the drawbacks previously identified. This facilitator would ideally be “someone who is seen as neutral, who has good facilitation skills, is trained at team building, who’s able to listen and identify key issues and then negotiate all of these different priorities between all of these groups
who have different priorities” (SOU # 65). The second new drawback identified by 25% of the SOUs was a possible competition between groups.

**Competition Within Learning Ecosystems**

In Phase 3, after identifying other STEM outreach units or STEM-based groups in their local ecosystem, participants were prompted to elaborate on if those groups competed, and if this competition affected their outreach efforts. This competition for student participation and indirect competition towards engaging parents was supported by 17% of SOUs in Phase 3 as a barrier that will need to be overcome. Another perceived barrier identified by 2 SOUs in Phase 3 (17%) was competition for opportunities to engage with educators. For example, SOU # 71 explained how:

*Teachers and schools have limited budgets so cannot get all of the available outreach programs, especially if we are doing similar activities. Therefore, our organization has to adjust based on what we hear other groups are doing. We were planning on delivering teacher PD focused on coding as part of a grant funding application, but another local group does coding workshops very well so we haven't even tried yet. I'm trying not to be jealous, but they have experts in IT, coding, and delivering workshops to teachers, and providing them with equipment for their classroom. If we want to do teacher PD, we need to find our niche (SOU # 71).*

Although the competition was an identified barrier for some SOUs, 4 SOUs in Phase 3 (33%) suggested that they are not affected by competition. For example, SOU # 20 stated that:

*We are fortunate to be the largest program in our area and therefore don't see the effect of competition. Some of this is attributed to having a positive relationship with other organizations in the community with the collective goal of working together and providing complementary programming to collectively have a higher impact on the youth in Regina and surrounding communities.*

Two of twelve SOUs (17%) view the other STEM-based groups in the ecosystem as being a positive thing by suggesting that competition drives their efforts, mentioning that “competition has caused us to be more aware of the marketplace. If an area is already being serviced, such as teacher professional development we do not seek to service that market” (SOU # 22) or “competition helps drive people to improve. We work hard to maintain positive and
valuable learning experiences for the youth we serve and good customer service for those we interact with” (SOU # 80).

**Role of STEM Outreach Units within a K-12 Learning Ecosystem**

When asked about the role that SOUs might have within an established K-12 STEM learning ecosystem, 75% of the university-based SOUs in Phase 3 suggested that it would be similar to the role they currently have, which is to be a leader in developing specific content using their internal knowledge and resources and to be on-the-ground delivering those initiatives.

Within an established collaborative ecosystem, however, a difference is that the content and initiatives could be more customized to the target audience and could include partnerships to enhance the content. For example, the SOUs could work with K-12 schools/educators to determine “what they already provide in terms of STEM education and identify gaps so that our team would not duplicate something and could focus on specializing in something that would be value-added. For example, since our organization is based in the Faculty of Engineering, we could focus more of our efforts on engineering instead of science” (SOU # 4). Two SOUs (17%) also explained how they could do a better job of supporting their university-based student-volunteer groups to deliver STEM workshops to youth by connecting them to their intended target audience.

For the 4 SOUs in Phase 3 (33%) who mentioned their role within an ecosystem would be similar to what they are already doing, they explained how a more formalized ecosystem could also extend their partnership with the community, allowing for dedicated resources for their partnerships. Four SOUs (33%) also mentioned that their role within a formal ecosystem would be new or different. As an example, SOU # 73 specifically mentioned that they could expand on their role by leveraging their existing relationship to support other groups:

*One thing we could offer [the ecosystem] is we have close ties to a lot of rural and remote communities. In a place where a lot of industries and the government, and even higher education have not great ties into small communities, we work with the small communities. We work with the educators and the people who are actually on the ground.*
I think that it would be a good place for us to be able to facilitate conversations and help to bring some of these higher-level organizations to the communities. I think that we can sort of bridge the gap.

Finally, three new roles that SOUs would establish are related to purposefully building the capacity of various groups (suggested by 25% of SOUs), taking on a lead facilitator role (suggested by 17% of SOUs), and becoming involved with educational policy discussions to improve the STEM education system (suggested by 17% of SOUs). With these roles in the ecosystem, SOUs might be in a “unique position because we work with parents, educators, students, pre-service teachers to be an advocate at the ministry of education level to help our learning ecosystem” (SOU # 20). This unique position of working with many of the groups within their local ecosystem to support K-12 STEM education suggests that there might be overlapping characteristics worth exploring between the role of SOUs and the concept of STEM knowledge brokers.

**RQ 3 – To what extent are STEM Outreach Units Knowledge Brokers within an Ecosystem?**

The following sections combine results from Phase 3 to answer the third research question: providing details about the conceptualization of university-based SOUs as potential knowledge brokers within K-12 STEM learning ecosystems.

**Similarities and Differences between STEM Outreach Units and Knowledge Brokers**

In Phase 3, participants were provided with a description of a knowledge brokering process as a person or organization that facilitates the creation and sharing of knowledge and helps address knowledge gaps between at least two other parties, providing value beyond what the individual parties can do alone. SOUs were asked to identify if/how the description of a knowledge broker compares to the role of their STEM outreach unit within their K-12 STEM learning ecosystem. After reading the description, 11 of the SOUs in Phase 3 (92%) suggested that their role within the K-12 STEM ecosystem has similarities to that of a knowledge broker.
A few possible justifications to explain the increased percentage of SOUs that see similarities with knowledge brokering between Phase 2 and Phase 3 could be linked to the SOUs involved in Phase 3. The concepts and terminology around knowledge brokering might have been new for the participants in Phase 2, whereas the SOUs in Phase 3 had prior exposure since they participated in the previous phase and were sent the interview questions in advance, providing more time to think about the concepts.

Expanding on the similarities between knowledge brokers and SOUs, the themes that emerged from Phase 3 are that SOUs: actively look to share/communicate STEM knowledge with a broad target audience (indicated by 58% of SOUs), they receive input, knowledge, and experiences from others in the ecosystem and use it (or the individual groups themselves with expertise) to inform their program and content design (indicated by 33% of SOUs), and are a reliable source of STEM knowledge due to its affiliation with a university (indicated 25% of SOUs). By actively sharing this STEM knowledge, SOUs help students, teachers, and individuals within the communities to build STEM awareness, confidence, knowledge, and capacity.

Although the majority of SOUs in Phase 3 suggested their role as an SOU is similar to a knowledge broker, 5 of them (42%) also suggested that there are some differences as the description of a broker does not capture the full essence of their role in the ecosystem. For those SOUs that suggested it was different or incomplete, their rationale was that they are not actively looking to broker STEM knowledge, and if/when they do, it is because they were approached and sometimes as a paid service. For example, SOU # 20, who was quoted earlier describing the similarities to brokering, continued to explain how “on paper, the creation and sharing of knowledge is something that we do but the difference is that it’s almost passive. We create relationships with groups in our community and space for students to learn about STEM, but it is passive, whereas a knowledge broker sounds like it actively seeks gaps to fill.” Similarly, SOU # 73 explained how knowledge brokering “isn’t fully a description of the position that we serve because it sounds like knowledge brokering is more universal; since we are the proprietor of the
content we create and share, it's not usually freely available to everyone in all circumstances.”

These participants highlight a possible terminology gap that will need to be further explored when thinking about SOUs as knowledge brokers, suggesting that the current description does not fully capture their work.

One SOU also suggested that brokering is not at all similar to their role. SOU # 39, who viewed knowledge brokering as dissimilar or unlike their current role, explained how, SOUs “try to find content that is already publicly available, distill it into something awesome because of our so-called expertise and then push the content out to the people that we think need it. This is not the same as formally connecting two parties.” Instead of a knowledge broker, SOU # 39 saw their role as a “knowledge mixer.”

In summary, most of the SOUs in Phase 3 have suggested that there are similarities between the description of knowledge brokering and the work SOUs do within their K-12 STEM learning ecosystem, raising a question about the strategies they use. More specifically, if the knowledge brokering functions identified from the literature and used to create the conceptual framework for my research are relevant, important, and/or currently utilized by SOUs.

**Knowledge Brokering Functions Being Used by STEM Outreach Units**

In Phase 3, the updated knowledge brokering functions were further explored as SOUs describe some examples (if any) of how they are using each function. Following describing if and how their SOUs use each brokering function, the Phase 3 participants identified the top three and bottom three priority functions for their SOU. For a synthesized description of each emerging theme relating to how SOUs are utilizing the brokering functions please refer to Table 20.
### Table 20

**Brokering Functions Major Themes and Descriptions as Provided by Phase 3 SOU participants**

<table>
<thead>
<tr>
<th>Function</th>
<th>Major themes</th>
<th>Synthesized description of how SOUs are utilizing the brokering functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engagement</td>
<td>Variety of hands-on</td>
<td>When SOUs develop programming, they try to make sure it engages a broad audience through hands-on, fun-filled, memorable, positive, and educational experiences. Instead of teaching STEM using worksheets, SOUs get students engaged in their learning with diverse activities.</td>
</tr>
<tr>
<td></td>
<td>Variety of hands-on</td>
<td>When SOUs develop programming, they try to make sure it engages a broad audience through hands-on, fun-filled, memorable, positive, and educational experiences. Instead of teaching STEM using worksheets, SOUs get students engaged in their learning with diverse activities.</td>
</tr>
<tr>
<td>High-quality programming</td>
<td>Accessibility</td>
<td>A goal of SOUs is to make sure the outreach content has meaningful connections to the curriculum that students are learning in school. SOUs create engaging experiences so students can apply their knowledge and see that STEM had real-world applications.</td>
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<tr>
<td></td>
<td>Accessibility</td>
<td>SOUs practices accessibility by traveling to rural communities and indigenous communities that don't always have access to enrichment programs that provide STEM content. SOUs also try to make their programs geographically accessible within the city by hosting events in various parts, not just everything at the university.</td>
</tr>
<tr>
<td></td>
<td>Accessibility</td>
<td>Accessibility is a core component of many of the SOUs’ missions. STEM education and outreach have spent a long time serving a specific demographic, which shows in the diversity in STEM today. If working towards diversifying STEM is important, it needs to be accessible.</td>
</tr>
<tr>
<td>Topic</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Free or very low costs</td>
<td>One thing SOUs emphasize is that programs are either free, low cost, or have bursaries to help students/schools access paid programs to make sure that those youth who want to attend, can do so, despite financial barriers.</td>
<td></td>
</tr>
<tr>
<td>Awareness</td>
<td>Awareness is essential to SOUs' mandate and is in all aspects of their work. SOUs try to engage students in STEM education beyond textbooks to create awareness. Also, SOUs focus on minority groups that have historically faced barriers within STEM education.</td>
<td></td>
</tr>
<tr>
<td>Various strategies</td>
<td>SOUs create awareness by being active in the schools and community setting through a variety of workshop offerings. By being in the schools, SOUs foster that bridge between teachers, parents, and students. SOUs are also active on social media to spread information about the work they are doing, but also information about important STEM topics such as celebrating individual black scientists and the contributes they have made.</td>
<td></td>
</tr>
<tr>
<td>Focus on increasing diversity in STEM content</td>
<td>A major area for SOUS is focused on increasing female enrollment in STEM programming, especially in engineering. SOUs are working on raising STEM awareness to young females (and other minority groups in engineering such as people of color and the queen community) in hopes to overcome internal biases and societal barriers that present themselves to youth.</td>
<td></td>
</tr>
</tbody>
</table>
SOUs try to make sure that there’s [geographically] local STEM knowledge that is going into programming to increase relevance based on where they are located.

<table>
<thead>
<tr>
<th>Linkage &amp; partnership</th>
<th>External university, community, and industry relations</th>
<th>SOUs create a link and partnership between the university, K-12 schools, and the community in an attempt to bring stakeholders groups together for the greater cause of STEM education and impactful outreach programs. For some events, SOUs will reach out to a variety of stakeholders and see if they want to be involved because it provides the participants with an idea of who exists in the community that can provide them with other STEM learning opportunities.</th>
</tr>
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<tbody>
<tr>
<td>Provide introductions</td>
<td>This is a small piece of what SOUs do. SOUs can leverage our community partners and connect them through introductions, but that's the end of their scope. SOUs don't explicitly work to connect stakeholders or do a follow-up.</td>
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<tr>
<td>Capacity building</td>
<td>Professional Development</td>
<td>SOUs offer professional development opportunities for in-service and pre-service teachers to help build their capacity for specific STEM topics/skills such as coding. They also have an open-sourced approach to our content for teachers to access so they can enhance their knowledge and provide STEM learning experiences for their students. Lastly, SOUs build the capacity of undergraduate students and industry mentors through training.</td>
</tr>
<tr>
<td>Area</td>
<td>Involvement</td>
<td>Details</td>
</tr>
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<td>----------------------------------</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Not involved</td>
<td>SOUs are a smaller team and just don’t have enough capacity, on top of our regular outreach delivery, to dedicate time towards things like teacher training.</td>
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</tr>
<tr>
<td>Important for STEM</td>
<td>Capacity building is critical and lies at the core of SOUs because at the end of the day they are trying to expand people’s ability to walk away having learned something about STEM and feel confident in their STEM knowledge. Capacity building is important but is a passive approach.</td>
<td></td>
</tr>
<tr>
<td>Implementation support</td>
<td>SOUs are the ones who deliver the workshop content and are not involved in consulting decisions as to if/how/when the content is required. SOUs might be doing this implicitly, probably more than they think they are, but it isn’t one of the goals.</td>
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<tr>
<td>Professional development and/or advice for schools, teachers, industry, and community</td>
<td>SOUs have consulted with schools to help them implement programs by providing support on classroom setup, equipment to purchase, activities to run, and strategies to include diversity. This is closely linked to teacher PD as they continued to assist how to implement the content in the classroom, and by sharing resources we developed. Outside of the school setting, SOUs support community leaders as well as the STEM industry to get involved in outreach, by inviting them to observe programs and/or participating in a training session.</td>
<td></td>
</tr>
<tr>
<td>Organizational development</td>
<td>This is a little outside the scope of SOUs’ mission, so it’s not a big part of what they do.</td>
<td></td>
</tr>
<tr>
<td>Internal growth and institutional alignment</td>
<td>To be a strong STEM outreach organization, you have to be doing this all the time. SOUs always had to be looking forward and looking backward and evaluating what they are doing, evaluating what others are doing, and figuring out how it fits within the outreach, affiliate faculty, and their university mandate and vision.</td>
<td></td>
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<tr>
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<td></td>
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<tr>
<td>(6/12 cases)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provide insight to community organizations, committees</td>
<td>SOUs support the library (and occasionally the school boards) by assisting them with knowledge around the latest STEM education trends, developing age-appropriate STEM content, and delivering training on educational technologies such as robotics. SOUs are building their capacity so the organization can provide STEM education/outreach opportunities. In addition to the library, SOUs have been involved in and contributed to planning committees for the provincial education sector, community engagement, and faculty recruitment.</td>
<td></td>
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<tr>
<td>(5/12 cases)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Policy influence</td>
<td>Not really involved (n = 9/12 cases) This is probably the furthest thing from what SOUs focus on.</td>
<td></td>
</tr>
<tr>
<td>Well-positioned to inform policy (5/12 cases)</td>
<td>STEM outreach has a unique position where it can talk about knowledge gaps from multiple perspectives and why/how policy changes need to happen. SOUs are too small to put a lot of time and energy into policy, but many of the SOUs are part of a national network and put their voice behind others who influence policy at a high level.</td>
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</tbody>
</table>
Figure 16 illustrates a summary of the emerging themes across all eight brokering functions, the number of SOUs supporting each theme, as well as illustrating the high priority and low priority brokering functions as suggested by the SOUs in Phase 3.

**Figure 16**

*Brokering Functions Themes as Provided by Phase 3 Interview Participants*

*Note.* The emerging themes from SOUs in Phase 3 for each knowledge brokering function are shown in the black circles. The brokering functions are also displayed in priority order, starting with engagement as the highest and policy influence as the lowest.

**High-priority knowledge brokering functions for SOUs.** There is an emerging theme suggesting a strong alignment between the work SOUs do within their local ecosystem and the brokering functions ‘engagement,’ ‘accessibility,’ and ‘awareness.’ Engagement, as identified by 11 of the Phase 3 SOUs (92%) was the highest priority brokering function. When developing their initiatives, 6 of Phase 3 SOUs (50%) try to make sure it engages the audience through hands-on, fun-filled, memorable, positive, and educational experiences. In doing so, it will lead to
high-quality programming, so students can apply their knowledge and see that STEM has real-world applications.

Accessibility was the second-highest priority brokering function selected by 83% of the Phase 3 SOUs. When providing examples of their rationale, 50% of SOUs described how they aim to make their programs geographically accessible by traveling to the target audience’s location/community, supported by 33% of SOUs that link accessibility with their mission to help make STEM education/enrichment more diverse. In addition to physically traveling to the target audience, especially the high priority target audiences such as those who are under-represented in STEM fields, 33% of the Phase 3 SOUs also try to make their initiatives accessible by offering programs for free, at low cost, or provide bursaries to help students/schools access paid programs to make sure that those who want to attend, can do so, despite barriers.

The third highest priority brokering function (as shown in Figure 16) selected by 67% of the Phase 3 SOUs is awareness. Increasing awareness was described by 67% of SOUs as being essential to achieving their mission and is in all aspects of their work. Fifty percent of the Phase 3 SOUs also try to increase STEM awareness by engaging students in STEM education beyond the textbooks, doing so via a variety of strategies such as workshops for youth in schools/communities and having an active social media presence to mobilize information. The information shared on social media can range from upcoming STEM outreach events, information about important STEM topics, and celebrating individual STEM contributors in our society (such as black scientists, and female engineers) and the contributions they have made. Five of the SOUs (42%) also highlighted how the focus on awareness overlaps with accessibility in the context of increasing diversity in STEM, with specific programs designed to increase female and other minority groups enrollment in STEM programming, in hopes to overcome internal biases and societal barriers that present themselves to youth. The focus on these three brokering functions supports the previously discussed results of SOUs mission, which is to
promote, provide, engage, or make accessible, various aspects relating STEM to youth, particularly from underrepresented and underserviced communities.

**Low priority knowledge brokering functions for SOUs.** On the low priority list of brokering functions shown in Figure 16, it was equally as clear that SOUs currently have less of a priority regarding ‘influencing policy,’ ‘organizational development,’ and ‘implementation support.’ Nine of the SOUs in Phase 3 (75%) suggested that policy influence is one of the furthest things they focus on, however, five of them (42%) do believe that SOUs offer a unique position to talk about knowledge gaps from multiple perspectives and needed policy changes. Similarly, with organizational development, 75% of SOUs indicated that helping external organizations is a little outside their scope but noted that for them to be a strong SOU, they internally reflect and evaluate their organization and align with their affiliate faculty’s mandate and vision.

Implementation support was the third-lowest priority brokering function as seven of the SOUs (58%) in Phase 3 suggested that they are the ones who deliver the workshop content and are not involved in consulting decisions as to if/how/when the content is required. SOUs might be doing this implicitly when they provide PD opportunities and/or advice for schools/community groups to help implement programs, purchase educational technologies, and/or EDI strategies in STEM, but implementation support, as identified by 42% of Phase 3 SOUs isn’t one of the primary goals.

**Mixed priority knowledge brokering functions for SOUs.** Two brokering functions with mixed responses in terms of high/low priority were ‘linkages and partnerships’ and ‘capacity building’. These two functions are of particular interest to this research as both have direct relevance to the K-12 STEM learning ecosystem. Before identifying the priority ranking of the brokering function, 50% of the SOUs in Phase 3 suggested that they create a link and partnership between the university, K-12 schools, and the community to bring stakeholders groups together for STEM education and impactful outreach programs. Also, 33% of the SOUs suggested that, when possible, they can leverage community partners and provide introductions to each other within the community, but they do not explicitly work to connect stakeholders or do a follow-up.
So even though half of the SOUs indicated they form partnerships, the lack of ‘intentional’ forming of linkages could explain their mixed results in terms of the brokering function priority.

The mixed results on the priority ranking of ‘capacity building’ could be linked to the target audience in mind when the SOUs were thinking about this function. For example, eight of the SOUs in Phase 3 (67%) spoke about capacity building in the direct context of teachers as the sole target audience, whereas the other 4 SOUs (33%) included youth, parents, teachers, and community leaders as target audiences. Those four SOUs who viewed capacity building with a broad audience in mind suggested that capacity building is critical and lies at the core of SOUs because at the end of the day they are trying to expand people’s ability to walk away having learned something about STEM and feel confident in their STEM knowledge. Of the eight SOUs in Phase 3 who viewed capacity building in the context of just teacher PD, five of them (42%) indicated that they don’t have enough capacity, on top of our regular outreach delivery, to dedicate resources towards teacher capacity building.

**Knowledge Brokering Relevance for STEM Outreach Units**

The idea of using knowledge brokering to explore and/or explain the role of SOUs within a community has potential relevance, as five of the Phase 3 SOUs (42%) suggested it could help reshape the image of SOUs. As described earlier within the organizational features of SOUs two of the major initiatives that have historically been offered by the SOUs are the fun science demonstration workshops and summer camps for youth. Summer camps and fun workshops are still being offered, however, there are not their sole initiatives and mission. By using the knowledge brokering concept to inform the work that SOUs do, it does not “sound like we are just a summer camp or a science magic show, it’s that we are purposefully trying to bring new knowledge, excitement, and passion behind the STEM fields and transferring that onto students so they can pursue STEM. Having the well-defined terms of knowledge brokering could help change people’s views on what we do” (SOU # 71). Also, using the KMb concept to help re-shape the image of SOUs and their mission might help contribute towards legitimizing their role.
within the K-12 STEM education ecosystem and provide guidance on how to do this role more effectively within their community.

Part of the SOU role is focused on staying current with STEM knowledge, STEM careers, emerging STEM education trends, and using this information to provide capacity-building learning opportunities for their intended target audiences. By doing these things, the work SOUs do is "equivalent to the research that is happening at our institution. This work is not any less important or powerful than some of the huge research that we have brought millions of dollars in. It just looks different on the ground." If SOUs are interested in doing this, it might require them to “let go of the model and vocabulary that we already have and look at knowledge brokering again because the more that you unpack it, all of the actions are ones that we are doing” (SOU # 1). In support of the idea that knowledge brokering could help with SOUs identity formation within the community, 25% of the Phase 3 participants also suggested that the specific brokering functions could help categorize their initiatives and/or be used as a priority mapping exercise to identify program gaps.

The idea of using the brokering functions to categorize outreach initiatives was highlighted by SOU # 1 who suggested:

*I think we purposefully are doing some of these, so having the functions will enhance our programming. Awareness, accessibility, and engagement are all key pieces that we are always learning about and pushing ourselves to get to the next level and in both our professional development and delivery. So I think there's a lot within this that can benefit us as a STEM outreach organization.*

For SOUs to think about their initiatives and categorize them based on the brokering functions, three of the SOUs (25%) suggested that they would need a tool with clear descriptions and contextual examples, using the language that SOUs are familiar with, that can be used for identifying the categories each of their initiatives would fall into. Having this tool, combined with training on how to utilize it, could help SOU personnel conduct a program evaluation and mapping exercise. This exercise could also be viewed as a needs assessment or asset inventory to
identify where the individual SOUs are concentrating their efforts and identify areas to redistribute resources towards to achieve their intended outcomes and impacts.

The concept of exploring knowledge brokering was not well received by all of the SOUs in Phase 3 as 25% did not think the terminology was relevant for STEM outreach or felt that it was forced. Three of the 12 SOUs identified their uncertainty of using the specific business-world language or vocabulary around brokering as knowledge brokering is a concept that has never been applied to STEM before and might not be appropriate for SOUs.

Finally, one SOU (#39) suggested that knowledge brokering was not relevant for their SOU as it felt more like a research framework being forced onto STEM outreach. This SOU has a strong link to their respective faculty and a very specific goal related to improving the systems in place to make STEM education and outreach more efficient and of higher quality. At the same time, this SOU did suggest that for “probably 90% of all the other outreach organizations, the framework of a brokering function like this may work because they probably ranked ‘awareness’ and ‘engagement’ as a priority, whereas, for us, these aren’t a high priority for our goals right now” (SOU #39). This comment is an early indicator to suggest that there could be several different categories within the university-based SOUs. For example, depending on the missions of an SOU, there could be a relationship with the knowledge brokering functions they identify as a high priority, and/or it could inform how the SOUs approach their role within their K-12 STEM learning ecosystem.
Chapter 8
Discussion

The Government of Canada’s labor market project s a shortage within the STEM workforce (Conference Board of Canada, 2013; Council of Canadian Academies, 2014), and by 2067, that an estimated 70% of the top-ranking jobs in Canada will require STEM knowledge and skills (Parkin & Crawford Urban, 2017). To address the projected STEM workforce needs and future demands, one strategy involves the promotion of K-12 STEM learning ecosystems. These STEM learning ecosystems include all the various stakeholders and groups such as, schools, parents/families, community settings, community groups, post-secondary institutions, government, and STEM business/industry who contribute towards providing STEM learning opportunities to the current K-12 student population, as they comprise the future workforce.

This study explored university-based STEM outreach units, which are positioned predominately in the ‘white space’ of K-12 STEM learning ecosystems, spanning the boundaries as knowledge brokers between the groups within it. The first objective of this research was to identify and describe the organizational features of university-based SOUs within Canada. The second objective was to explore if and how knowledge brokering functions and collaborative partnerships could be used to make sense of university-based SOUs position and role within K-12 STEM learning ecosystems. Finally, connections were made between how SOUs' role as knowledge brokers within an ecosystem, in turn, supports students in developing STEM knowledge and skills needed to reduce the projected workforce gap in Canada.

Chapter 4 and Chapter 5 detailed the findings from Phase 1 and 2, whereas Chapters 6 and 7 detail the findings from Phase 3 which included the twelve individual cases. Chapter 8 discusses how the findings have informed this study’s conceptual framework proposed in Chapter 2. This chapter also discusses four emerging themes from this dissertation and situates their significance within the pre-existing STEM outreach literature; provide suggestions for practical
implications based on the themes; before discussing the limitations of this research, future recommendations for research, and practice, then offering a conclusion.

The results across all three phases related to the first research question suggest that there is a commonality in SOUs mission statements and target audiences. However, there is great variety in how these organizations work to achieve their intended aims including diversity in their initiatives, resources, capacity, and approaches to partnerships. University-based SOUs are expanding their efforts towards increasing the number of typically underrepresented and underserviced youth, including Black, Indigenous, racialized, youth from low socio-economic communities, and girls who are participating in STEM outreach programming, as one strategy towards establishing equity, diversity, inclusivity, and indigeneity (EDII). Another finding noted that SOUs’ capacity for internal program evaluation is limited but they are interested in increasing program evaluation efforts related to outputs, outcomes, and impact. These results highlight the large variance in organizational features for Canadian university-based SOUs that directly influence their initiatives, most of which are purposeful in trying to engage traditionally under-represented and underserviced youth with STEM content from within their local communities.

The results across all three phases related to the second research question indicate that SOUs have positive views on the idea of collaborative partnerships. In many cases, SOUs have established mutually beneficial partnerships with their host institution, K-12 schools, students, and community groups within their ecosystem; and mixed relationships with other groups in an ecosystem such as educators, parents, community settings, and STEM business/industry. This suggests that K-12 STEM learning ecosystems already exist to some degree but could be optimized with increased priority towards establishing collaboration, partnership, and trusting relationships with all groups within the ecosystem. In doing so, it would help to reduce the duplication of resources and content within a given ecosystem that could be reinvested towards providing new STEM learning opportunities for youth that are currently not being offered.
Finally, findings across all three phases related to the third research question suggest that university-based SOUs see the relevance in terms of how the concept of knowledge brokering could inform their role, applying various brokering functions, within the white space of their local K-12 STEM learning ecosystem. However, a reevaluation of the traditional knowledge brokering terminology should be revisited to better fit the context of STEM outreach. Moving forward, this finding suggests that SOUs are already delivering outreach initiatives that can be categorized within a knowledge brokering function, but with increased awareness of what the brokering descriptions are, SOUs could become more intentional about specific initiatives. Also, the intentional brokering of STEM knowledge to youth from traditionally underrepresented and underserviced groups in STEM is a result that suggests that EDII overlaps all KMb brokering functions for university-based SOUs. That said, far more work is needed to understand the link between EDII and SOUs.

Earlier in this dissertation, Figure 7 was proposed as a conceptual framework depicting SOUs positioned in a central role within a K-12 STEM learning ecosystem, acting as knowledge brokers between the various groups. Figure 7 also overlays organizational feature categories and knowledge brokering functions on top of the university-based SOU, that influence their position and role as knowledge brokers within the ecosystem. This research has provided evidence that has allowed me to continuously update this original conceptual framework. The first update was also described earlier in Figure 15 that specifically used the results from this study to illustrate the directional partnerships between SOUs and the various groups within a K-12 STEM learning ecosystem. Figure 17 synthesizes the above-mentioned salient findings in Chapter 4 - 7 as an evidence-informed version of the conceptual framework illustrating the position and role of university-based SOUs predominantly within the ‘white space’ of a K-12 STEM learning ecosystem.
Figure 17

The Updated Conceptual Framework Highlighting SOU Position and Role within a K-12 STEM Learning Ecosystem

Note. This figure illustrates how the original conceptual framework evolved to include the directional partnerships within the ecosystem while including the EDII-lens situated between SOUs organizational features and brokering functions. It also includes collaborative evaluation of outcomes and impact between SOUs and the groups within a K-12 STEM learning ecosystem.

Within Figure 17, several changes have been made from the original framework presented in Chapter 2. Considering that university-based SOUs are at the heart of this dissertation, they are at the center of the ecosystem. Moving outwards, the first level illustrates the organizational features of SOUs (to be discussed in more detail below within theme 1 and theme 2); with the only modification being the removal of impact that was previously associated with program evaluation. The second level is a new addition (highlighted in yellow), shedding light on the focus that SOUs have on providing learning opportunities to youth from traditionally
underrepresented and underserved groups in STEM as one strategy towards EDII that is also discussed below within theme 2. The position of the EDII label within the updated conceptual framework is unique and purposeful as it influences both the SOU organizational features and their knowledge brokering functions which is the third level of the framework and will be discussed below as theme 3. Within this third level, only the five brokering functions that were identified as most important and relevant for SOUs were included, thereby removing three from the original functions. The fourth level, another new addition, illustrates the focus of program evaluation that seeks to measure short-term, medium-term outcomes, and long-term impacts that are discussed below as theme 4. The emphasis on program evaluation has strategically been placed on the outer ring of the conceptual framework between the university-based SOUs and the groups within the K-12 STEM learning ecosystem.

When interpreting Figure 17, university-based SOUs can identify their organizational features and continue thinking about if and how it has an EDII lens, identify the knowledge brokering functions best practices and approaches, and then partner with specific groups within their learning ecosystem, to deliver the STEM initiative while implementing collaborative program evaluation strategies. In applying this approach to STEM outreach, this study suggests it will contribute towards providing an increase in quantity and quality of STEM learning opportunities to the current K-12 student population, as they comprise the future workforce, closing the projected STEM workforce needs and future demands in Canada. This bold impact statement is supported and further explained when discussing the four emerging themes from this research.
Theme 1: K-12 STEM Learning Ecosystems Already Exist but could be Optimized with Increased Priority Towards Establishing Collaboration, Partnership, and Relationships within the Ecosystem

The first theme to discuss is the notion that from the perspective of the university-based SOUs, K-12 STEM learning ecosystems already informally exist in some communities, suggesting that the concept of collaborative ecosystems has been emerging in Canada. The evidence around partnerships as shown by the black two-way arrows in Figure 17 suggests that SOUs have strong mutually beneficial partnerships with several of the groups within their community (such as students, K-12 schools, their university, and community groups) as all parties acquire benefits, they could not have manifested themselves. However, this study also suggests that more infrastructure and adoption on formalized STEM ecosystems could strengthen all partnerships between SOUs are other groups such as pre-service/in-service educators, the government, and STEM business/industry.

Previous studies within the United States focusing on STEM outreach literature have explored the conceptualization of formalized STEM learning ecosystems (Traphagen & Traill, 2014; 2015; Vance, Nilsen, Garza, Keicher, & Handy, 2016) and STEM outreach models (Bisbee O’Connell, Keys, & Storksdieck, 2017; Ward, 2015). Recently, preliminary research exploring how the first five years of STEM ecosystem implementation have worked in practice (Allen, Lewis-Warner, & Noam, 2020; Berry, 2020; Allen, Kastelein, Mokros, Atkinson, & Byrd, 2020). This literature highlights the interconnectedness of groups and the importance of mutually beneficial relationships between SOUs and stakeholders and acknowledges that K-12 STEM education happens both within and outside the traditional classroom. One thing still missing from the literature is the clear indication as to where and how university-based SOUs fit within an ecosystem. This study is unique in that it has applied the concepts of knowledge brokering to better understand how ecosystems function and the explicit role of SOUs as knowledge brokers.
operating within the white space of K-12 STEM learning ecosystems. As such, future research on brokering in STEM outreach provides fertile ground to advance the impact of K-12 STEM learning ecosystems (Allen, Lewis-Warner, & Noam, 2020; Berry, 2020; Allen, Lewis-Warner, & Noam, 2020; Traill, Traphagen, & Devaney, 2015).

One of the perceived strengths of fostering a STEM learning ecosystem identified by SOUs in this study was that if buy-in towards multi-collaborative partnerships with groups is achieved through a shared vision and goals, it could increase the quality content and diverse STEM learning experiences for the youth. This finding is consistent with Ward’s (2015) systems model for STEM education outreach as well as Allen et al.’s (2020) study on ecosystem partnerships, suggesting that multiple domains with a shared vision, working in collaboration together, will enhance STEM education locally and state-wide. Within Allen et al.’s (2020) study, they draw upon the work of Noam & Tillinger’s (2004) partnership typology to unpack the kinds of partnerships within their ecosystem case study, which are relevant for university-based SOUs in Canada. According to Noam & Trillinger (2004), there are four types of partnerships:

1. Opportunity-based: Discovering overlapping interests. Member organizations maintain their autonomy. Collaboration is seen as functional. Members network to share knowledge and resources.

2. Collaborative: Joining forces. Member organizations develop common goals, benefit from one another’s strengths and experiences, and establish some accountability.

3. Interconnected: Developing an inclusive system. Member organizations develop clear communications and a level of intimacy. They engage in joint decision-making, shared programming, and group celebrations of accomplishments.

4. Transformational: Changing all partners. Member organizations accomplish more together than they do independently. Relationships are equal, not hierarchical.
When using the four types of partnerships outlined by Noam & Trillinger (2004) to reflect on the partnership results from this study between SOUs and the various groups within the K-12 STEM learning ecosystem, SOUs have Level 2 (collaborative partnerships) with students, schools, their university, and community groups. In some cases, SOUs have Level 2 partnerships with other groups such as community settings, STEM business/industry, and educators, but most university-based SOUs would be classified as having Level 1 (opportunity-based) partnerships.

With a more intentional focus on partnerships, even using the descriptions of partnerships proposed by Noam & Trillinger (2004) to categorize existing and new partners, university-based SOUs could move beyond the introductory level.

The results from this research suggest that for university-based SOUs to be involved within a K-12 STEM learning ecosystem, it is important to define and respect individual responsibilities and expectations. This would allow for SOUs to contribute their specialized strengths and STEM knowledge (niche) within the complementary system, to provide diverse learning opportunities for youth. In doing so, a transparent approach to roles and contributions of all parties involved would increase mutualism within the ecosystem. Defined roles might also minimize the tensions between SOUs and groups within an ecosystem and would help with overall alignment towards achieving the shared vision/goals, as there would be less competition towards access to students. One possible barrier acknowledged in the STEM outreach literature (Sadler, Eilam, Bigger, & Barry, 2018), as well as noted within the results of this study, is that SOUs might experience competing stakeholder needs.

Currently, one of the negative perceptions or concerns about fostering a collaborative ecosystem approach to STEM outreach is that SOUs have preferences in terms of partners, and some SOUs are not interested in working with specific groups, especially in a free open-sourced/sharing environment. Based on the results from some of the SOUs in this study, an emerging theme involves a slight concern over the control of content/resources they have created and the STEM outreach initiatives they deliver. Previous positive and negative experiences are
important drivers for future collaborations. The idea of SOUs working with specific groups, especially ones they have typically competed with for funding and target audience, leading to a negative experience, has been identified as a barrier for future collaborations. For some SOUs, partnerships are viewed as additional work, without the pay-off of being mutually beneficial. Instead, foraging and sustaining such partnerships becomes another under-resourced responsibility. This tension suggests that some K-12 STEM learning ecosystems are in imbalance, that they are not operating as sustainably as they could. However, like anything, change and optimizing STEM learning ecosystems, as mentioned by Allen, Lewis-Warner, & Noam, (2020) would require support in the form of a lead organization, an investment of time and financial resources, personnel to focus on partnerships. The findings of the current study suggest that university-based SOUs are well positioned within the ecosystem to be the lead organization and can act as a knowledge broker between partnerships. If K-12 STEM ecosystems were to have these components, it might mitigate the negative perceptions about collaboration, leading to a return on investment that could pay off over time. However, additional evidence is required to fully support this claim.

Practical Implication for SOUs

A systematic and collaborative approach to STEM outreach operationalized by organizations within a local learning ecosystem would also help SOUs with the scarcity of available resources as all groups would not have to spend time and money on developing STEM content that is essentially already developed and being offered by another group in the ecosystem. Embracing this approach may help SOUs to dedicate their resources to a few areas of expertise thereby avoiding duplication of efforts. However, there is minimal STEM outreach literature that explores and supports how STEM learning ecosystems are operationalized in practice. Recently, one research study (Liou & Daly, 2021) was published investigating multi-sector ecosystems that support a STEM pipeline for education and careers. The results from this article indicated that participating groups within the ecosystem have surface-level relationships and that deep
relationship involving strategic collaboration is limited. The literature result is similar to the
findings of this dissertation as shown by the level of partnerships within Figure 17, as well as
described above, suggesting that university-based SOUs predominantly have level 1 (opportunity-
based) or level 2 (collaboration) partnerships. One difference between the results in Liou &
Daly’s (2021) study and this dissertation research is the involvement of schools in the ecosystem
as within their study, the results indicated that schools and districts are rarely included as central
actors. The university-based SOUs within this dissertation appears to engage educators within the
formal in-school setting, with one intention being to increase student participation in the SOUs
informal STEM learning experiences, which could contribute to a larger reach and impact.

This study highlights the need for funding infrastructure to support university-based
SOUs to form, strengthen, and sustain partnerships within an ecosystem. In the STEM ecosystem
literature, funding has been identified as foundational to the sustainability of learning ecosystems
(Vance, Nilsen, Garza, Keicher, & Handy, 2016), particularly for leadership positions to help
facilitate partnerships. As more evidence emerges from the literature related to a successful
practice model, it could be used to inform university-based SOUs to secure financial resources to
sustain the K-12 STEM learning ecosystem. Overall, systematic collaborative partnerships within
an ecosystem that have similar goals, will yield better outcomes and impacts on youth than the
individual groups could achieve by themselves (Allen, Lewis-Warner, & Noam, 2020; Berry,
2020; Traphagen & Traill, 2015).

One of the main purposes for establishing collaborative partnerships within an ecosystem
identified by SOUs in this study is to gain access to youth as their intended target audience. To
achieve this, access hinges on relationships with key stakeholders that have the control/power to
both enhance and limit a youth’s STEM learning experiences and indirectly their STEM
perception and/or STEM knowledge. With positive relationships, SOUs would be able to move
beyond opportunity-based partnerships and cross into interconnected or transformational
partnerships (Noam & Trillinger, 2004), that support the sustainability and effectiveness of
STEM learning ecosystems (Allen, Lewis-Warner, & Noam, 2020). Within a K-12 STEM learning ecosystem, as supported by Bisbee O'Connell, Keys, & Storksdieck (2017), the first key stakeholder that SOUs should partner with is educators, who to some degree (acknowledging the limitations of resources, curriculum, and professional judgment) control the STEM experiences students receive in a typical school day and likewise, in-school and extra-curricular programming. The second key stakeholder for SOUs to partner with are parents and/or guardians, who play a significant role in shaping a child’s life. Finally, the third group of key stakeholders that SOUs should establish partnerships with is leaders within their local community who can also influence a child’s perceptions and knowledge of STEM.

Currently, many SOUs do not engage educators and parents in their outreach initiatives, as it is not within their mission, instead they primarily dedicate their resources towards engaging youth. For the select SOUs that do, it is very infrequent. But, by intentionally focusing on establishing a relationship between SOUs and these three key stakeholder groups, followed by strengthening and maintaining that relationship, the key stakeholders might see the mutualistic benefits and the support they get from partnerships with SOUs. One strategy SOUs could utilize in establishing a relationship is to explore the literature within Cooper et al.’s (2018) RPP framework that describes how positive partnerships contribute to network success (such as increased self-confidence and enthusiasm for those within the network). If a positive relationship was established between SOUs and key stakeholders within the K-12 STEM learning ecosystem, the ecosystems could progress towards optimal functionality, leading to the long-term impact of closing the projected STEM workforce gap in Canada.
Theme 2: There is a Large Variability of University-based SOU Organizational Features, with a Common Focus on Engaging Youth Who are Under-represented and Underserviced in STEM, Across the Pan-Canadian Landscape

This study found diverse organizational features across university-based SOUs in Canada. Supported by the literature on STEM outreach used in this dissertation’s literature review (Brawley et al., 2008; DeCoito, 2016; Eilam, Bigger, Sadler, Barry, & Bielik, 2016), as well as a new literature review article on STEM outreach (Tillinghast, Appel, Winsor, & Mansouri, 2020), the mission of SOUs is to provide engaging and inspiring STEM learning opportunities to youth, to increase their STEM activity and awareness, with the hope that they will continue to engage in STEM subjects and careers. This study extends that work by providing a national overview of university-based SOUs in Canada, where previously no work has existed to map that terrain.

The results of this study demonstrate how Canadian university-based SOUs are well-position to deliver formal STEM outreach initiatives complementary to the traditional K-12 curriculum often delivered to student’s in-class using a range of activities (Tillinghast, Appel, Winsor, & Mansouri, 2020) and informal initiatives such as in-school workshops, after-school clubs, and camps. However, the SOUs range dramatically in size, in both their resources and capacity. The range of annual operating budgets for SOUs varies from $150k to over $1 million. There was also a wide range of funding source types amongst SOUs, as some are fully dependent on external sources of funding, whereas others are largely dependent on revenue-generating programs such as summer camps. In terms of capacity, most of the SOUs have a small full-time staff (1 - 3 people) who are employed year-round to manage the STEM outreach initiatives, whereas some have no full-time staff and others have over ten. With this said, one consistent result across the SOUs was the reliance on university students during the spring and summer months as many SOUs experience a large influx in capacity due to seasonal staff. Regardless of their current resources and capacity, all the SOUs in this study indicated that they are under-
resourced and under-capacity, limiting their output potential and possible outcomes. The self-perception of being under-resourced is consistent with Tillinghast et al.’s (2020) STEM outreach literature review and another article that explicitly describes the barrier of limited institutional support structures from universities (Sadler, Eilam, Bigger, & Barry, 2018).

When analyzing the organizational features across the SOUs in terms of their size, compared to the number of partnerships they have within their ecosystem, there was no emerging trend. The findings suggest that the size of the SOU does not determine the number of partnerships. Rather an SOU’s approach to partnerships within an ecosystem might have more of a direct relationship with factors such as their mission, training of SOU staff members, or personal preference and existing relationships of the director/manager. The approach to establishing and sustaining partnerships may be linked to SOUs practitioner's capacity to speak the STEM education language and make connections between outreach initiatives and the various strands of the provincial STEM curriculum. Another approach to partnerships might have more to do with the manager/director's personal views about collaboration and their abilities to form and maintain professional relationships. For example, if the manager/director of an SOU sees value in working with others to achieve common goals or reciprocity, then they might be more predisposed to invest their resources into partnerships. The importance of communication between STEM outreach practitioners and stakeholders within schools to ensure the learning objectives of an outreach workshop are feasible and achieved is also discussed in prior literature (Bagiya, 2016; Bisbee O'Connell, Keys, & Storksdieck, 2017).

The final SOU organizational feature is the focus on engaging underrepresented and/or underserviced groups within STEM such as Black, Indigenous, racialized, youth from low socio-economic communities, and girls. That said, this study only collected data from the perspective of SOUs, and to confirm the level of engagement from SOUs and possible impact, it would be important to collect information from the groups themselves. Yet, this intentional engagement of specific youth has been widely identified within the literature (Allen, Lewis-Warner, & Noam,
2020; Bagiya, 2016; DeCoito, 2016; Rammel, Adonis, & Sainsbury, 2006; Tillinghast, Appel, Winsor, & Mansouri, 2020). However, within the STEM outreach literature, the emphasis on engaging underrepresented and underserviced youth is not as extensive, consistent, and deliberate, as it is for the Canadian university-based SOUs in this study who described their activities as one approach towards supporting equity, diversity, inclusion, and indigeneity (EDII) in STEM fields. SOUs focus on increasing the number of underrepresented and underserviced youth engaging in STEM outreach is one approach to EDII is an important cross-cutting theme that was prevalent in the remaining themes and an area for future research of this field.

**Practical Implication for SOUs**

Understanding organizational features are important for SOUs so they can decide how to best target their resources for maximum impact. Beyond the SOUs mission, a large determinate for SOUs activities, supported by the STEM outreach literature (Tillinghast, Appel, Winsor, & Mansouri, 2020), is linked to available financial resources. With financial granting programs in Canada such as CanCode and PromoScience from the Federal government encouraging, and in some cases making it a requirement to provide STEM learning opportunities to underrepresented and underserviced youth, suggests that outreach programs should align themselves with these high priority groups. In doing so, they increase their chances of external funding that significantly influences their organizational features. Similarly, the affiliate universities of the SOUs are interested in increasing the diversity of the student population enrolled in STEM programs at their institution. Therefore, a logical precursor is to explore the K-12 education system pipeline and find strategies to support future students’ exposure to various STEM fields/professions and the education pathways required to reach them.

Another implication for SOUs whose mission focuses on specific marginalized audiences is to be more inclined to partner with community groups or schools that already serve this target audience, as it would help increase accessibility to the outreach programming and achieve their mission simultaneously. The approach to establishing and sustaining partnerships requires
communication between STEM outreach practitioners and stakeholders to establish clear roles and responsibilities within the partnership to achieve the common goals or reciprocity.

Overall, positive STEM outreach learning experiences could inspire individuals to pursue a postsecondary STEM pathway that may eventually lead to a STEM career, closing the projected workforce gap in Canada. However, a lot of work needs to be done within the SOU, their affiliated university, stakeholders, and funders to help ensure SOUs have adequate organizational features to support their local K-12 STEM learning ecosystem, working towards achieving the desired outcomes.

Theme 3: Increasing the Number of Underrepresented and Underserviced Youth Involved in STEM Outreach is a Lens That Overlaps All KMb Brokering Functions for University-based SOUs within a K-12 STEM Learning Ecosystem

University-based SOUs are well-positioned within the K-12 STEM learning ecosystem, as knowledge brokers who are situated between various stakeholders to facilitate, share, and communicate STEM knowledge using brokering functions. These functions can help build STEM knowledge and capacity among diverse target audiences within a K-12 STEM learning ecosystem, similar to an interactive model to knowledge brokering (Landry, 2001). However, this study suggests there are mixed views regarding if SOUs actively look to broker knowledge or if the delivery of STEM outreach knowledge is more passive.

If knowledge brokering is defined as intentional in its efforts, then some university-based SOUs expressed differences between their role and that of knowledge brokering. The main justification for the difference is because many SOUs typically offer a fee-for-service such as camps or paid STEM outreach workshops in schools, a feeling that this cost-recovery model might not align with the concept of knowledge brokering, which they perceived to be a free service. Some SOUs are concerned that if they were to broker STEM content consistently free of charge, they would lose the proprietary value-add that helps stimulate the demand for their
services, in turn, helping generate revenue to support SOUs' operating expenses. This fee-for-service model raises a concern about accessibility for STEM outreach and equity to schools and students, as some schools and families cannot afford STEM outreach opportunities. To address this challenge, the various levels of government should continue to enhance financial support (such as PromoScience, CanCode, or other Federal and Provincial funding) for SOUs to offset their expenses so they can broker STEM knowledge by providing and facilitating free STEM outreach programming within the ecosystem. The need for funding is consistent in the KMb literature (Cooper, 2014; Hoing, 2004; Ward, 2017). This continual need transfers into this context suggesting that dedicated resources tied directly to KMb efforts are needed to increase a knowledge broker's role and success within an education setting.

This dissertation provides a novel contribution and advances the field of STEM outreach in two ways: 1) by applying knowledge brokering literature and concepts to advance research on STEM learning ecosystems and the explicit role of SOUs as knowledge brokers operating within the white space of K-12 STEM learning ecosystems, and 2) using the brokering concepts to explore and better understand the practice of university-based SOUs with diverse stakeholder groups and target audiences. The concept of knowledge brokering within a STEM learning ecosystem has started to emerge in three recent articles (Allen, Lewis-Warner, & Noam, 2020; Allen, Kastelein, Mokros, Atkinson, & Byrd, 2020; Liou & Daly, 2021). In the study conducted by Allen, Lewis-Warner, & Noam (2020), the specific knowledge brokering organization being explored was a regional STEM alliance group comprised of several organizations that advocate for education policy to give every study access to STEM education. Similar to the results of this study outlining the university-based SOUs brokering functions, the alliance knowledge brokering group from Allen, Lewis-Warner, & Noam (2020) were involved in providing training and professional development for STEM educators (capacity building function), collaborating with other organizations within the community to implement STEM programs and events (linkage and...
partnership function), and design/deliver STEM programming to children (awareness, accessibility, or engagement functions).

A STEM ecosystem knowledge broker, as described by Allen, Kastelein, Mokros, Atkinson, & Byrd (2020) as ‘STEM Guides’, refers to individuals who focus specifically on brokering activities that can help make ecosystem opportunities more accessible and equitable. This description of a STEM guide is very similar to the description of a knowledge broker used throughout this dissertation. Another similarity between this dissertation and the work of Allen et al. (2020), is that both studies provide a visual representation of knowledge brokering and the activities, situated within the ecosystem. More specifically in the Allen et al. (2020) model, the STEM learning ecosystem consists of youth and families at the center, then concentric circles showing a microsystem (of people and places that have direct contact with the youth, such as school or the library) and the mesosystem of informal STEM resources and opportunities that do not, as yet, have any direct connections with youth. This student-centered ecosystem visualization is similar to other models within the literature (Bisbee O'Connell, Keys, & Storksdieck, 2017; Traphagen & Traill, 2014), but is different than the conceptual framework for this dissertation that purposefully positions university-based SOUs at the center.

The study conducted by Allen et al. (2020) is also unique and different from this dissertation research in that the knowledge brokers were purposefully hired into a paid brokering role, with no allegiance to any particular organization, to facilitate knowledge sharing between the youth/families and the various STEM learning opportunities readily available but unfamiliar to them within the ecosystem. The main activities utilized by the brokers within Allen et al. (2020) consisted of:

1) shallow brokering: pointing to a STEM resource,
2) intermediate brokering: supporting youth to engage with a STEM resource, and
3) deep brokering: leading youth through the experience of a STEM resource.
This leveling approach to knowledge brokering activities was also apparent from the results of the SOU activity highlighted in this dissertation. In particular, SOUs are involved in sharing STEM education resources to target audiences which could be classified as shallow brokering (Allen, 2020), but also provide opportunities for youth to engage in hands-on learning as a form of deep brokering. The leveling approach also has relevance for university-based SOUs as they can be integrated within the proposed brokering functions within this dissertation. For example, for the capacity building function, any SOUs could be involved in shallow brokering, whereas the same SOU could be involved with deep brokering in terms of awareness.

The idea of universities in general as knowledge brokers, not explicitly outreach units within them, is hinted at in a recent study by Liou & Daly (2021). This study suggests that universities themselves occupy a central position within an ecosystem, connecting and bridging organizations together; but, their connectivity to the K-12 education sector is relatively limited in terms of partnerships. The results from this dissertation indicate that most of the university-based SOUs have a positive and reciprocal relationship with their host institution, however, many SOUs feel that they are the link between the university and the community. The disconnect between universities and the K-12 education sector as noted by Liou & Daly (2021) is similar to the results from this research. As such, future research on university-based STEM outreach units leveraging their university’s central position within the ecosystem to broker STEM knowledge to the K-12 education sector, could provide ground to advance K-12 STEM learning ecosystems.

**Practical Implication for SOUs**

This study incorporates knowledge brokering literature and concepts that can be applied to improve the work of SOUs. In terms of the knowledge brokering functions, this study confirmed that accessibility, awareness, and engagement are extremely relevant for university-based SOUs and contribute towards their established role within a K-12 STEM learning ecosystem. Similarly, but to a lesser degree, so are linkages and partnerships, and capacity building. What was surprising from the results was the common link between SOUs using the
brokering functions to purposefully increase the number of underrepresented and underserviced youth, as one strategy towards achieving equity, diversity, inclusion, and Indigeneity (EDII) in STEM. The focus on underrepresented and underserviced youth and its relevance to EDII have already been discussed in previous themes and remain an important area that has yet to be integrated across the knowledge brokering literature. Chapter 2 first presents the knowledge brokering functions that were generated based on Cooper’s (2014) KMb brokering literature but adapted to fit within the STEM education context of this research. Table 21 presents updated knowledge brokering function descriptions, which are informed by the results of this research and support the cross-cutting EDII theme and can be used by SOUs. As opposed to the original brokering descriptions that were broad, the updated descriptions include additional STEM outreach language and tangible examples that will help clarify the brokering functions for SOUs.

Table 21

*Updated Description of Knowledge Brokering Functions for SOUs*

<table>
<thead>
<tr>
<th>KMb Function</th>
<th>Original Brokering Function Descriptions</th>
<th>Updated Brokering Function Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engagement</td>
<td>Increasing engagement with STEM education and content by making it appeal to a variety of senses.</td>
<td>Making STEM knowledge and skills more relevant to various target audiences, through purposefully designed hands-on experiential learning opportunities for a specific audience, including those that are traditionally under-represented in STEM (<em>specific EDII influence</em>), that appeal to a variety of senses.</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Increasing accessibility to STEM education and outreach research by</td>
<td>Tailoring STEM knowledge and skills related to the intended target audiences that include a visual representation of the target audience(s) through SOU staff, mentors, or other collaborators to illustrate the</td>
</tr>
</tbody>
</table>
Tailoring products to accessibility and diversity of STEM careers (*EDII influence*). Accessibility constraints such as geographical location and participating costs of the STEM outreach initiatives need to be considered to increase inclusivity (*EDII influence*) of youth who might not have the financial means to participate.

<table>
<thead>
<tr>
<th>Awareness</th>
<th>Increasing awareness</th>
<th>Intentionally providing diverse STEM learning opportunities, covering a wide spectrum to STEM areas, to provide accurate information about the breadth of STEM fields and careers to a diverse target audience, including those traditionally underrepresented in STEM fields (<em>EDII influence</em>). Also, when relevant, include culturally relevant STEM content (such as Indigenous perspectives) within learning opportunities to decolonize STEM knowledge.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Linkage and Partnership</th>
<th>Facilitating connections among diverse STEM education stakeholders and groups within a local K-12 STEM learning ecosystem to identify specific individual roles, contributions, and shared resources, leading to providing continuous collaboration. and diverse STEM education learning opportunities for all youth (<em>EDII influence</em>).</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Capacity Building</th>
<th>Facilitating professional learning and skill development around STEM knowledge to a variety</th>
</tr>
</thead>
</table>
and skill development around STEM education/outreach. of target audiences (EDII influence), helping children, youth, and young adults to have the confidence and competence to pursue STEM career pathways.

By explicitly considering the brokering functions and the terminology, SOUs could: 1) map their priority initiatives onto each of the brokering functions; 2) consider their application towards increasing participation of youth from traditionally underrepresented and underserved groups in STEM), and 3) identify any partner groups within the ecosystem needed to operationalize the multi-directional flow of STEM knowledge. This practical implication could also help SOUs identify areas of strength and areas for improvement within their programs that could be used for future planning.

Drawing implication from Allen et al.’s (2020) study, SOUs as knowledge brokers should aim to build trust and credibility to understand the target audience’s needs; determine which level (shallow/pointing, intermediate/supporting, or deep/leading) of brokering involvement is appropriate for specific target audiences and individuals; identify access and cultural barriers that might exist for the target audience, and be aware of the logistical challenges and resources needed to bring multiple partners together.

**Theme 4: University-based SOUs are Interested in Shifting their Evaluation Efforts from Individual Program Outputs to Focus on Program Outcomes and Impact**

This study underlines the need to strengthen SOUs’ program evaluation capacity, which is consistently identified within STEM outreach literature (Bagiya, 2016; Bisbee O’Connell et al., 2017; Karmokar & Shekar, 2018; Ward, 2015; Young et al., 2017). SOUs regularly collect program evaluation information in the form of output data from their initiatives to showcase tangible products, capacities, or deliverables thought to result from the outreach activities. Within
Allen, Lewis-Warner, & Noam’s case study (2020) on ecosystems, they also report on output data suggesting that the ecosystem approach contributed to an increase in student program engagement. While these sentiments are important, and influence students’ desire to continue learning about STEM, they are not a direct assessment of the knowledge, skills, or attitudes attained or changes because of project activities (i.e., outcomes).

Measuring program outcomes which are assessed longitudinally over the short term (1-3 years), medium-term (4-6 years), and long term (7-10 years) can be a challenge, as noted in the K-12 STEM outreach literature (Brawley et al., 2008; DeCoito, 2016; Eilam et al., 2016; Turner et al., 2007). Most SOUs in this study acknowledged their reliance on output measures as a weakness and could be expanded greatly with increased organizational features, hence the need to include program evaluation as an organizational feature of SOUs. A need for dedicated resources such as time, finances, and administrative support as well as the need for formal education training, and the need to bring in a program evaluation person as a collaborator to explore strategies for tracking students’ development of STEM knowledge, skills, and attitudes over time, as well as their decisions to pursue and complete postsecondary STEM education and a STEM career, is consistent with other STEM outreach literature (Allen, Lewis-Warner, & Noam, 2020; Bisbee O’Connell et al., 2017; Traphagen & Traill, 2014; 2015; Ward, 2015).

Improving the continuous evaluation of STEM outreach programs and initiatives has also been discussed within the STEM outreach literature (DeCoito, 2014; 2016). Bagiya (2016) suggested that a program evaluation toolkit/quality framework is necessary to explore the outcomes and impact of STEM outreach (Bagiya, 2016). However, measuring impact is notoriously difficult, especially when the measurements of concern involve school-aged children. The focus on practical recommendations that could help SOUs evaluate outcomes and impacts of SOUs is a theme that is absent across STEM outreach literature. This study contributes important evaluation foundations that can be used to inform STEM outreach.

Practical Implication for SOUs
This study suggests that program evaluation is required both internally at the SOUs level as well as externally between SOUs and the groups within an ecosystem. By working in collaboration as a STEM learning ecosystem, the overall functionality of the system would increase, contributing towards achieving the intended outputs, outcomes, and impact of both the individual SOUs and the ecosystem.

Collaborative Approaches to Evaluation (CAE) is an approach to program evaluation wherein trained evaluators work in partnership with members of a given community to produce evaluative knowledge (Shulha, Whitmore, Cousins, Gilbert, & Hudib, 2016). If CAE were to be implemented into practice, university-based SOUs should first consider the following 8 guiding principles (Shulha, Whitmore, Cousins, Gilbert, & Hudib, 2016), as shown in Table 22.
### Table 22

**Principles of Collaborative Approaches to Evaluation Recommended for University-based SOUs**

<table>
<thead>
<tr>
<th>Principle</th>
<th>Factors to Consider (Shula et. al., 2016)</th>
<th>Link to an emerging theme from this research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarify motivation for collaboration</td>
<td>• What is the evaluation purpose?</td>
<td>• Theme 1 and 4 discussed the need for collaboration, a common mission, defined roles for groups within a STEM learning ecosystem.</td>
</tr>
<tr>
<td></td>
<td>• What are the stakeholder expectations?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• What processes are needed?</td>
<td></td>
</tr>
<tr>
<td>Foster meaningful inter-professional</td>
<td>• Is there respect, trust, and transparency?</td>
<td>• Theme 3 discussed the importance of establishing positive relationships which include trust.</td>
</tr>
<tr>
<td>relationships</td>
<td>• Structured and sustained activity?</td>
<td>• Theme 1 and 2 discussed the SOUs' organizational features and partnerships contributing to activities.</td>
</tr>
<tr>
<td></td>
<td>• Ways to include cultural competency?</td>
<td>• Cultural competency is discussed through themes 1 - 4.</td>
</tr>
<tr>
<td>Develop a shared understanding of the</td>
<td>• What are the individual program logics?</td>
<td>• Theme 1 and 2 discussed the significance of shared understanding and common goals for STEM outreach.</td>
</tr>
<tr>
<td>program</td>
<td>• What is the organizational context?</td>
<td>• Theme 4 discussed the use of logic models for representing ecosystems and brokering functions to support the achievement of the shared outcomes of STEM outreach</td>
</tr>
<tr>
<td>Promote appropriate participatory processes</td>
<td>• Is there a diversity of stakeholders?</td>
<td>• Is there depth of participation?</td>
</tr>
<tr>
<td>Monitor and respond to resource availability</td>
<td>• Who contributes to the budget?</td>
<td>• What is the time commitment?</td>
</tr>
<tr>
<td>Monitor evaluation progress &amp; quality</td>
<td>• How to set up an evaluation design?</td>
<td>• What do you do for data collection?</td>
</tr>
<tr>
<td>Promote evaluative thinking</td>
<td>• Is there an inquiry orientation?</td>
<td>• How do you evaluate a focus on learning objectives?</td>
</tr>
<tr>
<td>Optimize the influence of evaluation</td>
<td>• Are there practical outcomes?</td>
<td>• Are there transformative outcomes?</td>
</tr>
</tbody>
</table>
CAE is a formative approach to evaluation and can be used to solve practical problems (such as collaboration between groups in a K-12 STEM learning ecosystem); as a means to build capacity with SOUs personnel while working towards self-determination and action; and to develop understanding and meaning with all parties involved in a STEM learning ecosystem. For university-based SOUs interested in increasing their capacity towards program evaluation both at the organizational level (internal) and at the ecosystem level (external), one possible practical implication is to have an embedded program evaluation expert. Since partnerships are an essential core to ecosystems, the evaluation expert could be a partnership with groups embedded within their respective institutions, that have evaluation expertise, and can apply the principles of CAE to build the evaluation capacity of individuals within the SOU as well as individuals K-12 STEM learning ecosystem.

Due to the complexity of K-12 STEM learning ecosystems and the number of stakeholders involved, a collaborative approach to evaluation is poised to support several themes identified in this study. For university-based SOUs intending to use the eight-core principles (Shula et. al., 2016) and apply a collaborative evaluation framework, it is important to integrate them at the beginning of the overall design of the program and the ecosystem level. The rationale behind this decision is that taking a collaborative approach and increasing the stakeholder involvement, will increase the overall use of the program by the intended users (Patton, 2012).

Despite these promising results and themes that aim to understand the role of university-based SOUs within K-12 STEM learning ecosystems, acknowledging the limitations of this research, there remains space for further exploration to strengthen the conclusions and suggestions of this study.

**Limitations**

Within the design of this research, two categories of limitations need acknowledgment: 1) instrument design for the three phases, and 2) myself as the research instrument. Both limitations
were considered throughout the research and best efforts were used to manage research bias and mitigate the limitations.

**Instrument Design**

Taken individually, each phase of this study has its limitations. In Phase 1 (website analysis), the first limitation to acknowledge is the inclusion criteria used in the sample as the study was purposefully looking for formalized SOUs embedded within a university, excluding those units that are volunteer-based organizations or one-off STEM outreach initiatives. A limitation of the website analysis tool is that some university-based SOUs were excluded from Phase 1 due to the lack of publicly available information on their website. To minimize this limitation, a complete and thorough investigation of each website was conducted before any exclusion. For those SOUs that were subject to further investigation, a second limitation was that SOUs might be more involved in their ecosystem than what was featured on their websites. Although the website might not depict all the SOUs activities, it was a necessary and openly accessible starting point for mapping the landscape of university-based SOUs in Canada to be further explored in Phase 2. To counteract this limitation, the individual website analysis scores did not impact the inclusion criteria for Phase 2, as all identified SOUs in Phase 1 were recruited to participate in Phase 2.

Phase 2 (the online survey) introduced limitations based on its design. Firstly, the number of participating SOUs who completed the survey was 25, which is 31% of the Phase 1 participants. However, a response rate of 31% is within a normal range (Patton, 2002). As with any sample, caution should be exercised to avoid generalizing findings to be representative of all university-based SOUs. A second limitation in Phase 2 was the design of the online survey. The terminology that was used about the constructs ‘ecosystems’ and ‘knowledge brokering’, including the emphasis on research evidence, might have been new or unclear, thereby limiting the depth of participant responses in Phase 2. This language/terminology limitation from Phase 2 was minimized by conducting follow-up interviews in Phase 3 with the participants representing
the SOUs who had prior exposure to the terms since they participated in Phase 2 and were sent the interview questions in advance, providing more time to think about the concepts.

Nevertheless, Phase 2 highlights the breadth of SOU organizational features while starting to explore the conceptualization of SOUs functioning as potential knowledge brokers within the white space of K-12 STEM learning ecosystems.

The intent of Phase 3 was to interview 12 university-based SOUs as individual case studies that are best-suited to inform the research questions around the quintain. In doing this, it introduces several limitations associated with boundaries. This phase offers self-reported interpretations of K-12 STEM learning ecosystems and STEM knowledge brokers from the perspective of participants representing ten university-based SOUs in Canada. It did not include the perspective of the other STEM stakeholder or partner groups within an ecosystem, potentially leading to a one-sided or bias perspective and history. Therefore, caution should again be exercised when attempting to extrapolate findings across other ecosystems. Although strategies for establishing trustworthiness and increasing internal validity were taken, such as triangulating insights across all 3 phases and data sources to build a progressive understanding of the same research questions, the ability to generalize qualitative findings beyond these ten case studies still has limitations.

Overall, the findings from Phases 1 – 3 complemented one another in both scope and focus, arriving at an in-depth investigation of ten individual cases that include descriptions that are thick with details about the context, participants, and direct quotes to represent all SOUs. These twelve cases simultaneously showcased the breadth of differences across university-based SOUs, and how the concepts of K-12 STEM learning ecosystems and SOUs role as knowledge brokers within it could contribute towards increasing the STEM knowledge and skills of youth, with the long term impact of closing the projected STEM workforce gap in Canada. I encourage readers to infer beyond the limitations of this study and apply the awareness gained from the research to their own university-based professional education programs. In this way, the findings
can be treated as working hypotheses to be investigated in other contexts (Cronbach, 1975; Guba, 1978).

**Myself as the Instrument**

Throughout this dissertation, efforts have been made to enhance the quality and credibility of the research methods, which are both a strength and a limitation. As a solo researcher who designed, collected, and thematically analyzed all data, there are several possible limitations. The first limitation to acknowledge is the researcher's inside perspective to the context of this study. As a manager of a university-based SOU, who has established relationships with many of the directors or managers of the SOUs included in the study, personal experiences as an active member (SOU in a STEM learning ecosystem) could be viewed as a limitation. On the other hand, this position enables me to analyze the results through an experienced lens to make better sense of the data. However, this limitation must be considered when reading the dissertation. To help increase the credibility of the research, I demonstrated credibility by being thoughtful in my approach to building professional relationships with the participants by making sure the purpose of the research was explained as well as outlining the methods.

Secondly, the existing relationships with other SOUs in Canada could be viewed as a limitation as the participants might have felt obligated to participate in this study, but again, this could be viewed as a strength. Pre-existing relationships were used to increase participation rates and obtain authentic answers to the research questions as the participants were more likely to engage with a trusted professional working within STEM outreach. To minimize this limitation throughout the study as a way to increase transparency, I articulated my views and prior relationship in the autobiographical statement in Chapter 1, as well as discussed this topic with each participant before the Phase 3 interviews. Overall, when making sense of the data, I was careful to check any interpretations against cited literature, the conceptual framework (updated in Figure 17 at the beginning of this chapter), and this study’s committee members’ knowledge with STEM, knowledge mobilization, and program evaluation across professional education programs.
**Recommendations**

This work provides a starting point upon which to launch future research related to how Canadian university-based SOUs operationalize their role as STEM knowledge brokers, with a focus on increasing the number of youth from traditionally underrepresented and underserved groups in STEM, within a K-12 STEM learning ecosystem, to evaluate the outcomes and impact of their programs. K-12 STEM learning ecosystems that consist of multi-sector partnerships collaborating to increase STEM learning outcomes for all have expanded over the last few years in the United States to become a large macro-system (Traphagen & Traill, 2014; 2015). Evidence from Allen, Lewis-Warner, & Noam (2020) suggests that within an established ecosystem, partnerships across contributing organizations moved beyond opportunity-based, crossing into collaborative partnerships and early signs of interconnected partnerships. These strong partnerships are contributing towards sustainable impact from the ecosystem in terms of youth involved in programming as well as continuous funding.

The proposed recommendations related to research, and practice build from the need for more formalized K-12 STEM learning ecosystems within Canada, that involve university-based SOUs as knowledge brokers. One of the recommendations from Allen and colleagues (2020) exploring STEM knowledge brokers was to have someone in the community who already has regular access to youth. This knowledge broker would embrace the inherently entrepreneurial and boundary-crossing nature of brokering, which includes not only the familiar and appealing aspects of working directly with youth but also a role negotiating with organizations and individuals toward a larger vision, much like a community organizer. Based on the results of this dissertation, university-based SOUs can fulfill this role. Table 23 includes practical recommendations for university-based SOUs when considering collaborating with various groups as knowledge brokers within a K-12 STEM learning ecosystem. It is important to note that although most of the recommendations within Table 23 are evidence-based from the data in this
study, some of the recommendations, such as the recommendations towards school leadership and parents, did not emerge from the data but are areas to consider.

**Table 23**

*Practical Recommendations for University-based SOUs towards Ecosystem Groups*

<table>
<thead>
<tr>
<th>Ecosystem Group</th>
<th>Recommendations</th>
</tr>
</thead>
</table>
| University-based SOUs | • Receive training on knowledge brokering functions that can help build internal capacity when designing STEM outreach initiatives with curriculum links, pedagogy, age-appropriate language, and dynamic, interactive, and accessible activities.  
  • Use Collaborative Approaches to Evaluation to engage ecosystem partners in the process of improving data collection related to program outputs, outcomes, and impact. |
| Educators | • Explore the capacity and willingness to partner with SOUs, thereby providing access to students. |
| Parents | • Increase awareness of the ecosystem groups and their STEM programs designed to engage students while providing strategies for parents in understanding and supporting students’ STEM success. |
| Affiliated University | • Consider using the KMb brokering terminology, embedded with the EDII lens, to align your SOUs with the Faculty/University’s strategic vision. |
| Community Settings | • Identify the community setting within your ecosystem that currently provides services to youth, especially those settings attended by underrepresented populations in STEM, and learn about their community |
values towards education and collaboration. Following, discuss with key stakeholders any common goals and possibilities to collaborate, with specifics about reciprocity, to mutually benefit their target audiences.

| Community Groups | Identify the community groups within your ecosystem that currently provide services to youth, especially those groups who service underrepresented populations in STEM (EDII lens), and learn about their niche contribution to the ecosystem. Following, discuss with key stakeholders any common organizational goals and possibilities to collaborate, with specifics about reciprocity, to benefit their target audiences. |
| STEM Business & Industry | Engage local STEM businesses and industry as community partners to contribute personnel and financial resources to address the identified resource gaps within STEM education. Ensure to highlight the reciprocated benefits of giving back to the community such as increased awareness of their business, the positive perception it provides, the opportunity for employees to represent their business, etc. |
| Government | Apply to NSERC’s PromoScience funding as a pilot project encouraging collaboration among partners. This will demonstrate the interest in establishing formalized and collaborative K-12 STEM learning ecosystems. This interest would provide evidence to the various levels of government to support the development and coordination of STEM learning ecosystems; especially those that provide opportunities to underrepresented and underserviced youth. |
| Program Evaluation Experts | Seek out opportunities to involve experienced program evaluators, or invest in internal program evaluation capacity building, to implement the |
collaborative approaches to evaluation within your SOUs as well as within the K-12 STEM learning ecosystem.

In terms of future research recommendations, four areas are suggested based on the results and emerging themes that will help further explore K-12 STEM learning ecosystems. First, this dissertation explored the role of SOUs within a K-12 STEM learning ecosystem from the perspective of university-based SOUs. The first recommendation is to revisit the ten case-study ecosystems within this study to learn more about the role of university-based SOUs within the ecosystem but from the perspective of various stakeholder groups/partners identified within the conceptual framework (see Figure 1) such as schools, educators, or other community groups. With this multi-stakeholder perspective, it would provide evidence and clarity towards the perceived role of university-based SOUs, helping them understand what their contribution could be within a formal K-12 STEM learning ecosystem. Within this proposed area of research, a further recommendation would be to explore the stakeholder's/group’s views on multi-partner collaborative ecosystems to gauge interest levels and information about feasibility.

Within a K-12 STEM learning ecosystem, there are other types of SOUs such as for-profit organizations, non-profit/charitable organizations (such as Actua and Let’s Talk Science), student-led volunteer-based organizations (such as chapters of Let’s Talk Science and Women in Science and Engineering outreach chapters) within that might have a different role and intervention to achieve the intended outcomes of STEM outreach. Therefore, a second recommendation is to conduct a case study with one of the non-profit/charitable organizations (e.g. Actua or Let’s Talk Science) that have a national presence to learn more about their organizational features, brokering functions (if any), and role within local ecosystems and the larger Canadian K-12 STEM learning ecosystem (macro-system).

The third future research recommendation is to conduct an in-depth case study with the only formalized STEM learning ecosystem in Canada (‘symbiosis’ in B.C.) to learn more about
what is working and not working. More specifically, it would be interesting to learn about the governance of the ecosystem, the best practices towards sustaining mutually beneficial partnerships, challenges, and benefits of shared resources, the role of university-based SOUs, strategies towards program evaluation towards outputs, outcomes, and impact. Also, as Symbiosis is part of the larger STEM learning ecosystem community of practice established in the United States, learning more about this relationship and/or model and the transferability to the Canadian context would be valuable.

A final research recommendation is to explore the complexities related to outreach program evaluation and if/how CAE is useful for university-based SOUs. A valuable next step for SOUs is to learn more about how to assess learning outcomes, as many SOUs are good at tracking outputs of individual programs but have limited ways to track the longer-term outcomes and impact of all the STEM learning experiences they provide to youth. This evaluation would need to be done in collaboration with research ethics boards and community stakeholders.

**Conclusion**

To address the projected STEM workforce gaps in Canada, university-based STEM outreach units have a role to play in educating the *current* K-12 student population, as they comprise the future workforce. This dissertation concludes that university-based SOUs are already making valuable contributions to K-12 STEM learning ecosystems. In addition, can also be concluded that SOUs can play the role of STEM knowledge brokers, spanning the boundaries between stakeholders and other participating groups, within a K-12 STEM learning ecosystem. In doing so, university-based SOUs as knowledge brokers within a K-12 STEM learning ecosystem would contribute towards improving the STEM education learning opportunities within the ecosystem, supporting students in developing STEM knowledge and skills needed to reduce the projected workforce gap in Canada.
This research towards exploring the conceptual role for SOUs provides practical contributions to the literature on the currently under-explored topics of STEM outreach, K-12 STEM learning ecosystems, and STEM education knowledge brokering. It also provides immediate practical implications for university-based SOUs. Through the personal knowledge obtained through the dissertation as the researcher, I am now able to utilize the results, themes, and recommendations within my role as a manager of an SOU. In doing so, the plan is to mobilize this knowledge within a network of other SOUs managers across the country, encouraging them to interpret the findings of this research through their lenses and think about how it could inform the development of their K-12 STEM learning ecosystems. The hope is that the findings of this dissertation can lead to further conversations within and across university-based SOUs, challenging them to actively think about their role within the ecosystem, and how through collaborative partnerships with STEM education stakeholders can achieve the desired societal impact.
References


Appendix A

Research Design Information

A1 – General Research Ethics Board Approval

September 26, 2019

Mr. Scott Coupeau
Ph.D. Candidate
Faculty of Education
Queen's University
Dunsmuir McArthur Hall
511 Union Street West
Kingston, ON, K7M 5R7

GREB Ref #: GEDUC 973-19; TRAQ # 6027592
Title: "GEDUC 973-19 Knowledge Mobilization Intermediaries in K-12 STEM Education: A Case Study of Canadian University-Based STEM Outreach Organizations"

Dear Mr. Coupeau:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposed entitled "GEDUC 973-19 Knowledge Mobilization Intermediaries in K-12 STEM Education: A Case Study of Canadian University-Based STEM Outreach Organizations" for ethical compliance with the Tri-Council Guidelines (TCPS 2 (2014)) and Queen's ethics policies. In accordance with the Tri-Council Guidelines (Article 6.14) and Standard Operating Procedures (405.001), your project has been cleared for one year. You are reminded of your obligation to submit an annual renewal form prior to the annual renewal due date. (access this form at http://www.queensu.ca/trac/signon.html; click on "Events," under "Create New Event" click on "General Research Ethics Board Annual Renewal/Closure Form for Cleared Studies"). Please note that when your research project is completed, you need to submit an Annual Renewal/Closure Form in ResearchIQ indicating that the project is 'completed' so that the file can be closed. This should be submitted at the time of completion; there is no need to wait until the annual renewal due date.

You are reminded of your obligation to advise the GREB of any adverse event(s) that occur during this one-year period (access this form at http://www.queensu.ca/trac/signon.html; click on "Events," under "Create New Event" click on "General Research Ethics Board Adverse Event Form"). An adverse event includes, but is not limited to, a complaint, a change or an unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example, you must report changes to the level of risk, participant characteristics, and implementation of new procedures. To submit an amendment form, access the application by at http://www.queensu.ca/trac/signon.html; click on "Events," under "Create New Event" click on "General Research Ethics Board Request for the Amendment of Approved Studies." These changes must be submitted, and they will be automatically sent to the Ethics Coordinator, Ms. Gail Irving, at University Research Services for further review and clearance by the GREB or Chair, GREB.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Sincerely,

Chair, General Research Ethics Board (GREB)
Professor Dana A. Tripp, PhD
Departments of Psychology, Anesthesiology & Urology Queen’s University

cc: Dr. Amanda Cooper, Supervisor
Dr. Pamela Beach, Chair, Unit REB
Haven Jerret-Poole, Dept. Admin.
A2 – Participant Recruitment Script(s)

Phase 2 – Online Survey.

Date: September 24, 2019

Dear Manager,

**Introduction:** My name is Scott Compeau, and I am a Ph.D. Candidate in the Faculty of Education, working under the supervision of Dr. Amanda Cooper. I obtained your contact information from your institutional STEM outreach website. I am reaching out to invite you to take part in a research study investigating the organizational features and partnerships of university-based STEM outreach organizations within their local K-12 STEM education community.

**Participation:** Participation is voluntary. If you agree to take part, the study will involve completing an online questionnaire that should take approximately 30 minutes to complete. There are no known risks for taking part in this study. You will not be obliged to answer any question with which there is discomfort. You can choose not to answer a question or to stop answering questions at any point in time. While there are no direct benefits to you as a participant, study results will help inform the role of STEM outreach organizations within the broader STEM education. There are no direct benefits to you as a participant; however, study results will help inform how STEM outreach organizations function with partners in a STEM learning ecosystem. You will not be paid for taking part in this study.

**Confidentiality:** Only the investigators directly involved in this study (i.e., my supervisor, my two doctoral committee members, and myself) will know the identity of the participating institution, program names, and individuals who volunteer to participate. Direct quotes that could potentially reveal your identity or the institution will not be used in manuscripts. The institution will not be named (i.e., it will be referred to as a mid-sized Canadian university) and each participant will be assigned a pseudonym. A file linking individuals' names, titles, and programs to pseudonyms will be stored on my password-protected Student OneDrive account. All hard copy data will be stored in a locked file cabinet. Even though I will take purposeful steps to maintain confidentiality, it is possible that the publication of the research could reveal the participant's identity. I will keep your data securely for five years. After five years, I will either destroy the data or work with Queen's University Open Scholarship Services to de-identify and preserve the data.

If you are interested in participating, please email me, Scott Compeau, at scott.compeau@queensu.ca. Thank you in advance for your consideration.

Kind regards,

Scott Compeau
Date: September 24, 2019

Dear Manager,

**Introduction:** My name is Scott Compeau, and I am a Ph.D. Candidate in the Faculty of Education, working under the supervision of Dr. Amanda Cooper. I obtained your contact information from your institutional STEM outreach website. I am reaching out to invite you to take part in a research study investigating if university-based STEM outreach organizations function as knowledge mobilization intermediaries between partners within their local K-12 STEM education community.

**Participation:** Participation is voluntary. If you agree to take part, the study will involve two phases. Phase one involves completing an online questionnaire that should take approximately 30 minutes to complete. At the end of Phase 1, you will have the opportunity to indicate if you are interested in participating in a follow-up interview (which will require completing a separate Letter of Information and Consent Form). If you agree to take part in Phase 2, the interview should take approximately 45 – 60 minutes to complete. I will interview you online via Zoom or Skype. The interview will be audio-recorded and later transcribed. Following the interviews, I will send you an interview summary and ask that you check for the accuracy of my exact interview transcriptions. If there are sections of the interview that you wish are not to be used or quoted in the study, you will have the opportunity to identify them and they will be removed from the transcription. In total, the study will take up to 90 minutes of your time. There are no known risks for taking part in either phase of this study and you will not be obliged to answer any question with which there is discomfort. There are no direct benefits to you as a participant; however, study results will help inform if/how STEM outreach organizations function as knowledge mobilization intermediaries within a K-12 STEM learning ecosystem and the broader K-12 STEM education. You will not be paid for taking part in this phase of the study.

**Confidentiality:** Only the investigators directly involved in this study (i.e., my supervisor, my two doctoral committee members, and myself) will know the identity of the participating institution, program names, and individuals who volunteer to participate. In addition to the investigators, only a hired transcriber will have access to the phase two audio files. The transcriber will be required to sign and return a confidentiality agreement. Direct quotes that could potentially reveal your identity or the institution will not be used in manuscripts. The institution will not be named (i.e., it will be referred to as a mid-sized Canadian university) and each participant will be assigned a pseudonym. A file linking individuals' names, titles, and programs to pseudonyms will be stored on my password-protected Student OneDrive account. All hard copy data will be stored in a locked file cabinet. Even though I will take purposeful steps to maintain confidentiality, it is possible that the publication of the research could reveal the participant's identity. I will keep your data securely for five years. After five years, I will either destroy the data or work with Queen's University Open Scholarship Services to de-identify and preserve the data.

If you are interested in participating, please email me, Scott Compeau, at scott.compeau@queensu.ca. Thank you in advance for your consideration.

Scott Compeau
A3 – LOI’s and Consent Forms

Phase 2 – Online Survey.

Study Title: An exploratory study of university-based STEM outreach organizations as knowledge mobilization intermediaries

Name of Principal Investigator: Scott Compeau, Faculty of Education, Queen’s University
Name of Supervisor: Dr. Amanda Cooper

I am asking STEM outreach organizations senior leaders (directors and/or managers) to take part in a research study investigating the knowledge mobilization intermediary functions utilized by university-based STEM outreach organizations and how they are positioned as intermediaries within their local K-12 STEM learning ecosystems. If you agree to take part, the study will involve two phases. Phase one involves completing an online questionnaire that should take approximately 30 minutes to complete. At the end of Phase 1, you will have the opportunity to indicate if you are interested in participating in a follow-up interview (which will require completing a separate Letter of Information and Consent Form). There are no known risks for taking part in phase one of this study. There are no direct benefits to you as a participant; however, study results will help inform if/how STEM outreach organizations function as knowledge mobilization intermediaries within a K-12 STEM learning ecosystem and the broader K-12 STEM education. You will not be paid for taking part in this phase of the study.

Participation is voluntary. You don’t have to answer any questions you don’t want to. You can stop participating at any time without penalty. You may withdraw as a participant from the study immediately by closing the web browser that contains the questionnaire, or up until three weeks after completing the questionnaire by contacting me at scott.compeau@queensu.ca. You may request to have your data withdrawn from the phase one questionnaire up until the three-week mark after the date of completion by contacting me at scott.compeau@queensu.ca. Once data have been included in my dissertation or a manuscript and submitted for publication, data cannot be removed.

Your confidentiality will be protected, to the extent permitted by applicable laws. I will do this by replacing your name/organizational name with a pseudonym in all publications and a study ID number in all study records. The study data will be stored on an encrypted hard drive on Queen’s University servers. The code file that links real names with pseudonyms and study ID numbers will be stored securely and separately from the data on an encrypted USB key. I will keep your data securely for at least five years per Queen’s University Policy, after which the de-identified data will be deposited into the Queen’s University’s Institutional Repository. The code file identifying your pseudonym and study ID number will be destroyed five years after study closure.

I plan to publish the results of this study in academic journals and present them at conferences. I will include quotes from some of the questionnaire responses when presenting my findings. I will never include any real personal or organizational names with quotes. I will do my best to make sure quotes do not identify participants. During the interview, please let me know if you say anything you do not want me to quote.

The Queen's General Research Ethics Board (GREB) may request access to study data to ensure that the researcher(s) have or are meeting their ethical obligations in conducting this research. NOTE: GREB is bound by confidentiality and will not disclose any personal information.
If you have any ethics concerns please contact the General Research Ethics Board (GREB) at 1-844-535-2988 (Toll-free in North America) or chair.GREB@queensu.ca. Call 1-613-533-2988 if outside North America. If non-English speaking participants wish to contact the Chair for ethics concerns, translation assistance may be necessary, as the GREB Chair communicates in English only.

If you have any questions about the research, please contact me at scott.compeau@queensu.ca or my supervisor Dr. Amanda Cooper at Amanda.copper@queensu.ca at 613-533-6000 ext. 77286.

This Letter of Information provides you with the details to help you make an informed choice. All your questions should be answered to your satisfaction before you decide whether or not to participate in this research study. By clicking on the ‘next button (forward indicating arrow), you are verifying that you have read the Letter of Information described above, all of your questions have been answered, and that you consent to participate in phase one of this study (the questionnaire). You will have the opportunity to agree to participate in phase two (the interview) once Phase 1 is completed. You have not waived any legal rights by consenting to participate in this study.
Phase 3 – Interviews.

**Study Title:** Knowledge Mobilization Intermediaries in K-12 STEM Education: A Case Study of Canadian University-Based STEM Outreach Organizations

**Name of Principal Investigator:** Scott Compeau, Faculty of Education, Queen’s University

**Name of Supervisor:** Dr. Amanda Cooper

I am asking STEM outreach organizations senior leaders (directors and/or managers) to take part in a research study investigating the knowledge mobilization intermediary functions utilized by university-based STEM outreach organizations and how they are positioned as intermediaries within their local K-12 STEM learning ecosystems. The study involves two phases. The first phase was an online questionnaire (that you have previously completed) and phase two is a follow-up interview. If you agree to take part, the interview should take approximately 45 – 60 minutes to complete. I will interview you online via Zoom or Skype. The interview will be audio-recorded and later transcribed. Following the interviews, I will send you an interview summary and ask that you check for the accuracy of my exact interview transcriptions. If there are sections of the interview that you wish are not to be used or quoted in the study, you will have the opportunity to identify them and they will be removed from the transcription. There are no known risks for taking part in this study. There are no direct benefits to you as a participant; however, study results will help inform how STEM outreach organizations function as knowledge mobilization intermediaries within K-12 STEM education. You will not be paid for taking part in this study.

Participation is voluntary. You don’t have to answer any questions you don’t want to. You can stop participating at any time without penalty. You may withdraw as a participant from the study immediately by closing the communication application (either Zoom or Skype), or up until three weeks after completing the questionnaire by contacting me at scott.compeau@queensu.ca. You may request to have your data withdrawn from the interview up until the three-week mark after the date of completion by contacting me at scott.compeau@queensu.ca. Once data have been included in my dissertation or a manuscript and submitted for publication, data cannot be removed.

Your confidentiality will be protected, to the extent permitted by applicable laws. I will do this by replacing your name/organizational name with a pseudonym in all publications and a study ID number in all study records. The study data will be stored on an encrypted hard drive on Queen’s University servers. The code file that links real names with pseudonyms and study ID numbers will be stored securely and separately from the data on an encrypted USB key. I will keep your data securely for at least five years per Queen’s University Policy, after which the de-identified data will be deposited into the Queen’s University's Institutional Repository. The code file identifying your pseudonym and study ID number will be destroyed five years after study closure.

I plan to publish the results of this study in academic journals and present them at conferences. I will include quotes from some of the interviews when presenting my findings. I will never include any real names with quotes. I will do my best to make sure quotes do not identify participants. During the interview, please let me know if you say anything you do not want me to quote.
The Queen's General Research Ethics Board (GREB) may request access to study data to ensure that the researcher(s) have or are meeting their ethical obligations in conducting this research. 

**NOTE:** GREB is bound by confidentiality and will not disclose any personal information.

If you have any ethics concerns please contact the General Research Ethics Board (GREB) at 1-844-535-2988 (Toll-free in North America) or chair.GREB@queensu.ca. Call 1-613-533-2988 if outside North America. If non-English speaking participants wish to contact the Chair for ethics concerns, translation assistance may be necessary, as the GREB Chair communicates in English only.

If you have any questions about the research, please contact me at scott.compeau@queensu.ca or my supervisor Dr. Amanda Cooper at Amanda.copper@queensu.ca at 613-533-6000 ext. 77286.

This Letter of Information provides you with the details to help you make an informed choice. All your questions should be answered to your satisfaction before you decide whether or not to participate in this research study. Keep one copy of the Letter of Information for your records and return one copy to the Researcher, Scott Compeau. You have not waived any legal rights by consenting to participate in this study.

By signing below, I am verifying that: I have read the Letter of Information and all of my questions have been answered. Please indicate your consent choice, sign and date the consent form, and email the form to scott.compeau@queensu.ca

☐ Yes, you have my permission to use quotes/audio records (circle action if only 1 option is permissible)

☐ No, you do not have my permission to use quotes/audio records (circle action if only 1 option is NOT permissible)

____________________________  __________________________
Signature of Participant       PRINTED NAME       Date
### A4 – Phase 2 Survey Questions

**Study Title:** Knowledge Mobilization Intermediaries in K-12 STEM Education: A Case Study of Canadian University-Based STEM Outreach Organizations

**Name of Principal Investigator:** Scott Compeau, Faculty of Education, Queen’s University  
**Name of Supervisor:** Dr. Amanda Cooper

<table>
<thead>
<tr>
<th>Component</th>
<th>Question</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. STEM outreach demographics</td>
<td>What is the name of the university?</td>
<td>- Create a geographical representation of the STEM outreach units across Canada</td>
</tr>
<tr>
<td></td>
<td>What faculty or department is the STEM outreach unit associated with?</td>
<td>- To see where outreach is embedded within the university</td>
</tr>
<tr>
<td></td>
<td>What is the name of the STEM outreach program?</td>
<td>-</td>
</tr>
<tr>
<td>2. STEM outreach organizational features &amp; partnerships</td>
<td>What is the mission or likewise the goal of the STEM outreach program?</td>
<td>- To identify areas of focus that are a priority that may not be captured in Phase 1.</td>
</tr>
<tr>
<td></td>
<td>Identify and rank stakeholders of this STEM outreach program.</td>
<td>- Determine which stakeholders and target audiences are influential</td>
</tr>
<tr>
<td>Identify and rank the target audience of this STEM outreach program.</td>
<td>Determine the size of SOUs</td>
<td></td>
</tr>
<tr>
<td>Identify the staff members and describe their strategic roles.</td>
<td>Determine the operating budget and diverse funders of SOUs</td>
<td></td>
</tr>
<tr>
<td>Identify the funding sources for this STEM outreach program.</td>
<td>Determine the level of partnership SOUs have with others in the ecosystem.</td>
<td></td>
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<tr>
<td>Identify and describe relationships with other STEM outreach providers.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. K-12 STEM learning ecosystems & knowledge brokering

| Identify three barriers and three facilitators to STEM outreach. | Insight into STEM outreach challenges and strengths |
| To what extent does the description of knowledge brokers relate to their SOUs work within an ecosystem? | Insight into if/how the managers/directors view themselves as knowledge brokers. |
| Which of the eight knowledge brokering functions does this STEM outreach program adhere to? | Determine the level at which each SOU uses the brokering function. |
A5 – Phase 3 Interview Protocol & Questions

Study Title: Knowledge Mobilization Intermediaries in K-12 STEM Education: A Case Study of Canadian University-Based STEM Outreach Organizations

Name of Researcher: Scott Compeau, Faculty of Education, Queen’s University

Name of Supervisor: Dr. Amanda Cooper, Faculty of Education, Queen’s University

Welcome

• Thank you for your interest in participating in this study
• If you haven't had a chance to do so already, please take a few moments to review the combined Letter of Information and Consent Form
• If you have any questions or concerns while reading, please do not hesitate to ask me for clarification
• As a reminder, the purpose of this research is to better understand more about university-based STEM outreach organizations within a K-12 STEM learning ecosystem and if they function as knowledge brokers within their community.

Introductions

• My name is Scott Compeau – I am a Ph.D. Candidate in the Faculty of Education at Queen's University
• I am conducting this study as part of my Ph.D. Dissertation. My supervisor is Dr. Amanda Cooper, Associate Professor, Faculty of Education, Queen's University

Confidentiality

• As a senior leader in your outreach organization, I am interested in hearing your thoughts on knowledge brokering, ecosystems, and your organizations' role within them.
• Everything that you say during the interview will be considered confidential
• You do not have to answer any questions you don't want to
• You can stop answering questions at any point
• With your permission, the interview will be audio-recorded. Do I have your permission to audio-record?
• As a reminder, I will never include any real names with quotes, and I will do my best to make sure quotes do not include information that could directly identify you as a participant
• During the interview, please let me know if you say anything you do not want me to quote.
• Once I have transcribed the interview, I will send it over for you to review. At this point, you will have the opportunity to add/remove/modify any of your answers.
• Do you have any questions so far?

Collection signed consent form (each participant keeps a copy for their records)

If the individual would not like to participate at this time:

• Thank you for your time and consideration
• Should you change your mind and wish to participate in the future, you may do so by contacting me via email (scott.compeau@queensu.ca).
• If you think that there is someone else in your program that I should be speaking to, please recommend that they get in touch with me via email (scott.compeau@queensu.ca)
Interview Questions

Warm-up

1. Can you please start by telling me some information about yourself and how you ended up working for a STEM outreach organization?
2. Approximately how long have you been in your current role?

Purpose of study (i.e. key concepts to be explored):
Within the interview, I am interested in exploring three concepts. The first is the organizational features of your STEM outreach unit, followed by the idea of K-12 STEM learning ecosystems, and the third is knowledge brokering. Are you ready to begin?

Phase 3 - Interview Questions

<table>
<thead>
<tr>
<th>Focus</th>
<th>Interview Question</th>
<th>Probing questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational Features</td>
<td>Thank you again for completing the online survey and helping me understand the organizational features of your SOU as shown in the image [show conceptual framework image]. I would like to take this time to learn about your partnerships and impact/evaluation.</td>
<td>Are some partnerships valued over others? If so which ones?</td>
</tr>
<tr>
<td>Partnerships</td>
<td>1. How important are relationships and partnerships for achieving your mission/mandate?</td>
<td>From your experience, what makes a partnership successful/unsuccesful? Can you provide me with an illustrative example of each?</td>
</tr>
<tr>
<td>Partnership</td>
<td>2. Can you provide me with an example of when a partnership with another group in your community was a positive success? What made it successful? What about an unsuccessful partnership? Why was it unsuccessful?</td>
<td></td>
</tr>
</tbody>
</table>
| Partnership | 3. Mutualism refers to a two-way street of engagement. To what extent are your SOUs partnerships mutually beneficial? | • What does your organization get back from the partnerships? What does your organization provide the partner?  
• To what extent does your organization take a leading role in the partnership? |
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Program Evaluation</td>
<td>4. How are you currently evaluating (or determining) the impact of your outreach on your target audiences?</td>
<td>• What would help your organization evaluate your initiatives? Overall program?</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>One approach towards K-12 STEM outreach that is emerging is the concept of STEM learning ecosystems. This approach involves collaborative partnerships between STEM education stakeholders [show a conceptual diagram of STEM learning ecosystem stakeholders to the right] to increase the STEM knowledge and skills of intended target audiences in a given community.</td>
<td></td>
</tr>
</tbody>
</table>
| Ecosystem | 5. What might be the benefits and drawbacks of a systematic multi-partner collaborative approach to STEM outreach delivery within your community? | • What are the strengths and challenges?  
• What are the benefits and drawbacks?  
• Can you indicate who might be part of your ecosystem today? |
| Ecosystem | 6. If this ecosystem approach were to be adopted within your community, what do you think your organization’s role would be? How would it be similar/different to that of your current role? | • Who would be best positioned to lead the ecosystem? (which of the groups) |
Ecosystem 7. If resources were not an issue, what do you believe are the top two barriers preventing you from achieving a fully collaborative STEM learning ecosystem within your community? Please explain.

Knowledge Brokering Another concept that is emerging in the field of education is knowledge brokering. A knowledge broker refers to a person and/or organization that facilitates the creation and sharing of knowledge (both empirical and tacit) that help address knowledge gaps in education between two or more stakeholders and/or partners. I am interested to learn if/how this concept might apply to K-12 STEM education.

Brokering 8. To what extent is the role of a knowledge broker similar to the role your SOU has within your community? How is it different?

Brokering Functions Knowledge brokering literature refers to eight different functions. I would like to explore these with you to see which one(s) (if any) your organization is currently using, which you think are important for STEM outreach, and which ones are not applicable.

Brokering Functions 9. Present and go through the eight brokering functions one by one, exploring their organization’s capacity (i.e., barriers and strengths) to engage in each of the following: Linkages…; Capacity building; …

- What are some examples from this function that could apply to your STEM unit?
| Brokering | 10. Knowledge brokering organizations must set their priority activities, as it can be difficult to use them all. Please rate each potential brokering function listed below in terms of its level of priority | • How do you see these high-priority brokering functions being useful towards increasing the impact of SOUs? The overall K-12 STEM learning ecosystem? |
| Brokering | 11. To what extent do you think the concept of knowledge brokering is relevant/useful for supporting your organization in conducting future STEM outreach initiatives? | • What would your organization need to enhance your role as a knowledge broker? • What goals might you set for improving your brokering function within your community? |
## A6 – SOU Twelve Case Study Summary and Integration Table

### SOU Case Study Integration Table

<table>
<thead>
<tr>
<th>SOU</th>
<th>Mission</th>
<th>Target Aud. &amp; Program Eval</th>
<th>Capacity &amp; Program Eval</th>
<th>Partners</th>
<th>Brokering Functions</th>
<th>Brokering Role &amp; Relevance</th>
</tr>
</thead>
</table>
| 1   | Spark STEM Curiosity  
Develop Skills and Work Habits  
Mental Health | Audience(s)  
Students  
Under-rep. youth  
School boards  
Stakeholders  
Students  
Schools  
Parents | Annual Op. Budget  
$150k - $300k  
Staffing  
FT = 1-3  
PT = 0  
Casual = 8+  
Sum Stud= 8+  
# youth/year  
4500  
Program Eval  
Low satisfaction | Stud – Two-way  
Sch – Two-way  
Pre-service – No  
In-service – No  
Uni – Two-way  
In/Bus. – One-way (in)  
Com Set – One-way (out)  
Com Gr – Two-way  
Gov – One-way (in)  
Home – One-way (out) | Top 3:  
Accessibility  
Awareness  
Engagement | Role  
Similar  
Knowledge sharing  
SOU Source of knowledge  
Relevance  
Issues with broker term  
Reshape image  
Useful to categorize SOU initiatives |
| 4   | Spark STEM Curiosity | Audience(s)  
 Students  
Under-rep. youth  
Schools  
Stakeholders  
University  
Students  
Schools | Annual Op. Budget  
$900k+  
Staffing  
FT = 1-3,  
PT = 8  
Casual = 8+  
Sum Stud = 8+  
# youth/year  
21000  
Program Eval  
Neutral | Stud – One-way (out)  
Sch – One-way (out)  
Pre-service – No  
In-service – No  
Uni – Two-way  
STEM In. – No  
Com Gr – Two-way  
Com Set – One-way (out)  
Gov – One-way (in)  
Home – One-way (out) | Top 3:  
Awareness  
Accessibility  
Engagement | Role  
Similar  
Knowledge sharing  
Relevance  
Useful to categorize SOU initiatives as functions.  
Reshape image |
<table>
<thead>
<tr>
<th>14</th>
<th><strong>Sparks STEM Curiosity</strong></th>
<th><strong>Audience(s)</strong></th>
<th><strong>Annual Op. Budget</strong></th>
<th><strong>Program Eval</strong></th>
<th><strong>Top 3:</strong></th>
<th><strong>Role</strong></th>
<th><strong>Relevance</strong></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Students</td>
<td>$300k - $450k</td>
<td>Low satisfaction</td>
<td></td>
<td>Accessibility</td>
<td>Similar</td>
<td>Knowledge sharing</td>
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<td>Under-rep youth</td>
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<td>Awareness</td>
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<td>Knowledge from ecosystem</td>
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<td></td>
<td>Com Groups Stakeholders</td>
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<td></td>
<td></td>
<td>Engagement</td>
<td></td>
<td>Reshape SOU image</td>
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<td>University</td>
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<td>Issues with broker terminology</td>
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<td>Federal Gov.</td>
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<td>Students</td>
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<td></td>
<td>Under-rep youth</td>
<td>$600k - $750k</td>
<td>Low satisfaction</td>
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<td>Accessibility</td>
<td>Similar</td>
<td>Knowledge sharing</td>
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<td></td>
<td>Schools</td>
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<td></td>
<td></td>
<td>Engagement</td>
<td></td>
<td>Knowledge from ecosystem</td>
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<td></td>
<td>Parents</td>
<td></td>
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<td>Link &amp; Part</td>
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<td>Reshape SOU image</td>
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<td>Com Groups Stakeholders</td>
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<td>Policy</td>
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<td>Issues with broker terminology</td>
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<td>Imp. Supt</td>
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<tr>
<td></td>
<td>Parents</td>
<td>$300k - $450k</td>
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<td></td>
<td>Schools</td>
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<tr>
<td></td>
<td>Students</td>
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</tbody>
</table>

**Useful to categorize SOU initiatives**
<table>
<thead>
<tr>
<th>Issue</th>
<th>Audience(s)</th>
<th>Annual Op. Budget</th>
<th>Staffing</th>
<th>Program Eval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involve the Community</td>
<td>Students, Under-represented youth, Com Groups, Stakeholders, University, STEM Industry</td>
<td>$600k - $750k</td>
<td>FT = 1-3, PT = 1-3, Casual = 8+, Sum Students = 8+ # youth/year, 37000</td>
<td>Low satisfaction</td>
</tr>
<tr>
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Program Eval: Low satisfaction

Bottom 3:
- Policy
- Org. Dev
- Link & Part

Relevance
- Useful to categorize SOU initiatives

Definition missing elements