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# STEAM Education in Ontario, Canada: A Case Study on the Curriculum and Instructional Models of Four K-8 STEAM Programs

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# Abstract

STEM (Science, Technology, Engineering, and Mathematics) learning and project-based learning are important educational initiatives in North America. However, it is important to consider whether current STEM educational practices are sufficient to prepare students for the world they are to live and work in. This prompts discussions about STEAM (Science, Technology, Engineering, Arts and Mathematics) which is shifting educational paradigms towards art integration in STEM subjects. This study investigates the STEAM education reform movement in Canada to better understand the STEAM curriculum and instructional programs offered by non-profit organizations and publicly funded schools. This research study addresses the following major questions: 1) what curriculum and instruction models of STEAM education are implemented in non-profit and in-school contexts in Ontario, Canada? 2) What do students learn through different models of STEAM education? 3) What types of assessment of student learning is happening in STEAM education? 4) How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals? To explore these questions, I took a small sample of four different STEAM programs in Ontario, Canada. I conducted interviews, observations, content analysis of curriculum documents and a focus group interview. At the four research sites, the main pedagogies used are design-based and inquiry-based models which focused on the students' interests and encourages students to construct their own knowledge. Students learn character-building skills that empower them to solve real-world problems, develop perseverance and grit, engage in their community and develop a global perspective. The instructors/teachers describe the STEAM tasks at each site as rich and authentic experiences. The findings also suggest that sharing the learning in the STEAM program with the community extends the learning experiences to a wider community and contributes to the collective knowledge about how students learn. This study can inform teaching practices for teachers who seek to engage and motivate students by integrating the arts in STEM subjects. This study also promises to deepen the field's understanding of STEAM education in Canada and to provide new insights into the practicality, affordances, and tensions of designing and implementing a STEAM program.

## Keywords

STEAM, STEM and Arts, STEM and creativity, Art Integration, Integrated Curriculum, Art-based curriculum, STEAM and Canada, Case Study

# Dedication

I dedicate this work to my dad Doug Bertrand and my mom Eulene Bertrand for encouraging me to work hard, continue learning and further my education. I also want to thank my 9-year-old daughter Aurianna who supported me throughout this entire process and was understanding when I had to work evenings and weekends to complete my thesis. This study is also dedicated to my brother Craig Bertrand who has always encouraged and supported me in educational endeavors.

# Acknowledgments

My journey started as a MPEd student, and I developed a passion for research in curriculum studies through my work with Dr. Immaculate Namukasa. After taking the course Diverse Traditions, I decided to transfer to the MA program and pursue my passion for mathematics, computational thinking and STEAM education. I have had the privilege and honor of working with Dr. Namukasa in different capacities as an RA, colleague and graduate student over the last three years. Working in the field with Dr. Immaculate Namukasa allowed me to experience firsthand how we can engage both students and teachers with the pleasure of doing, teaching and learning mathematics. I was able to use this knowledge to inform my own research on STEM/STEAM (Science, Technology, Engineering, Arts and Mathematics) education.

I want to thank my supervisor Dr. Immaculate Namukasa for her meticulous work in providing me with thorough feedback, constructive criticism from a positive perspective and the opportunity to meet with her in person when needed. I thank you Dr. Namukasa for pushing me to a higher level with my education and research pursuits. I also want to thank Dr. George Gadanidis from my supervisory committee who has been supportive in my aspirations to embark upon a PhD and has encouraged me to be more critical in the analysis of the data. I also wanted to thank Dr. Gadanidis for suggesting to collect data from both in-school and out-of-school research sites to study STEAM education in different contexts. I was extremely thankful for your suggestion to conduct a Focus Group near the end of my study because this added a new dimension to my study and to get classroom teachers' views on how STEAM education is meeting their curriculum and instruction goals.

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# Chapter 1

## 1 Introduction

STEM (Science, Technology, Engineering, and Mathematics) initiatives and project-based learning are of current interest for both in-school and out-of-school contexts in North America. However, it is important to consider whether or not current STEM educational practices are sufficient in preparing students for the world in which they live and work. This prompts discussions about STEAM (Science, Technology, Engineering, Arts and Mathematics), which Yakman and Lee (2012) maintained was a considerably new concept at the time and was shifting educational paradigms towards art integration in STEM subjects. Jeong and Kim (2015) observed a major concern with students' lack of interest, engagement and motivation in STEM subjects in the United States and Korea.

One of STEAM education's main goals is to provide students with an authentic learning experience. According to Reeves et al. (2004), students should have authentic tasks that have a real-world context, ill-defined problems, complex or multistep questions, multiple ways to approach a problem, integrate across the disciplines, and have failure and iterations built into the assignment itself (Armory, 2014).

Educators in North America have approached STEAM education in different ways depending on available resources, developing STEAM schools, after-school programs, clubs, out-of-school programs, non-profit organizations and/or community partnerships. The STEAM movement in Canada is very recent and has occurred over the last seven years, mainly being represented through non-profit organizations and school initiatives. This study investigates curriculum and instructional models of STEAM education and how classroom teachers view these models in a Canadian context and what students learn from these models. The main purpose of this study is to better understand the STEAM instructional programs offered by non-profit organizations and by publicly funded schools. The study has implications for teachers, principals, policy makers and researchers on the implementation of STEAM to meet curricular and pedagogical goals in schools.

## 1.1 Research Questions

This study addresses the following research questions:

1. What curriculum and instruction models of STEAM education are implemented in non-profit and in-school contexts in Ontario, Canada?
2. What do students learn through different models of STEAM education?
3. What types of assessment of student learning is happening in STEAM education?
4. How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals?

STEAM programs in Canada are implemented through both non-school contexts, such as non-profit organizations, and through school initiatives. In the following paragraph, I illustrate several examples of STEAM initiatives that have been adopted by both elementary and secondary schools in Canada. For example, Elizabeth Buckley School, located in Victoria, BC, claims to be the first STEAM school in Canada that is incorporating STEAM and the arts into everyday living ("Elizabeth Buckley School", 2018). Sail Academy program notes on its website that it has a STEAM program for K-7 students to prepare them "for a rapidly changing world" by "developing independent learners, critical thinkers, collaborators, innovators and contributors" ("SAIL Academy", 2018). This program is described as interdisciplinary, in which "students learn through inquiry and project-based learning" ("SAIL Academy", 2018). STEAM Academy in Brantford, Ontario has been reported to offer "a revolutionary approach to education, with graduates gaining a full two-year software engineering technician diploma concurrently with a fully accredited Ontario Secondary School Diploma (OSSD)" (National Post, 2018). The STEAM not-for-profit "school" in St. Thomas, Ontario follows the "school within a school model." STEAM Centre planned that five to seven schools will participate in this school project through visits to the Centre on a weekly or bi-weekly basis "developing skills, incorporating new learning and technologies into ongoing projects, and developing 'STEAM-based' workshops for . . . younger students" ("STEAM School – STEAM Centre", 2018).

This study investigated STEAM initiatives in Canada to better understand the STEAM instructional programs at out-of-school and in-school contexts. Several studies inform this research including literature on STEM/STEAM education in general, studies on art integration outside STEAM, models of STEAM education, specifically school-based, community-based and higher education-based models of STEAM, and generally the state of STEAM education in Canada. The literature review presented in Chapter 2 is helpful for understanding the models of STEAM education in the four STEAM programs in this study.

## 1.2 Research Problem and Statement

The STEM to STEAM movement grew out of educators' dissatisfaction with students' lack of success academically and their inability to make meaningful connections to the material (Yakman & Lee, 2012). According to the Council of Canadian Academies (2015), "STEM skills are necessary . . . but they are not sufficient on their own …. other skills such as leadership, creativity, adaptability, and entrepreneurial ability may be required to maximize the impact of STEM skills" (p. xvii). Many scholars have found that some of these skills can be obtained by integrating the arts with STEM (i.e., STEAM). Proponents of STEAM suggest that integrating the arts with STEM "bring new energy and language to the table" (p.6) and can encourage student's curiosity, experimentation and discovery of the unknown through creative and innovative solutions (Colegrove, 2017). Taylor (2016) explains that STEAM "is not just another curriculum fad but an important response to the pressing need to prepare young people with higher-order abilities to deal positively and productively with 21$^{st}$ century global challenges (crises) that are impacting the economy, the natural environment and our diverse cultural heritage" (p. 89). Nations would like their students to be able to compete globally and be able to create innovative solutions to current global issues (Madden et al., 2013).

Countries, such as Canada and Australia, see the benefits in STEAM education, recognizing that the "design and creativity of the arts are crucial underpinnings of the successful mathematician, scientist and engineer" (Hogan & Down, 2016, p. 50), as well as an essential component of student engagement and motivation. The United States and Korea want to increase student interest, engagement, motivation, and value in STEM education through STEAM education (Jeong & Kim, 2015; So, Ryoo, Park & Choi, 2018). The overall goal is the same: to train students to be world leaders in science and technology by fostering an interest and deeper understanding through the integration of arts, "experiential and inquiry-based approaches" (So et al., 2018, p.2) to develop creativity, innovation, critical-thinking and problem-solving skills (Jeong & Kim, 2015; Land, 2013). STEAM practices can be described as "thinking through the materials" (p. 17), which helps students have a deeper understanding of the material and make connections between the other disciplines (Guyotte, Sochacka, Constantino, Walther & Kellam, 2014). According to Dobson and Burke (2013), "a balance of critical thinking, analytical skills and creativity is key for innovation. STEM, arts and humanities can be integrated to engage students in pursuing a balanced education —an education that will create more employment opportunities and options in the future" (p. 20). STEAM education can also encourage "effective communication and collaboration that is more student-centric," (p. 321) these skills are needed in both post-secondary education and the workforce (Connor, Karmokar & Whittington, 2015; Herro & Quigley, 2016).

So far, the STEAM initiatives mentioned above have been more politically driven to encourage students to study mathematics, science and engineering at the post-secondary level and, subsequently, to become world experts in this field of study. Besides the political initiatives, STEAM has the potential to provide all students with academic success and a more meaningful learning experience by solving a problem creatively or connecting it to a real-world context (Land, 2013). A study by Connor et al. (2015) included projects that were student-centric and meant "to motivate students to take ownership of their own learning experience" (p. 45) and to be actively engaged in the process. Harris and de Bruin (2018) maintain that, as educators, we want to meet the child's individual needs by building their self-confidence, self-esteem and creating a safe learning environment for them to make mistakes and excel, which is a major component of STEAM education.

The literature lacks research on STEAM education in Canada. The STEAM movement in Canada is very recent and has occurred over the last seven years. Review of existing studies and exploratory research, such as case studies, needs to be done on STEAM-based institutions or programs in a Canadian context. This is to better understand the curriculum and instruction models, student learning and assessment of STEAM in a Canadian context.

## 1.3 Significance of this Study

The results of this study promise to inform the practices of teachers who seek to engage and motivate students to learn STEM subjects by integrating the arts. Ghanbari (2014) stresses the importance of building better understanding of how “innovative STEAM programming is necessary to document various models of STEAM-based learning and evaluate programs in the intersection of the arts and STEM" (p. 102) for educators, researchers and policy makers. For instance, the findings from this study can be helpful to an educator and policy maker for designing, implementing and researching STEAM programs. Despite the growing interest in STEAM education globally “few cases are documented in depth” (Herro & Quigley, 2016, p. 321) and “there is minimal research [about] . . . the process of creating STEAM-based curriculums” (Ghanbari, 2015, p. 2). This study can also be useful in determining which model of STEAM education would be the most appropriate for a given context or demographic of students. It investigates the STEAM education reform movement in Canada to better understand the STEAM instructional programs offered by non-profit organizations and by publicly funded schools. The findings from this study will also deepen the understanding of STEAM education in Canada and provide new insights into this curricular movement, including classroom teachers’ views on such models of STEAM education as meeting their curriculum and instructional goals.

## 1.4 Organization of the Thesis

In the literature review chapter, I include relevant research on models of art integration in STEAM. I also outline relevant research such as collaboration and capacity building; components of a productive STEAM pedagogy; and transdisciplinary and assessment in STEAM education. The theoretical framework chapter explores Papert’s Constructionism, Design-Based Learning and Low Floor, High Ceiling, Wide Walls as a critical lens to analyze and interpret the data in this study. I will also outline the curriculum frameworks used to analyze the STEAM tasks and the integrated learning opportunities in the curriculum documents from each site. The method and design chapter explains the rationale for selecting a collective case study and naturalistic paradigm. The methods section also discusses the research design, data collection, data organization and data analysis of the research study. The results and discussion chapter are organized based on the five themes and four research questions respectively. This chapter focuses on STEAM curriculum and instructional models, student learning and assessment, and how classroom teachers view such model as meeting their goals. The final chapter discusses the implications of the current study for research, practice, and policy, as well as study limitations; next steps and the summary of the findings.

# Chapter 2

# 2 Literature Review

In this literature review chapter, I first synthesize research on models of art integration and STEAM, such as school-based, higher education, community-based, non-profit organizations, makerspaces and Canadian-based models of STEAM education. I then outline relevant research such as collaboration and capacity building; components of a productive STEAM pedagogy; and transdisciplinary and assessment in STEAM education. This review is helpful for understanding the processes, challenges, and successes of STEAM education models.

## 2.1 Models of Art Integration and STEAM

Several venues of teaching STEAM are noted in the literature, ranging from schools (Bequette & Bequette, 2012; Drake & Reid, 2010; Wynn & Harris, 2012; Ghanbari, 2015; Herro & Quigley, 2016; Mote, Strelecki & Johnson, 2014), community agencies (Clark & Button, 2011; DiMaggio & Anheier, 1990; Harvard Family Research Project, 2008; Huang & Dietel, 2011) to university initiatives (Madden et al., 2013; Ghanbari, 2015), faculties of education (Conley et al., 2014), museums, other organizations (Clark & Button, 2011), such as non-profit laboratories or centers, and collaborations among these partners (Clark & Button, 2011). STEAM education is being implemented at every level of education, through art integration in STEM, as well as through other pedagogical approaches such as designed-based learning, project-based learning, and creative problem solving. Several curricular and instructional models for STEAM education are noted in the literature.

### 2.1.1 School-Based STEAM Models

The approach to STEAM varies from school to school at the elementary, secondary and post-secondary level, and district to district: some fully integrate the arts into STEM subjects; others develop and implement a STEAM curriculum (STEAM schools and STEAM-related classes, and STEAM programs in an in-school or out-of-school context); others create “makerspaces” where students go to work on STEAM projects; some host

STEAM workshops and others have STEAM competitions or challenges (Herro & Quigley, 2016; littleBits Education, n.d.).

Delaney (2014) notes that there has been an increase in schools in the United States, Europe and Korea that have adopted STEAM curriculum and/or STEAM programs as the school's main curricular approach to teaching and learning (Herro & Quigley, 2016). In the United States, there were a few schools that embraced the idea of STEAM before the movement, which included "Andover High School in Massachusetts, Da Vinci Schools in California, Drew Charter School in Georgia, Fisher STEAM Middle School in South Carolina, Quatama Elementary School in Oregon, and Pulaski Middle School in Virginia" (Herro & Quigley, 2016, p. 320).

The STEAM movement continued to expand and now there are many models of schools that integrate the arts with STEM. Several model STEAM schools are reported in the literature including:

1. The Boston Arts Academy (Nathan, 2008)
2. Robious Middle School (Bequette & Bequette, 2012; Drake & Reid, 2010; Wynn & Harris, 2012)
3. Stephen W. Hawking Charter School (Ghanbari, 2015; Mote et al., 2014)
4. Union Point STEAM Academy (Ghanbari, 2015)

The Boston Arts Academy (BAA) is a model that integrates arts and academics. The BAA "demonstrates the value of incorporating arts into academics, rather than segregating education into two separate spheres of learning" (Nathan, 2008, p. 177). BAA operates a STEAM lab that is supported with a STEAM lab director to help "teachers and students explore the connections between the arts, science, and math, and incorporate new technology into their projects" through "3D modeling and design, electronics, digital media and fabrication" ("STEAM lab," 2016, para 1). BAA models how the arts can be seamlessly integrated into the curriculum versus simply adding art as a section on its own.

The Watershed Project at Robious Middle School (RMS) teaches through an integrative curriculum and, according to Wynn and Harris (2012), provides their students with an experiential learning experience. Drake and Reid (2010) maintain that integrating multiple subjects into the curriculum naturally lends itself to higher-order thinking skills (i.e., Blooms taxonomy and 21st century skills) while increasing students' overall engagement. Wynn and Harris further report on an example of an authentic artistic representation created by the 6th grade students of RMS, which focused on the "human impact on the environment, by designing a mosaic that represents Virginia's watershed system," (p. 46). Wynn and Harris further explain that RMS embraced an art integrative approach to STEAM education because they wanted their students to gain more than just knowledge, but to have an authentic and meaningful experience with the materials, by creating a mosaic that represents the environment and the watershed system. Through an analysis of literature Shaffer and Resnick (1999) found four main types of authentic learning "(a) learning that is personally meaningful for the learner, (b) learning that relates to the real-world outside of school, (c) learning that provides an opportunity to think in the modes of a particular discipline, and (d) learning where the means of assessment reflects the learning process" they can be both "interdependent and mutually-supporting" (p. 195) in a "thick" authentic learning environment. To Bequette & Bequette (2012), integrating art and engineering promote problem-based learning (PBL), which, in turn, engages, motivates and integrates authentic tasks into the curriculum. Authentic experiences are the type of meaningful experiences that students will remember long after the courses have finished or the school year has ended.

Stephen W. Hawking Charter School in San Diego and Union Point STEAM Academy (UPSA) in Union Point Georgia (K-8) (Ghanbari, 2015) are other examples of STEAM schools. UPSA "incorporates project-based learning through [the] lens of constructionism with a focus on authentic, experiential learning and meaningful design products" (Mote et al., 2014, p. 2). The UPSA arts-integrated curriculum is child-centered and provides "access and equality for traditionally underrepresented students (low-income, female, and students of color)" (Mote et al., 2014, p. 3). UPSA supports the idea that the arts and the design process are essential factors in the development of problem-solving skills, creativity and innovation (Mote et al., 2014).

The UPSA combined art-integration, project-based learning, and design thinking to engage the students in an unconventional manner. In this learning environment, students construct their own knowledge, learn by making, approach a problem using different mediums and create a design product at the end of each unit. For example, Elizabeth Buckley School, Sail Academy, STEAM Academy, BAA, RMS, UPSA among other schools mentioned in the introduction chapter 1 and this section (Section, 2.1.1) employ the three theoretical frameworks that I have chosen, Papert's Constructionism, Design-Based Learning, and Low Floor, High Ceiling, Wide Walls. I return to these frameworks in the theoretical and curriculum frameworks chapter.

### 2.1.2 Higher Education STEAM Models

Madden et al., (2013) and Ghanbari (2015) report on higher education STEAM models. Industry leaders, such as Lockheed Martin, are calling for, as well as rallying behind, the STEM/STEAM movement with the objective of supporting students to be creative, innovative, collaborative, and "approach problems both divergently and convergently" (Madden et al., 2013, p. 543). In response to this call from industry, certain colleges and universities are beginning to integrate the arts with STEM subjects at the post-secondary level with multidisciplinary programs and integrated courses (Madden et al., 2013). Some STEAM programs focus more on a community approach to learning. The goal is to develop a higher education program that fosters creative scientists to develop innovative solutions to serious global problems (Madden et al., 2013). Ghanbari (2015) mentions STEAM programs at the University of Texas-Dallas and the New York Film Academy, which has a partnership with NASA. Madden et al. mentions the following examples of STEAM models in higher education: State University of New York, Rhode Island School of Design, Maryland Institute College of Art, Bryant College and Rensselaer Polytechnic Institute. Madden et al. further notes that the State University of New York at Potsdam has already created a multidisciplinary program, supported by Lockheed Martin, that encourages creative thinking by integrating arts, humanities, and STEM. Another example noted by Madden et al. is the Rhode Island School of Design, which addresses the initiative of bridging STEM to STEAM with integrated courses. The Maryland Institute College of Art also has a graduate research program that implements elements of

STEAM education informally and is considered an art and design school (Madden et al., 2013). Other post-secondary institutions integrate creativity with business and engineering, such as Bryant College in Rhode Island, which “addresses creative problem solving, teamwork, and the innovation process” in global business (Madden et al., 2013, p. 543). Rensselaer Polytechnic Institute “offers programs in electronic arts, games and simulation arts and sciences, and design, innovation and society” and incorporates STEM to STEAM assignments (p. 543). Many of these post-secondary institutions are providing students with the opportunity to be creative, innovative and collaborative through these multidisciplinary and integrated courses that promote STEAM education (Madden et al., 2013).

### 2.1.3 Community-Based STEAM Models

Aside from approaching STEAM education from a higher education, secondary or elementary point of view, some STEAM initiatives focus more on a community approach to learning by creating partnerships with museums and other organizations. Clark and Button (2011) studied a higher education STEAM initiative, the Sustainability Transdisciplinary Education project. In the Sustainability Transdisciplinary Education project, students, museum personnel (from, New Britain Museum of American Art, NBMAA), several other non-governmental organizations personnel, state and federal elected officials, and community members were involved (Clark & Button, 2011). The main goal of this project was for K-12 students, university students and the community to have a shared learning experience (Clark & Button, 2011). Clark and Button found the following: “students were learning from instructors, instructors were learning from students, students were learning from students, instructors were learning from instructors, and all were learning and sharing knowledge with the greater community” (p. 41). Clark and Button (2011) referred to this learning model as the partnering model in which the instructor is learning alongside the student, which allows the student to take a more active role in the learning process, share their ideas and contribute to the overall knowledge gained. Also, students learning from and sharing knowledge beyond the classroom and within the community provided them with a context and connection to the real world.

### 2.1.4 Faculties of Education STEAM Initiatives

The Conley et al. (2014) study in Spain focused on how STEAM facilitated pre-service teachers integrate mathematics and art into the curriculum. The researchers partnered with the Columbus Museum of Art to integrate the "learning-thinking model to observe, describe, interpret, and prove (ODIP)" (Conley et al., 2014, p. 89). ODIP was used as a pedagogical tool to promote the Standards for Mathematical Practice. Conley et al.'s work shows a model of teaching STEAM from a community perspective through mutually beneficial partnerships with universities (Brodie & Gadanidis, 2014), museums (Wynn & Harris, 2012) and other organizations (Clark & Button, 2011).

### 2.1.5 After School STEAM Programs by Non-Profit Community Organizations

Besides STEAM schools, there are many after-school programs and non-profit organizations that promote STEAM education. DiMaggio & Anheier (1990) observed that non-profit organizations in the education sector are "more conducive than for-profit . . . [because they] empower professionals with access to private donors or funding agencies," and they have more creative autonomy (p. 142). According to Harvard Family Research Project (2008), over the past decade, many research studies have shown a connection between student participation in after-school or out-of-school programs and how a student benefits academically, socially and emotionally (Pierce, Hamm, & Vandell, 1999; Posner & Vandell, 1994; Huang & Dietel, 2011). Several of the studies reviewed in the outgoing sections are based in the United States. In the next section, I report on studies in Canada.

### 2.1.6 STEAM Education and Makerspaces in Canada

Few studies, such as Hughes (2017), Mulcaster (2017), and Wang, Wang, Wilson & Ahmed (2016), report on STEAM models and programs in Canada. In this subsection, I summarize literature and professional publications on STEAM, as well as report on schools and programs that I found through hand and online searches of STEAM initiatives in Southwestern Ontario where this study took place.

Canada has taken a vested interest in STEAM and its potential benefits. Elizabeth Buckley School, located in Victoria, BC, claims to be the first STEAM school in Canada which is incorporating STEAM and the arts into everyday living ("Elizabeth Buckley School", 2018). The Elizabeth Buckley school has a "hands-on, experiential program that develops critical-thinking skills, global citizenship, and literacy in STEM (Science, Technology, Engineering, Math) and the Arts" ("Elizabeth Buckley School", 2018, para 9) their definition of arts includes "Visual Arts, Music, [and] Dramatic Play" ("Elizabeth Buckley School," 2018, para 1). Similarly, Ian Brodie, an elementary school teacher affiliated with both Western University and York University, taught mathematical concepts through music, dance, drama and visual arts in his classroom and at the Math Performance Festival at Western University (Brodie & Gadanidis, 2014). Specifically, patterns, numbers and probability were taught through music; geometric shapes, angles, position, distance and time were interpreted through dance; an abstract concept was brought to life by acting it out; and geometry, proportions, patterns, number, measurement and data were represented in a drawing or painting (Brodie & Gadanidis, 2014). Similarly, George Hart, a "world-renowned mathematician and sculptor" (p. 25) has worked with students' grades 7-12 in Kingston, Ontario to create beautiful sculptures using geometry, engineering, and design (Colgan, 2017).

Several school boards in Ontario have created makerspaces in the school library and other spaces such as the Library Learning Commons to provide a learning space that facilitates STEM and STEAM initiatives (Mulcaster, 2017). For example, Professor Janette Hughes from the University of Ontario Institute of Technology has worked with at risk youth with makerspace activities "creating interactive stories, simulations, games, and both physical and wearable technologies," (p. 104) which developed their perseverance and self-confidence (Hughes, 2017). Makerspaces also inspire students' curiosity, creativity, innovation and critical-thinking skills (Dougherty, 2016). The maker movement or makerspaces use both STEM/STEAM initiatives as a framework, but also promote "inquiry, play, imagination, innovation, critical thinking, problem solving, collaboration and personalized learning" (Hughes, 2017, p.103). Although the maker movement was happening on an international level, it is claimed that Toronto was the first to create a makerspace for kids in 2012, which held workshops on coding, robotics, Minecraft, 3D printing, wearable technology, and crafting ("MakerKids," 2018). Wang et al. (2016) mentioned that the DH MakerBus —the first mobile makerspace in Canada, funded for and made by the London Public Library in Ontario— is open to the community and used for librarian and teacher professional development (Wang et al., 2016).

The STEAM programs mentioned in the literature review share several commonalities. Besides STEAM schools and makerspaces, there are several non-profit organizations in Ontario, such as a STEAM lab in Toronto and a STEAM centre in St. Thomas. There are also community partnerships between universities and school boards. For example, Dr. Gadanidis from the University of Western Ontario has partnered with the local school board to implement computational thinking activities that blend coding with creativity. Gadanidis incorporated elements of STEAM into his activities and encouraged elementary students to express themselves creatively through song, visual arts, and math stories which "add[s] excitement to children's math learning" (Gadanidis, 2014, June, p. 39). His research begins to bridge the gap between researchers and educators, by putting research into practice. These partnerships provide teachers and students with the opportunity to share their knowledge with the greater community (Clark & Button, 2011). By sharing the learning and instruction that is happening with the community this "extends [the] learning experiences to wider audiences and contributes to the collective knowledge about how students learn" (Krechevsky, Rivard & Burton, 2010; Mulcaster, 2017). Every STEAM school or program has both commonalities and differences, but their goals are the same to provide meaningful experiences that enhance the learning experience for both the student and the teacher.

## 2.2 Collaboration and Capacity Building in Schools

Fullan (2007) affirms that teachers in schools are important change agents when it comes to reform and integrating new approaches to teaching and learning. According to Stroll and Louis (2007), an effective teacher learning community, such as Professional Learning Community (PLC), nurtures "positive school culture", encourages "a group of teachers sharing and critically interrogating their practice in an ongoing, reflective, collaborative, inclusive, learning-oriented, growth promoting way" (p. 2) thus empowering teachers (Ho & Lee, 2016). The same can be said about instructors in community after-school programs for children and teens, in which the instructors can be agents of change for the learning and interactions of the students in these out-of-school contexts. Directors, instructors, museum staff, university and government partners are in charge of the STEAM programs in the community settings. According to Allina (2018), a productive STEAM education program includes a co-teaching models, co-planning with other teachers, and collaborations with local artists, scientists, non-profit organizations and other experts. Collaboration and capacity building are an integral part of STEAM programs' growth and sustainability. Collaboration and capacity building can "growing [grow] out of common interests and commitment" (p. 501) to student learning (Ho & Lee, 2016). The learning and instruction can be shared through "collaborative conversations" with the students, their parents, educators and the broader community "for the purpose of furthering learning and connecting learners to their world" (Ontario Ministry of Education, 2015, p. 6). The whole process of capacity building can be described as organic, constantly changing, continuously growing, and based on these mutually beneficial relationships that are built through willingness to change, mutual respect and persistence when things don't go as planned (Hartman, 2017).

## 2.3 Components of a Productive Pedagogy in STEAM

The number of students participating in after-school programs has significantly increased in recent years. This means that it is important to consider what components contribute to the productivity of a STEAM program whether it is offered during the regular school day or as an after-school or out-of-school program. When speaking of after-school programs, Huang and Dietel (2011) note that an effective STEAM program has the following five components: 1) specific program goals and objectives, 2) experienced leadership, 3) highly qualified or trained staff members, 4) a program that aligns with the school curriculum, and 5) some sort of program assessment or evaluation. The type of projects made at the STEAM program is also a key component and can affect the students' learning experience. According to Blikstein (2013), educators should avoid "quick demonstration projects" that are aesthetically pleasing to the students but require little effort. Instead they should promote "multiple cycles of design" so that students create complex solutions and products, design "powerful interdisciplinary projects" that narrow the gap between disciplines, "contextualized the learning in STEM [/STEAM]" to make abstract concepts more meaningful and engaging, and generate an "environment that values multiple ways of working" to design and build a prototype (p. 18). All of these components in a well-structured in-school, after-school, or out-of-school program work together to create a conducive learning environment that promotes several learning skills, such as the development of 21$^{st}$ century skills, which develop high-order thinking skills, such as critical thinking, communication, innovation, creativity, and collaboration.

The structure of the different curricular and instructional models for STEAM education depends on the environment and the program's desired outcomes. The physical and social environment is important in programs such as STEAM (Gross & Gross, 2016; Harris & de Bruin, 2018). Besides the environment, the relationships and interactions between the teacher and student are key factors in creating an atmosphere that is safe and encourages student ingenuity and risk taking (Harris & Bruin, 2018). STEAM education is being implemented at every level of education through a variety of pedagogical approaches. For example, in a creative environment such as STEAM, "teachers cultivate learning environments in which students feel safe and in which they have permission to explore, take risks, … fail" (p. 165) and make mistakes (Harris & de Bruin, 2018).

Another characteristic of STEAM education is that students learn by making and sharing the products they have designed. Alexander's (2004) concept of "dialogic teaching" enhances the students' knowledge, thinking, overall understanding and learning experience by sharing their thoughts and ideas with others (Harris & de Bruin, 2018). In all the STEAM programs there are many opportunities for the student to share or present their ideas to an authentic audience (i.e., parents, school, community or globally). Guyotte et al. (2014) views the "framework of STEAM as a social practice of doing . . . consisting of: Thinking through Materials, Considering Audience, and Engaging with Community" (p. 17), which complements the idea of students sharing their learning experience with a wider community and having an opportunity to display their work. This allows students to be more purposeful in their design and provide them with an opportunity to share their thoughts, how they made the prototype, and how they reflected on feedback from others.

## 2.4 Curriculum Models and the Transdisciplinary Approach to STEAM

STEAM is not only interdisciplinary but can be described as transdisciplinary because it "goes beyond, or transcends, the boundaries of particular discipline" (Costantino, 2018; Herro & Quigley, 2016; Kreber, 2009, p. 25). In a transdisciplinary space, students are able to transfer their knowledge across a discipline and solve creative problems in another context, both in the classroom and out of school (Gess, 2017; Liao, 2016). STEAM teaches students skills, such as "critical thinking and problem solving; collaboration and communication; and creativity and innovation" (Liao, Motter & Patton, 2016, p. 29) that can be transferred to another context. Transdisciplinary approach to STEAM education is highly valued by both the teacher and the student because it allows the student to view the problem or design process from multiple angles or different perspectives that can be applied to a real-world context (Costantino, 2018). According to Quigley and Herro (2016), the transdisciplinary approach can be difficult to implement in a classroom because the teacher requires a certain amount of expertise across content areas in order to create an authentic learning experience for the students (Herro, Quigley, Andrews & Delacruz, 2017). This is because of the traditional structure of the education system of teaching subjects in isolation. Teachers who are more familiar with implementing multidisciplinary units and projects in STEAM education may have less difficulty seeing the connections between the different disciplines and beyond the material being taught (Herro & Quigley, 2016).

## 2.5 Assessment in STEAM Pedagogical Models

According to the Ontario Ministry of Education (2010) "the primary purpose of assessment is to improve student learning . . . which may include observations, discussions, learning conversations, questioning, conferences, homework, tasks done in groups, demonstrations, projects, portfolios, developmental continua, performances, peer and self-assessments, self-reflections, essays, and tests" (p. 28). Assessment and documentation are important in STEAM education to observe, record, interpret and share the learning experience (Krechevsky et al., 2010). The Ontario Ministry of Education (2012, 2015) suggest three stages for pedagogical documentation: first of all, observing and recording student experiences; secondly, interpreting the learning in the service of pedagogy; finally, responding, sharing and building a culture of inquiry and collaboration (Mulcaster, 2017). According to Harste (2001) "learning does not end with presentation [product] but rather with reflection, reflexivity, and action" (p.15). Through anecdotal notes, photos, and video recordings, the teachers can use this documentation to better understand the learner's thinking and things the teacher might wonder about, question or notice with respect to the students' overall learning experience. Pedagogical documentation can also be used as a reflection of the teacher's practices, whether the activity was student-centered, biases like some students receiving more attention than others, differences based on gender, ethnicity or social status, and how the teacher can support each student's learning (Mulcaster, 2017; Ontario Ministry of Education [OME], 2015). In the Capacity Building Series (OME, 2015), "pedagogical documentation is intended to uncover the student's thinking and learning process, it has the potential to help us look at learning in new ways" (p.1) and differentiate the learning experience for the student based on their individual needs. When teachers reflect upon the learning experience, they are using metacognitive thinking which "requires a shift from thinking about teaching content within a domain to . . . knowledge [that] can be used" (Gross & Gross, 2016, p. 543) in a real-world context. It also has the potential to bring "assessment for and as learning to life" (OME, p.1). According to Allina (2018), a study was done on "award winning programs' best practices" and it was found that a productive STEAM program must include "built-in, tailored assessments that help students and teachers understand what students have learned and what they have not" learned (p. 84).

## 2.6 Rationale for an Integrative Curriculum

Research suggests several enablers and constraints of an integrative curriculum. Although the planning of an integrative curriculum may require more time and preparation by teachers and school leaders —proponents of STEAM and STEM argue— the benefits, outweigh the costs. Gresnigt et al. (2014) stated that the constraints with implementing an integrative curriculum are lack of time for interdisciplinary units, difficulty connecting the activity with the curriculum, lack of confidence in teaching subjects that are less familiar, struggles with assessment and evaluation of the tasks, and lack of support from administration. Despite the hindrances to teachers and school leaders, studies have found that interdisciplinary units provide a meaningful context for students, they approach a topic from different perspectives, and students apply prior knowledge in new situations effectively (Lee, 2007). Consequently, students are more likely to be engaged and motivated to learn. Upitis (2011) observed that "student engagement is central to learning … [and that] the arts play a vital role in ensuring that students remain engaged by encouraging them to learn" (p. 1) both kinaesthetically and cognitively using their bodies, through collaboration and connecting them emotionally with the concepts they are learning. A major component of the arts and integrative curriculum is inquiry based because students are given the opportunity to question and use critical-thinking skills to approach a problem that has multiple solutions (Ghanbari, 2015). The integration of the arts promotes communication and critical-thinking skills, and helps students to develop a global perspective (Conley, Douglass & Trinkley, 2014).

Bequette and Bequette (2012) caution educators that STEAM as an integrative curriculum may "weaken each discipline and confuse the boundaries between different approaches" (p. 40), so it is necessary that teachers get proper training prior to and during implementation. As Moore et al. (2014) noted, "there is no guarantee that students will identify them or make the connections on their own. Consequently, the desired integrated STEM learning may well be lost" (English, 2016, p. 3). According to English (2016), more research needs to be done "on ways to help students make STEM connections more transparent and meaningful across disciplines" (p. 3). In contrast, the integration of subjects, including the integration of the arts in STEM subjects, provides students with multiple representations, multiple ways to approach a problem, multiple ways to express themselves, and multiple entry points of engagement that can bridge the achievement gap by providing disadvantaged students with the same opportunities for academic success and a high quality education (Robinson, 2013). STEAM can be described as a holistic approach to learning by educating the “whole child” (Connelly, 2012) and meeting their needs socially, emotionally and academically (Katz-Buonincontro, 2018). STEAM education has the potential to meet the individual needs of students since this type of curriculum is very student-centered and open-ended with multiple entry points, meaning that students of all levels and abilities can be successful. According to Ejiwale (2012), “it is important that learning activities are open-ended, giving students the freedom to explore and experiment within their own interests and learning styles” (p. 91). Leszczynski’s et al. (2017) found both benefits and challenges to open-ended inquiry, and they noted that “the challenges of an open-ended lab [inquiry] were that any tool could be used” and students expressed “feelings of uncertainty and cluelessness” (p. 30). In contrast “the open-endedness, need for collaboration, uncertainty, identification and allocation of necessary tools and resources, and interdisciplinary nature of the project resembled the work of [real] scientists” (Leszczynski, E., Monahan, C., Munakata, M., & Vaidya, A., 2017, p. 31).

## 2.7 Gaps in the Literature

An initial literature review for this study was conducted in 2016. I conducted several other searches for more scholarly articles on STEAM education, and my most recent search was done in November 2018[1]. I continued to read studies on STEAM education and themes emerged like the transdisciplinary approach in STEAM; I added these to my

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[1] For the literature review, I searched the following online databases: ProQuest Education, CBCA Education, Eric, JStor, Doctoral Dissertations, and Google Scholar. I varied search terms to include: STEAM, STEM, STEAM education, Art Integration, Science Integration, STEAM labs, STEAM After school, Cross-Disciplinary approach, Designed-based learning, Authentic learning experiences, Makerspaces, Maker education. I also combined search terms into phrases and search strings such as: STEAM Education; Integrated Curriculum; STEM and Arts; Science and Art; Mathematics and art; Art-based curriculum; STEM education and Arts and Canada; STEAM education and Canada; STEM and Creativity; Creativity and education; Art-based learning; Makerspaces and Canada. I also carried out a hand search following up on references in publications that I reviewed, as well as searching STEAM related journals and conference proceedings, including: *International Journal of Education & the Arts; International Journal of Innovation in Science and Mathematics Education; Science & Technology Education; The STEAM Journal.* Finally, I searched the library catalogue for publications with the word STEM or STEAM. The library catalogue search resulted in publications, such as From STEM to STEAM, STEAM Point, and Imagination in Teaching and Learning.

literature review. Presently, there is little research that discusses the process of creating a STEAM-based curriculum and the benefits of those existing programs (Ghanbari, 2015; Herro & Quigley, 2016). Throughout my literature review, I have found many publications on STEAM education that are based neither on empirical research nor on theoretical conceptualizations. I have chosen not to include these types of publications, many of which are opinion-based, in my literature review because several are simply promoting STEAM education. I have only found two case studies on the integration of the arts with STEM, which is at the middle school and post-secondary level (Ghanbari, 2014; Ghanbari, 2015). On the other hand, I have found several case studies on STEM education where I have adapted their research instruments for this study (e.g., Luna, 2015 & Misher, 2014) and I elaborate on this in Chapter 4. Many of the scholarly articles I read included STEAM models in higher education but neglected to include examples at the elementary and secondary level.

According to Herro and Quigley (2016), there are few cases of STEAM education that are documented in depth. To address this issue, they conducted a case study on middle school teachers to further conceptualize STEAM "by revealing the process, challenges, and successes of STEAM teaching from the perspective of teachers implementing it in their classrooms" (Herro & Quigley, 2016, p. 321). There is also a lack of research and literature on STEAM education in Canada compared to the United States. This is probably because the STEAM movement in Canada is very recent and has occurred over the last seven years. A case study needs to be done at the elementary or secondary level on a STEAM-based institution or program, specifically looking at curriculum and instruction, and to provide educators with a model for STEAM education in a Canadian context.

## 2.8 Summary

STEAM education is being implemented at every level in education. There are many different curricular and instructional models for STEAM education including art-integration, design-based, inquiry-based, project-based and problem-based models that are being implemented at schools, higher education and community-based programs. The physical and social environment in programs such as STEAM is important, which depends upon the teacher-student interactions, environment, available resources and the programs' desired outcomes (Harris & de Bruin, 2018). In this chapter, I also outlined different components of a productive STEAM program, which included collaboration and capacity building, transdisciplinary models, and assessment and documentation. In this study, I use a naturalistic approach to explore STEAM education by using qualitative research methods to study the curriculum and instructional models implemented in varied contexts both out-of-school and in-school, student learning, assessment and how classroom teachers view such models in meeting their curriculum and instructional goals.

# Chapter 3

## 3 Theoretical and Curriculum Frameworks

In this chapter, I will discuss three theoretical frameworks, Papert's Constructionism, Design-Based Learning, and Low Floor, High Ceiling, Wide Walls. Then I will outline two curriculum frameworks, the Integrated Curriculum Model and the Subject-Based Curriculum Frameworks. The theoretical frameworks were used as a lens to analyze pedagogy, curriculum and instruction models in the four STEAM programs. The curriculum frameworks were used to analyze the curriculum documents, specifically the integrated learning opportunities, and the STEAM tasks. As noted in the literature review section (Chapter 2), the STEAM programs were guided by different curricular, pedagogical and theoretical models. For instance, the school-based models, such as Elizabeth Buckley School, Sail Academy, STEAM Academy, BAA, RMS, and UPSA, employ constructionism, design-based learning, and low floor, high ceiling, wide walls. I used these theoretical frameworks to provide a critical lens, which Creswell (2014) says helps to analyze data thoroughly. The three theoretical frameworks also influence the questions asked and the interpretations of the data.

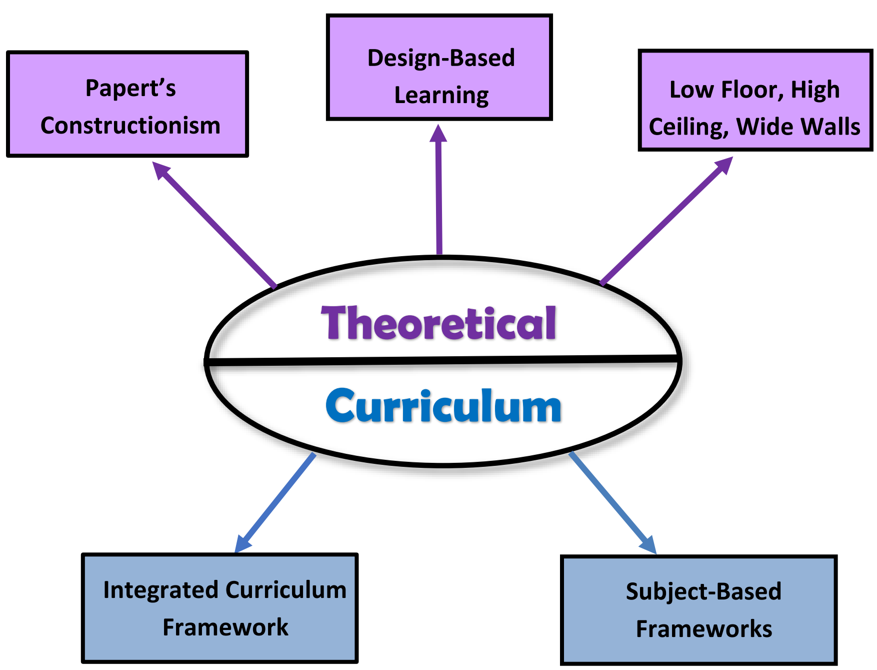



*Figure 1.* The theoretical and curriculum frameworks that were used as a critical lens.

I will use three theoretical frameworks, as seen in Figure 2. The first theory that I use is Papert's constructionism developed by Papert Seymour, who was an educator and researcher at MIT. The second theory that I use is Design-Based Learning, which was developed by Doreen Nelson, who is a professor at California State Polytechnic University. I chose Papert's Constructionism because students in the STEAM programs constructed their own knowledge by designing and building a prototype and sharing their final product with an authentic audience. Similarly, I selected Design-Based Learning because the curriculum and instruction of the STEAM programs incorporated design thinking and inquiry-based models. The third theory I selected was "low floor, high ceiling, wide walls" approach to learning which can be incorporated into the other two frameworks, since both Papert's Constructionism and Design-Based Learning have multiple entry levels (i.e., simple to complex products produced), multiple representations and multiple ways to approach a problem. I will discuss this connection between the three frameworks in further detail in section 3.3.

| Constructionism | Design-Based Learning | Low Floor, High Ceiling, Wide Walls |
|---|---|---|
| • "Learning-by-making" (Papert & Harel, 1991, p. 6)<br><br>• Students making a public artifact that "can be shown, discussed, probed, and admired" (Papert, 1993, p. 142). | • Students engaging in the design process in a real-world context<br><br>• Students creating a plan and designing a prototype that will be tested and then redesigned<br><br>Doppelt, 2009 | Learning Environment provides:<br>• multiple entry points<br>• multiple ways to approach a problem<br>• multiple representations of these activities<br>• Students of all ages and abilities the opportunity to participate<br><br>Gadanidis, Hughes & Cordy, 2011 |

*Figure 2.* The overview of the three theoretical frameworks, Papert's Constructionism, Design-Based Learning, and Low Floor, High Ceiling, Wide Walls

I will use two curriculum frameworks as seen in Figure 3. The Integrated Curriculum Model (ICM) framework, developed by VanTassel-Baska's in 1986, was used to analyze the quality of the STEAM tasks and the integrated learning opportunities. For the subject-based STEAM tasks, I selected the Ministry of Education's Ontario and British Columbia curricula and the National Generation Science Standards curriculum for Engineering Design to analyze the science, technology, engineering, arts and mathematics skills taught in the STEAM tasks. I chose the Ontario Ministry of Education curriculum for arts, mathematics and science since the four research sites were all located in Ontario, Canada. The Ontario curriculum did not have a stand-alone curriculum for technology, so I selected the British Columbia Applied Design, Skills, and Technology curriculum (ADST) because there were specific standards for technology, such as robotics, media arts, power technology (devices that transform energy), digital literacy and computational thinking that corresponded to skills taught and found in the site's curriculum documents. The Ontario curriculum also did not have a stand-alone engineering curriculum, so I used the Middle School Engineering Design Standards (MS-ETS1) from the National Generation Science Standards (NGSS) website (https://www.nextgenscience.org/) as a critical lens to analyze the engineering standards in the curriculum documents for each research site. In this chapter, I will discuss the theories first, and then I will explain the curriculum frameworks that I used as a critical lens to analyze the observations, interviews and curriculum documents.

| Integrated Curriculum Model (ICM) | Subject-Based Frameworks |
|---|---|
| I selected:<br>• ICM because it has advanced content, high-level process and product work<br>• Intra- and interdisciplinary concept development and understanding<br>VanTassel-Baska & Brown, 2007, p. 350 | I selected:<br>• The Ontario curriculum for Arts, Mathematics and Science<br>• The British Columbia Applied Design, Skills, and Technology (ADST) curriculum<br>• The Middle School Engineering Design Standards (MS-ETS1) |

*Figure 3.* The overview of the two curriculum frameworks, Integrated Curriculum Model and Subject-Based Curriculum frameworks.

## 3.1 Papert's Constructionism

According to Papert (1991, p. 6), the most basic definition of contructionism is "learning-by-making." Papert explained that constructionism "shares [Piaget's] constructivism's view of learning as 'building knowledge structures' through progressive internalization of actions… it then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe" (Papert & Harel, 1991, p.1). Papert demonstrated that learning happens when students articulate their thought process, make a public artifact that "can be shown, discussed, probed, and admired" (Papert, 1993, p. 142; Yu, 2016).

Papert acknowledged the importance of using tools, technologies, media and a real-world context that children can identify with and which promotes conversations and interactions (Ackermann, 2001). Papert was interested in how people communicate and engage with one another, through human interactions, as well as how these interactions promote self-directed learning and construction of new ideas (Ackermann, 2001). It is important to note that "making does not equal constructionism - necessarily" (Skillen, 2014, n.p.). Rather, there are two equally important components of constructionism: making and sharing (Mulcaster, 2017). Constructionism is student-centered because students learn through discovery, exploration, building and making a tangible object (Alesandrini & Larson, 2002).

## 3.2 Design-Based Learning

Design-Based Learning (DBL) is a theory about learning in a real-world context. Educators who espouse this theory claim that DBL has the power to influence education reform, and they have developed their own approach to teaching and learning that incorporates "hands-on problem solving, project-based learning and portfolio assessment" (Davis, 1998, p. 1). DBL is also "an inquiry-based form of learning, or pedagogy, that is based on integration of design thinking and the design process into the classroom" (Barron & Darling-Hammond, 2008, n.p.). In DBL, the student engages in the design process in a real-world context by creating a plan and designing a prototype that will be tested and redesigned (Doppelt, 2009). Doppelt identified six stages of the design process: “defining the problem and identifying the need, collecting information, introducing alternative solutions, choosing the optimal solution, designing and constructing a prototype, and evaluation” (Doppelt, 2009, p. 57). In DBL the learner is required to consider the process and real-life factors involved in such a design (de Vries, 1997).

To Davis (1998), DBL creates a “bridge between fine arts and other areas of the curriculum, such as science, mathematics, social studies, and language arts” through design (p. 1). Davis further argued that DBL can be used to improve teacher instruction, integration of the curriculum, and improve teaching and learning by allowing students to apply their knowledge through “creative problem solving to improve student performance in any subject area and in daily life” (p. 1). It has been noted that DBL utilizes elements of “project-based learning and problem solving through students’ creative design” (Kim, Suh & Song, 2015, p. 576). DBL is also student-driven because it allows students to create a design based on their interests and needs rather than the parameters being defined by the curriculum or the teacher (Mehalik, Doppelt & Schuun, 2008).

DBL is a key element in STEAM education, and it is used as a model in STEAM labs and centres. These labs and centres incorporate coding, programming, game design, 3D design and printing, and designing and engineering a prototype into their courses. DBL enables students to engage in designing real experiments rather than simply learning content knowledge.

## 3.3 Low Floor, High Ceiling, Wide Walls

The idea of “low floor” and “high ceiling” was inspired by Papert’s work with Logo (i.e., a programing language he created) to teach children mathematics through computer programming. Papert argued that in order to engage kids of all ages in computer programming that “programming languages should have a ‘low floor’ (i.e., easy to get started) and a ‘high ceiling’ (i.e., opportunities to create increasingly complex projects over time)" (Resnick et al., 2009, p. 63). Resnick (2008) was inspired by Papert's theory of constructionism and his efforts to create activities that were fun for children, but at the same time challenging. Resnick suggested that a third dimension was required "wide walls" which encouraged multiple pathways to create different outcomes (i.e., products) and to facilitate students with different interests and learning styles (Resnick et al., 2009).

Inspired by both Papert's and Resnick's work, Gadanidis (2014) coined the term "low floor, high ceiling, wide walls" learning environments and developed activities that integrate mathematics and coding in the classroom to enhance the students' overall learning experience and make it more meaningful.  DBL activities appear similar to what is referred to as "low floor, high ceiling, wide walls" (Gadanidis, 2015) learning environment because they provide multiple entry points, multiple ways to approach a problem, and multiple representations of these activities so that students of all ages and abilities can participate (Gadanidis, Hughes & Cordy, 2011).

## 3.4 Integrated Curriculum Framework

STEAM is considered an integrated approach to teaching and learning. The Integrated Curriculum Model (ICM) was created by VanTassel-Baska for gifted and high-ability learners and has shown success with low-income students in recent studies (VanTassel-Baska, Bracken, Feng & Brown, 2009; VanTassel-Baska & Brown, 2007). The ICM framework has been used to plan and develop curriculum in Canada, Australia and the United States. ICM "has three dimensions: (a) advanced content, (b) high-level process and product work, and (c) intra- and inter-disciplinary concept development and understanding . . . in the core subject areas of language arts, science, social studies, and, more recently, mathematics" (VanTassel-Baska & Brown, 2007, p. 350). ICM incorporates "inquiry-based instruction, integration of technology, authentic assessment, and constructivist models for learning" (VanTassel-Baska & Brown, 2007, p. 350), which works well with both Papert's Constructionism and Design-Based Learning. ICM encourages students to solve real-world problems using "higher-order thinking skills such as critical thinking, creativity, decision making, and problem solving" and develop a deeper understanding of the concepts (Kahveci & Atalay, 2015, p. 95).

## 3.5 Subject-Based Curriculum Frameworks

The Ontario curriculum for arts, mathematics and science; the British Columbia ADST curriculum; and the MS-ETS1 curriculum from NGSS were used as a critical lens to analyze the curriculum documents from both the non-profit and in-school research sites. I implemented these subject-based curriculum frameworks when I analyzed and deconstructed the curriculum documents from the four research sites. The curriculum documents outlined several disciplinary concepts with suggested pedagogies and assessment methods. For example, students learn about electricity and electrical devices from the Ontario Science curriculum (OME, 2007) at different grade levels K-8. For example, "sensors, control systems, and effectors" as the main component of robotics is a technology learning objective in the British Columbia ADST curriculum for technology for grades K-8 (ADST, 2016, p.7). The Next Generation Science Standards (NGSS, 2014), specifically the middle school standards (MS-ETS1-1, 2014), were used as a critical lens for the engineering design learning standards. Many of the engineering design tasks in the STEAM programs provided students with the opportunity to "evaluate competing design solutions [of a prototype] using a systematic process to determine how well they meet the criteria and constraints of the problem" (MS-ETS1-2, 2014, p.1).

In the Ontario Arts curriculum (OME, 2009) for grades K-8, "students learn and are expected to use a creative process" (p. 19). The creative process consists of the following stages: challenging and inspiring; imagining and generating; planning and focusing; exploring and experimenting; producing preliminary work (prototype); revising and refining; presenting, performing and sharing; and reflecting and evaluating (OME, 2009). In the Ontario Arts curriculum (OME, 2009), students were challenged to "use a variety of materials, tools, techniques and technologies" (p. 144 and 155) to create works of art.

## 3.6 Summary

Papert's Constructionism is a useful theoretical framework to examine the STEAM programs because it conceptualizes students as "learning-by-making" and places value on sharing the final product with an authentic audience (Papert & Harel, 1991, p. 6). Papert's Constructionism and Design-Based Learning complement one another. For example, Design-Based Learning requires a making stage in which the students design and construct a prototype, and then the students showcase or share their final product with others. Similarly, "low floor, high ceiling, wide walls" approach to learning can be incorporated into the other two frameworks because they both have multiple entry levels, multiple representations and multiple ways to approach a problem. I combined these curriculum frameworks and theories in my analysis of the STEAM programs' curriculum documents, where Papert's Constructionism, Design-Based Learning, and Low Floor, High Ceiling, Wide Walls were built into the ICM framework, the Ontario Arts curriculum (OME, 2009), the ADST curriculum and Middle School Engineering Design Standards. In the next chapter, I discuss the research design, data collection, data organization and data analysis that were conducted.

# Chapter 4

# 4 Methods

The naturalistic paradigm acknowledges that the data cannot be universally generalizable because there are "multiple interpretations of, and perspectives on, single events and situations" (p. 21), which make the data analysis and interpretation more complex (Cohen, Manion & Morrison, 2007). The goal of the naturalistic approach is to explore a phenomenon in greater depth and gather "thick" descriptive data to represent "the complexity of the situation" (Cohen et al., 2007, p. 21). In the real world, an event or situation is not simple, but multidimensional and complex (Cohen et al., 2007). In order to gather "thick" descriptive data, the researcher must conduct in-depth interviews (Greenfield, Greene, & Johanson, 2007). This research study used the naturalistic paradigm, which focuses "primarily . . . on participant observations and informal interviewing" and also "includes analysis of documents, reported conversations, description of events, location and action of individuals" (Arthur, Waring, Coe, & Hedges, 2012, pp. 76-77). In naturalistic inquiry, the researcher interprets the data through the participants' perspective rather than with a computer-based system (Arthur et al., 2012). In order to avoid bias when interpreting the data, the researcher must be able to self-reflect, critique their own work, have a diverse background and experience, and rely on their readings to analyze the data (Arthur et al., 2012). I return to my self-reflection and background in the section 4.4 of the researcher as a research instrument.

## 4.1 Research Design

According to Yin (2004), a case study sheds light on a particular phenomenon, reveals a more in-depth perspective and develops a better understanding of the situation. A case study can be defined as a "qualitative research approach in which researchers focus on a unit of study known as a bounded system (e.g., individual teacher, a classroom, or a school)" (Gay, Mills, & Airasian, 2009, p. 426). The main purpose of a case study is to focus on a particular phenomenon, such as a process, event, person, or other area of interest (Gall, Gall, & Borg, 2007). A case study is the appropriate choice for the study because I studied a particular phenomenon in a bounded system: STEAM programs in Ontario and their curriculum and instructional model of STEAM (Science, Technology, Engineering, Arts and Mathematics) education in two non-profit and two in-school research sites.

A case study method can play a significant role in human learning and be characterized as heuristic because it deepens the reader's understanding and provides new insight of the phenomenon beyond their initial understanding (Gay et al., 2009). Stake (2005) classifies case studies into three categories: *intrinsic, instrumental* and *collective.* The goal of an intrinsic case study is to research the case as a whole, trying to understand everything about the student, teacher, board and school within the bounded system of the case (Hamilton & Corbett-Whittier, 2013). On the other hand, instrumental case study focuses on a particular "aspect, concern or issue of the case" (Hamilton & Corbett-Whittier, 2013, p.12). The third method is a collective case study, in which the researcher selects more than one case to provide a representative sample (Cousin, 2005). This approach allows the researcher to make more theoretical generalizations and explore the concept in further depth (Cousin, 2005).

I conducted a collective case study and focused on a particular bounded phenomenon! STEAM curriculum and instruction models— what these models are and how classroom teachers view such models in meeting their curriculum and instruction goals. A collective case study on STEAM education from multiple data sources and different viewpoints requires that the researcher has "highly developed language skills in order to identify constructs, themes, and patterns in verbal data and to write a report that brings the case alive for the reader" (Gall et al., 2007).

## 4.2 Research Questions

This research study addressed the following questions:

1. What curriculum and instruction models of STEAM education are implemented in non-profit and in-school contexts in Ontario, Canada?
2. What do students learn through different models of STEAM education?
3. What types of assessment of student learning is happening in STEAM education?
4. How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals?

Prior to the data collection, this research study thought to address questions 1 and 4. During the data collection and analysis, questions 2 and 3 emerged from the data.

## 4.3 Participants and Settings

I took a small sample of four different STEAM programs in Ontario, Canada. Specifically, the STEAM programs in two non-profit organizations and two in-school research sites. The STEAM programs for this study were selected based on the following criteria (Huang & Dietel, 2011; Kahn, Bronte-Tinkew & Theokas, 2008).

A) The STEAM program selected evinced:

1. Specific program goals and objectives (inputs)
2. Experienced leadership
3. Highly qualified or trained staff members with professional development opportunities

B) The STEAM program with a specified curriculum that has:

4. Academic alignment and achievement
5. Forms of assessment or evaluation for measuring outcomes
6. Articulated measures for program sustainability and growth

There was a total of 103 research participants (19 adult participants and 84 student participants). I interviewed 52 participants (directors, teachers, instructors, teacher librarians and students) from the four research sites. Both the non-profit and in-school research sites were co-ed, ages 6-13. The ratios of girls to boys varied depending upon the course taught, and the class or research site. After I analyzed all the interview, observation and curriculum document data, I conducted a focus group with four elementary classroom teachers at which I presented the results on the curriculum and instructional models of STEAM and orchestrated discussion on how classroom teachers view such models as meeting their goals. Table 1 summarizes the settings of the research sites. Table 2 summarizes the details of the research participants.

*Table 1.* Environment, Programs, Goals and Curricula Studied

| | Environment and Programming | Goals, programs and Curriculum Studied |
|---|---|---|
| Non-Profit 1<br><br>Observed 3 lessons per class, total of 6 observations. | Urban STEAM center/lab in a metropolitan area. Caters to K-7 children and with programs for teens/adults.<br><br>A one room STEAM lab/center Large space divided by movable walls. Space set up for small group work, with desks and chairs as well as floor mats. All stations (e.g., the cutting station) are set in the one room.<br><br>Offers paid programs: weekend, after school, PD, school hours and summer workshops. Staff consists of a director, instructors and volunteers.<br><br>Academic alignment was stated in the curriculum documents and posted on the website. Assessment was mentioned by the director as consisting of observations, questions and conversations with the students. Measures for program's sustainability were articulated on the Google drive and in the pre-interviews with the director. | I studied the weekend program offered on Sundays for 7 weeks.<br><br>Imagineering: "a class that introduces kids 6-9 years old to the fundamental skills of making and programming. Students will take part in activities that teach 21st century skills through games, storytelling and of course, making."<br><br>Inventioneering: "a class for kids 9-12 year olds using a combination of high tech tools (3D printing, laser cutting, electronics), wood working and craft. Provide the mentorship and structure to help you turn your sketched ideas into working prototypes – led by your own interests, imagination and ingenuity."<br><br>(Non-Profit 1 Curriculum Documents, 2016) |
| Non-Profit 2<br><br>Observed 4 lessons per class, total of 8 observations. | Urban STEAM center/lab in a metropolitan area. Caters to K-7 children and with programs for teens/adults.<br><br>Multiple rooms set up as a computer laboratory for students to work individually or in pairs at desks. Stations (e.g., the Laser/Wood cutter room) were located in different rooms. | I studied the after-school workshops on Wednesdays and Thursdays offered for 5 weeks.<br><br>STEAM 101: "Discover the exciting world of Science, Technology, Engineering, Art and Math. Get a taste of 3D printing, Digital Design, Coding, new technologies, and other fun ways of learning 21st century skills."<br><br>Creative Coding - Intro to Coding with Scratch: "See how easy learning computer coding can be! Scratch is all about fun games |

| | | |
|---|---|---|
| | Offers paid programs: weekend, after school, PD, school hours and summer workshops. Staff consists of a director, instructors and volunteers.<br><br>Academic alignment was stated in the curriculum documents and posted on the website. Assessment was mentioned by the director as consisting of parent/student survey. Measures for program's sustainability were articulated in the pre-interviews with the director. | and playful learning with the amusing Scratch Cat. Enjoy digital literacy by learning to code with friendly drag and drop colour coded blocks."<br><br>(Non-Profit 2 Curriculum Documents, 2018) |
| In-School 1<br><br>Observed two classes once for a single lesson as well as the SUMO event. | Urban public school in a metropolitan area catering to K-8 students.<br><br>Its learning environment is set in the Maker Lab located in the Library Learning Commons. It is a STEAM center/lab with work benches and stations for students.<br><br>The STEAM program consists of 1 teacher librarian and selected school teachers. | Grade 1: At two stations students were either programming with the Code-a-pillars or creating a-b-c pattern towers in Minecraft.<br><br>Grade 5: Students were working on programming the LEGO EV3 robots to go around the perimeter of their challenge mats.<br><br>SUMO Event: Different robotics teams from different schools were competing with their LEGO EV3 robots. The goal was to push the other robot outside of the given perimeter. |
| In-School 2<br><br>Observed two classes as well as the Micro:bit and STEAM clubs. | Urban public school in a metropolitan area catering to K-8 students. Its learning environment in the Makerspace, the Library Learning Commons, has both stationary and mobile stations.<br><br>Some of the lessons happened outside of the Makerspace, such as the Science and Technology Application Centre (S.T.A.C.) room or in their regular classroom.<br><br>The STEAM program consists of 1 teacher librarian and selected school teachers. | Grade 5: Observed this class 3 times during the same week. Design-Inquiry Process: How might we design a product that transforms energy from one form to another and serves a purpose or function in our lives?<br><br>Self-Contained Grades 1, 2 and 3 Class: Observed the little red hen lesson. Students worked collaboratively in groups of 3 to design a paper airplane using an iPad and a pencil to sketch and design their prototype.<br><br>Micro:bit and STEAM clubs: During second break students get to tinker and explore with Micro:bits and other technologies |

*Table 2.* Adult and Student Participants at Research Sites

| | Adult participants | Student Participants |
|---|---|---|
| Non-Profit 1 | 1 Director, 1 Instructor and 5 volunteers. Ages 20+, female and male. The director and instructor had a background in education. | Students ages 6 to 12, boys and girls. |
| Non-Profit 2 | 1 Director, 2 Instructors and 3 volunteers. Ages 20+, female and male. Both instructors had a background in education. | Students ages 6 to 12, boys and girls. |
| In-School 1 | 1 Teacher librarian and 4 elementary school teachers with a formal teaching degree. | Students ages 6 to 13, boys and girls. |
| In-School 2 | 1 Teacher librarian and 4 elementary school teachers with a formal teaching degree. | Students ages 6 to 13, boys and girls. |

## 4.4 Researcher Roles

According to Creswell (2014), the "personal background, culture, and experiences hold potential for shaping" (p. 175) the interpretation of the data and direction of the study. I have twelve years of experience teaching mathematics, biology, chemistry, physics and general science in Canada and the United States, as a full-time, occasional and pre-service studies teacher. I am presently working as a Graduate Research Assistant at Western University, and one of my main areas of research is STEM/STEAM education and computational thinking tools. I also taught a Math Intermediate/Senior course for pre-service teachers, which incorporated mathematics pedagogy, research, technology, and classroom practices. Besides teaching and research, I have presented at conferences and facilitated workshops on the topic of STEM/STEAM. I have designed Computational Thinking and Coding activities for implementing in K-8 classrooms. These activities are designed to facilitate a holistic approach to teaching and learning mathematics, as well as to promote inclusiveness, integration, real-world connections and STEAM education. I am passionate about mathematics and STEAM education. I am aware that my passion for STEAM might bias my interpretations of the results of this study. Rather than being a detached observer, I used my frame of reference to bring a context and connection to the study. At the moment of collecting the data, most of my knowledge about STEAM education came from the literature rather than in the field experience. As a researcher, I observed the participants in the STEAM program and recorded what happened naturally in their environment without influencing, modifying or changing the students' learning environment (Arthur et al., 2012; Mears, 2009). I developed my skills to identify constructs, themes and patterns through readings, courses and resources on both qualitative analysis and the Nvivo software. I also brought my background as an educator and researcher during the reflection on and the formal analysis of the data, specifically when I looked for particular themes that emerged in the observations, interviews, curriculum and focus group data.

## 4.5 Ethics of the Study

I followed the protocol on Human Research Ethics through the Western University link. Participants were chosen from those who had given consent and volunteered to participate in the interviews, focus group and observations. The participants were informed about the study via an email scripted letter sent to the director/principal of the research site (Appendix B). The focus group details were sent in an email to elementary classroom teachers using a list through acquaintances at the Faculty of Education and the local school board. All participants received participation consent forms (Appendix C).

Ethical issues may arise if the researcher cannot effectively disguise the identity of the participants and the institution (Gall et al., 2007). To ensure anonymity, I used pseudo names for the directors, instructors, students, and classroom teachers. I let the participants know in the letter of information that their anonymity cannot be guaranteed because the school population is small. The trends and observations of the instructors/teachers and students were described based on the themes, patterns and trends, and no identifying descriptive information is used. Photos and scans of student work products used in the study were anonymous.

All photos taken of the environment ensured the participant's anonymity by showing no faces, name tags or other distinguishing features. If pictures and videos were taken from the front, I blurred the identifying features in these pictures of the students in the research reports. Although the focus group was audio-recorded, the responses remained anonymous, and no names were mentioned in the report. Digital research data were stored on password-protected devices. All the data in the Nvivo software were password protected and kept confidential. To ensure confidentiality, records were kept in a locked cabinet at the student researcher's home office. All data remained confidential and accessible only to the investigators of this study. All the consent forms were kept by the researcher in a secure place, separate from corresponding study files.

The potential risk of harm (i.e., physical, social, emotional or economic) in this study to adult and student participants is low or non-existent. None of the participants were asked any personally intrusive questions. The adult participants were given the opportunity to review their responses on interview transcripts (member check), and to give permission for the data to be released and used in the research study. The observations and interviews of students were always conducted in the presence of their instructor/teacher. Interviews with the director were conducted at his or her office; interviews of the instructors/teachers were conducted in a public but quiet place convenient to them. Participants had the opportunity to drop out of the study at anytime. I have outlined in the methods section in detail the rationale for each data collection method and the guidelines I followed during the data collection process. I made sure that the results reported, and their discussion and conclusion did not potentially interfere with the mission or policies of the non-profit organizations that participated in the study.

## 4.6 Trustworthiness and Reliability of the Study

According to Creswell (2014) there are eight strategies to convince the reader of the study's validity and reliability, such as triangulation, member checking, thick descriptive data, clarification of any bias (by/of researcher's), present negative or contradictory evidence, data collected over a prolonged period of time, peer debriefing, and external auditor (review entire manuscript). Also, to increase the reliability of my data, I checked the transcripts for any mistakes after the initial transcription and cross-checked the codes myself (Gibbs, 2007; Guest, MacQueen, & Namey, 2011). The adult participants in this study were given the opportunity to look over their responses through member checking.

I wrote the research report with clarity keeping the evidence, which is presented in Chapter 5 on findings, and the interpretations, which is presented in the discussion in Chapter 6, separate from one another in the report (Yin, 2004). I presented the data with supporting evidence. I described a detailed record of the events directly from my field notes and transcribed audio recordings. I based my observations, results and conclusions on evidence or facts, not my opinions.

The literature search was done over a period of time so that I was able to attain the most recent studies on STEAM. Throughout the discussion of the findings, I refer to the literature, theoretical and curriculum frameworks to supports the findings. I do not "make claims about cause and effect," (p. 28) but focus on identifying the associations to avoid jeopardizing the internal validity of the case (Arthur et al., 2012). To obtain internal validity, I utilized observation and interview templates from other research studies, checked the findings with the participants through member checking, cross-checked the findings from multiple data sources, did not make assumptions or generalizations, supported my findings with triangulation of data and the literature, and included every detail in the methods section in Chapter 4 so that this study could be replicated by another researcher to obtain similar results (Creswell, 2014).

## 4.7 Data Collection

Yin (2004) states that "case study evidence also can include both qualitative and quantitative data" and "both types of data can be highly complex" (p.11) during the analysis. I decided to use only qualitative data to understand STEAM curricular and instructional models in greater depth and to collect rich descriptive data (Gay et al., 2009). The data also consisted of interviews, observations and curriculum documents, which were more descriptive and a collection of verbal data of two non-profit STEAM programs and two school-based STEAM programs. In order to triangulate the data, I used multiple data sources, which included interviewing and observing key participants at the four research sites, carrying out a document analysis and conducting a focus group with classroom teachers to better understand the curriculum and instruction in the STEAM programs. I triangulated the data to add validity and corroborate the research findings (Arthur et al., 2012).

### 4.7.1 Interview Data

I conducted face-to-face interviews with the participants individually (i.e., adults, students) and in groups of three to five people (i.e., students). The interviews were intended to capture general trends, personal stories and deep insights from the participants (Arthur et al., 2012). According to Creswell (2014), one possible limitation of interview data is the fact the information obtained is filtered through the lens, opinion and view of the participant. The interviews were conducted to investigate what STEAM curriculum and instruction models were implemented and the student learning and assessment that occurred in the non-profit and in-school contexts. The interviews conducted can be described as "unstructured and generally open-ended questions that are . . . intended to elicit views and opinions from the participants" (Creswell, 2014, pp. 239-240). The interview process does not have clearly defined guidelines "interview research is characterized by an emerging design, with data collection blurring into data analysis . . . and no iron-clad rules of what constitutes sufficient data" (Arthur et al., 2012, p. 173; Mears, 2009). I used interview templates that were adapted from other STEM/STEAM research study templates such as the Ghanbari (2014), Misher (2014), and Johnston and Tolkunow (2016) studies in appendices D-I, templates for leadership, teachers, instructors, students, and focus group interviews for classroom teachers. The interview templates consisted of questions on demography, curriculum and instruction models, students' learning, and the benefits and challenges of STEAM programs.

I modified the interview design based on information from the literature review and emerging themes that were found in the initial observation and document analysis data. For example, during my introductory interview with the teacher librarian, it was evident that collaboration and capacity building was an important aspect of the STEAM program, and it was necessary to add two additional questions that addressed this aspect. The fluidity of the interview process in this study may make it difficult to replicate. For example, the addition or elimination of questions, unplanned follow-up questions, or the use of further questioning to probe or get more clarification on an answer.

I conducted introductory (pre-observation) interviews with the directors and teacher librarians, who were in charge of the STEAM programs, as a screening process to determine whether the non-profit organizations and in-school research sites met the selection criteria (section 4.3) about program objectives, staff complement, curriculum, assessment and monitoring for the collective case study (Gay et al., 2009). For the non-profit research sites, I interviewed the directors, instructors/teachers and students, using open-ended questions (Arthur et al., 2012). Specifically, I interviewed 2 directors, 3 instructors, and 14 students in two non-profit STEAM programs.

For the school-based research sites, I interviewed both the classroom teachers and the teacher librarian in charge of the curriculum and instruction for the STEAM program. Specifically, I interviewed 8 teachers, 2 teacher librarians and 23 students in two school-based STEAM programs. I interviewed 14 students from the non-profit and 23 students from the school-based STEAM programs. The interviews of the instructors/teachers were conducted in a quiet public place convenient to them. The individual interviews for the adults took 15 minutes to 1.5 hours. I conducted in-depth interviews, including multiple interviews with the same participant, ranging from 40 minutes to 1.5 hours with 2 directors, 3 instructors, 2 teacher librarians and 2 teachers (Arthur et al., 2012). The purpose of these interviews were to gain a deeper understanding of each participant "to discover and record what the person has experienced [in the STEAM program], what he or she thinks and feels about it [curriculum, instruction and student learning], and what significance or meaning it might have" (Arthur et al., 2012, p. 170; Mears, 2009). Unfortunately, this gaining of depth of knowledge of participant's experience was not the case for all the teachers since 6 out of the 8 teachers interviewed for a single interview, 15 to 25 minutes in length. Due to time constraints, teachers were able to conduct interviews only during their preparation period or the nutritional break but not after school. Although these teacher interviews were quite informative, I did not get the same depth of knowledge as the interviews that were greater in length.

The student interviews were conducted either individually (i.e., in-school sites) or in groups of three to five (i.e., non-profit sites) when I observed the lessons. I asked the students a series of four questions. I conducted student interviews that lasted 5 to 20 minutes. The student interviews were shorter at the non-profit sites because they were fewer opportunities to do a sit-down interview with the students since they were constantly moving to different workstations and, in some cases, trying to complete their project before the end of the course.

Similarly, when I interviewed the Grade 1 students at In-School 1 they were constantly moving, and I had to interview them on the spot as they were building their pattern tower in Minecraft or programming their code-a-pillar. Unlike the adult participants, the students answered the interview questions with brief statements that in most cases were incomplete sentences. I got a snap shot of what their favourite activity was, interests were and what they had learned in the STEAM program.

It appeared to me that it didn't matter whether I interviewed the students individually or in groups; I got a similar level of depth in answers. However, the interview length appeared to significantly affect the depth of the answers the students gave. Those students at the in-school sites that I interviewed individually for 15-20 minutes I was able to get more in-depth answers about the specific science, technology, engineering, arts and mathematics standards that were learned (as mentioned in section 5.4.2). The length of the interview might have accounted for some of the discrepancy between the non-profit and in-school sites when they answered the question "what have you learned about Science, Technology, Engineering, Arts and Mathematics so far in the STEAM program?" If I had more interview time with each individual student at the non-profit sites, they might have been able to articulate better what specific academic skills they had learned.

### 4.7.2 Observations Data

Utilizing naturalistic observation (Arthur et al., 2012; Mears, 2009), I observed the instructors/teachers and students in the STEAM program and what happened naturally in this environment, with respect to the curriculum and instruction, and the students' overall learning experience. To observe different curricular and instructional models and the impact on school learning, I also conducted several observations of instructors/teachers, students during STEAM lessons or sessions and studied the learning environment at each research site. I used the Classroom Observation Protocol (Appendix J) to record the field notes on the environment, technology, pedagogy, instruction and student learning experiences during a particular lesson. During the post-observation interview, I followed up with the teacher/instructor for clarification on the teacher's instruction and pedagogy. I recorded my notes for a particular lesson using a descriptive observational tool (see Appendix J), and I also audio recorded each observation session.

The observation template consisted of the following aspects: environment, technology, pedagogy, instruction and student engagement, attitude towards STEM and learning experiences during a particular lesson. During each observation, I briefly interviewed students who consented to participate in the research study. I observed three to eight classes per research site. In some cases, such as the non-profit sites and In-School 2, I observed the class more than once, and in others, such as In-School 1, I only viewed a single lesson due to the instructor's/teacher's availability. Specifically, I observed a total of six sessions for Non-Profit 1, three sessions per class; eight sessions for Non-Profit 2, four sessions per class; three single sessions for In-School 1; and four sessions (i.e., three sessions for one class and a single session for another) for In-School 2. Another factor that determined the number of classes observed was the student consent forms. Those classes for which I was able to get consent forms in a timely manner were the ones that I observed more frequently. For the in-school research sites, it was difficult to observe the students more than once because the teacher librarian usually only sees a class once a week or once every two weeks.

### 4.7.3 Curriculum Document Data

I carried out a document analysis (Hodder, 2000) to understand how classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals. The curriculum documents consisted of course and program overview, collaborative meeting notes, unit plans and lesson plans for each of the STEAM research sites. The curriculum documents and lesson plans were collected from the adult participants, both digitally (i.e., email and Google drive) and paper copies. The documents were stored electronically. At Non-Profit 1, I was given access to 85 curriculum documents on a Google drive, most of these documents tended to be shorter in length and less detailed. I reduced this number to 12 documents of interest. At Non-Profit 2, I received a total of 8 curriculum documents digitally via email. At the in-school sites, I received the 8 documents from In-School 1, which were paper copies, and 10 digital documents from In-School 2. Non-Profit 1 had a large amount of curriculum documents authored by a team of instructors versus one individual member creating the lesson plans which was the case at the other research sites. In total, I analyzed 111 documents and I reduced this number to 38 documents of interest, totaling 258 pages including reference materials and figures.

### 4.7.4 Focus Group Interview Data

I conducted a focus group interview with four classroom teachers at the elementary level to respond to the research question on how classroom teachers' view such models of STEAM education as meeting their curriculum and instruction goals. The focus group interview can be described as interactive and a way of getting various perspectives on a topic, such as the models of STEAM education (Arthur et al., 2012). It is suggested that a focus group should be 4 to 12 people in size (Cousins, 2009; Hopkins, 2007; Vaughn, Schumm & Sinagub, 1996). The focus group in this research study consisted of four elementary classroom teachers, two male and two females. Among the group of four teachers there was one teacher librarian and one instructional coach that were classroom teachers. I invited 31 teachers, 4 responded. The timing of the focus group was in Fall term (i.e., October 25$^{th}$). I presented a summary of the findings from the research study with breaks between sections for the focus group questions. The sections were on

STEAM, Curriculum and Instructional Models of STEAM, Four Stages of a Lesson/Session and Common Themes. The classroom teachers shared their views on STEAM education, the curriculum and instructional models of the STEAM programs and thoughts about the common themes.

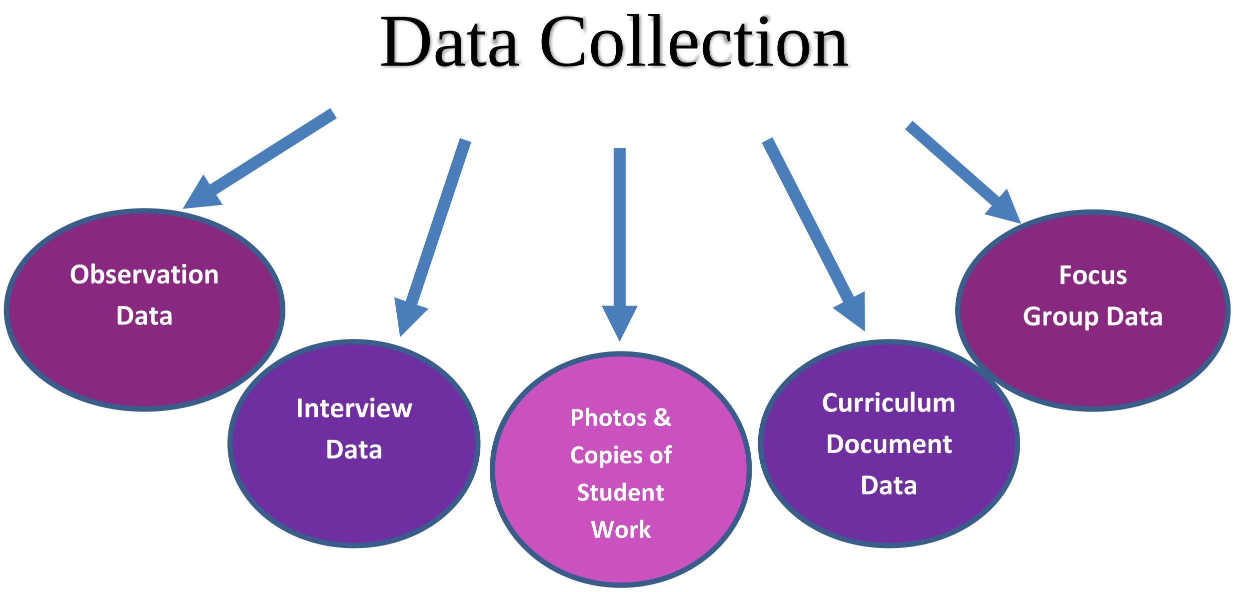



*Figure 4.* The different types of data that were collected, organized and analyzed.

## 4.8 Data Organization

All of the data from each research site were stored electronically, except for the photocopies of student work and curriculum documents that were in hard print. Initially, I used participant initials to create pseudo codes for differentiating between each participant in the research study. Eventually I found it more helpful for the transcribed interviews to use labels such as Grade 2 teacher at In-School 2 that indicated the grade and the research site for the participant. I removed all the data that had any identifying features, such as pictures of students or adults in which their face was recognizable. Whereas the interview transcripts were organized by the research sites, the observation data were organized based on both the date of the observation as well as the site. Similarly, I organized the photos in each research site by the physical environment (e.g., pictures of the work area and stations), stage of a lesson (e.g., making stage) and technology (e.g., 3D printing) used. I organized the photocopies of the students work by the research sites and the technology used.

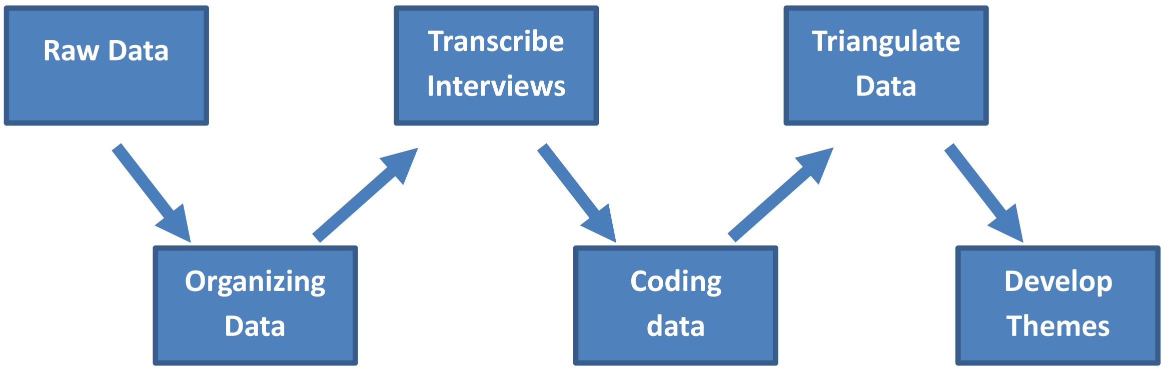



*Figure 5.* The data analysis can be broken down into six stages which is modified from Creswell's (2014) section on Data Analysis and Interpretation in Chapter 9.

## 4.9 Data Analysis

*Raw Data:* Prior to data analysis, I found some pre-existing themes such as collaboration and capacity building. During the field work, I found some emerging themes, such as teacher collaboration and building teacher capacity.

*Organizing and Preparing Data for Analysis:* I created a summary and overview of the field notes, which allowed me to see the initial data codes that were emerging. Most of the analysis was conducted after my field work was completed. This was due to the fact that the majority of the data were collected over a four-month period and the magnitude of the data collected (e.g., transcribed 25 audio recorded interviews each transcript 10-25 pages in length, analyzed 38 curriculum documents a total of 258 pages, 642 photos of the STEAM products, students and environment, and 28 photocopies of students' written work).

*Transcription of the Interview Data:* I transcribed all of the audio-recorded interviews and conducted all the data analysis myself. After transcribing the interview data, I examined the observations notes, photos and copies of student work.

*Coding the Data:* During the coding of the interview transcripts, I found emerging themes. I noticed how they connected with my pre-existing themes and interconnections among themes on student learning, teacher pedagogy, and instruction. I examined the transcripts for interrelating themes, and I interpreted the meaning of those themes through the theoretical theories in Chapter 3 and literature review in Chapter 2.

*Curriculum Document Data:* I analyzed the curriculum documents and focus group data. As I continued my analysis, the overarching themes helped me triangulate the data (i.e., find common themes in the observations, interviews and curriculum documents) and see the interconnections between different data sources.

*Triangulation of the Data and Corroboration:* To triangulate the data, I created overarching themes that allowed me to see the connections between the different data sources and helped me to better understand the curriculum and instructional models of these STEAM programs. I triangulated the data to add validity and corroborate the findings in the research study (Arthur et al., 2012) such as during the analysis stage I selected teacher interviews, student interviews and pictures of student work that corroborated and strengthened my findings on the character-building and academic skills in the curriculum documents. I also did find data that did not corroborate other sources, such as the value of collaboration and capacity building which differed among the instructors, teachers and teacher librarians at the non-profit sites, focus group and in-school sites respectively.

*Development of the Themes:* As I expanded my result section to include the observation, interview, document analysis and focus group data, I began to see the connections between different data sources. I clustered these sections and used a descriptive phrase to help the reader better understand my findings.

### 4.9.1 Interview and Focus Group Data

I used Nvivo software to code the data. I coded the transcripts in Nvivo and created "nodes" arranging these nodes into a hierarchical structure to visually see different levels within each theme (Arthur et al., 2012). I organized the interview data by the cases and the type of interviewee, such as the director, instructor or teacher. By labeling the different cases and the participants in the transcript, I was able to compare different code patterns in each STEAM program. I coded the interview transcripts looking for common codes and found 18 emerging broader codes. I started looking for general trends and categories for the codes (Arthur et al., 2012; Gibbs, 2007) which then formed the themes. The descriptive phrases for some of the overarching themes were further refined when drafting the findings chapter and the phrases for the rest were informed by the literature review (Arthur et al., 2012; Gibbs, 2007).

### 4.9.2 Observation Data

I summarized the descriptive data that I compiled during the observations into a table and looked at the demographics of the students at the non-profit sites, commonalities and differences among the pedagogy and instruction, social interactions between teacher-student, physical and social environment, and student learning experience at the different research sites. During the analysis of the observation data, I also focused my attention on the physical and social environment, pedagogy and specific examples of the pedagogy and instruction from each STEAM program. During the observation of a lesson or session, I also observed some details of curriculum units and lessons displayed on a screen, bulletin boards, wall and flip charts, all of which I triangulated through studying the curriculum documents.

### 4.9.3 Curriculum Document Analysis

The lessons that the instructors/teachers shared with me were both electronic and hard copies. I analyzed the text of the STEAM curriculum documents manually and without using the Nvivo QDA software. I looked for key words, themes, and trends that were found in the curriculum documents and lesson plans to investigate the questions on curricular and instructional models (Hodder, 2000), as well as on planned student learning. I also focused on the presence of STEM/STEAM curriculum standards that were embedded into the lessons and curriculum documents. For analyzing the documents on specific learning standards, I used the Ontario curriculum for grades 1-8 for the Science, Art and Mathematics tasks (OME, 2005, 2007, and 2009). I used the Applied Design, Skills, and Technology (ADST, 2016) curriculum from British Columbia (Canada) for the Technology tasks. I used the learning standards in ADST in the Robotics and Computational Thinking sections in the K-8 curriculum. Finally, I used the Next Generation Science Standards (NGSS, 2014) for the specific Engineering tasks (MS-ETS1, 1-4). Referring to these standards was helpful when analyzing the programs' student learning objectives in relation to broader curriculum goals. Using curriculum frameworks in addition to the theoretical frameworks of constructionism, design-based learning and "low floor, high ceiling, wide walls" was especially helpful in the document analysis because the terminology used in the curriculum documents was not consistent from site to site. Also, the Non-Profit sites are not mandated by any provincial curricula. There is no engineering focus in the provincial curriculum for K-8. The technology curriculum that is part of the Science curriculum in Ontario predates the recent emphasis on teaching technology evinced in current STEM/STEAM initiatives. Further, the curriculum documents from each research site were drastically different in the length, format (digital and paper copies) and language used.

When I analyzed themes, I examined the structures of curriculum units and sessions (i.e. lesson, unit or course) and focused on the learning objectives (e.g., STEAM curriculum standards and anticipated learning skills) that are stipulated in the documents. I was able to triangulate the data from the curriculum, using the interview and observation data to provide examples of the different stages or student learning. For example, at the interview I asked questions to the teachers such as: "what do you think the students learned in the activity or lesson from your perspective?" I asked the students questions such as: "what have you learned about Science, Technology, Engineering, Arts and Mathematics so far at the STEAM program?" And during the observations I noted the instruction, pedagogy, character-building skills, and tasks that the students were working on.

## 4.10 Conclusion

In this chapter, I outlined the methods, research questions, ethics, trustworthiness and reliability, participants, data collection, and the data organization and analysis. I outlined the different types of data collected, interviews, observations, curriculum documents and the focus group data. This chapter provided a context to the results section by describing in detail the participants, environment and programs observed to describe the unique environment of each research site. I also discussed the different types of data collected. In this section, I included important details about the observation and interview templates used. I also described how I coded the interview transcripts and developed the overarching themes. These details are extremely important for the trustworthiness and reliability of the study.

# Chapter 5

# 5 Results

This chapter presents research results of the interview, observation, document analysis and focus group data to answer the research questions on the curriculum and instructional models of STEAM education, students' learning experiences, assessment of student learning, and how teachers view those as meeting their goals. I have organized the results section based on the overarching themes that showed the interconnections between the different data sources. For each theme, I presented the findings for the non-profit and in-school sites separately to highlight the commonalities and differences within each context. Next, I summarized a theme for all the research sites before I moved on to the next theme. The results section is organized according to the following five themes: 1) Pedagogy, Instruction and Environment; 2) Curriculum Models of STEAM; 3) Student Learning and Transferable Skills; 4) STEAM Tasks and Learning Experiences; and 5) Assessment, Documentation and Sharing their Learning Experiences. Themes 1 and 2 address the research question on the curriculum and instruction models of STEAM; Themes 2 and 3 the question on students learning; Theme 5 addresses the question on assessment, documentation and sharing of student learning. Themes 1-5 address the research question on how classroom teachers view such curriculum and instructional models as meeting their goals.

## 5.1 Theme 1: Pedagogy, Instruction and Environment

In this first theme, I provide descriptive data of the models, including the physical and social environment, pedagogy, teacher-student interactions, teaching style, teacher values, and method of assessment and documentation of STEAM education. In this study, the teacher cultivated a creative learning environment through the physical and social environment, instruction and pedagogy, and the teacher-student and student-student interactions. Data were collected from the interviews, observations and curriculum documents to better understand the physical and social environment, instruction and pedagogy, teacher-student interactions, teaching style, teacher's values, assessment and documentation. Most of the data were collected by observing sessions. To show the uniqueness within an out-of-school and in-school context, I present findings for the non-profits first, then findings for the in-school sites.

### 5.1.1 Non-Profit Case Studies: Physical Environment, Pedagogy and Examples

Both non-profit cases catered to students ages 6 to 12. The schools were in urban settings, operated a co-ed model of teaching boys and girls together, and used hands-on activities and cooperative learning. The two non-profit sites indicate the acronym STEAM in their organization's name. On their website, they each assert that their objective is to promote creativity and technology as the kids use Science, Technology, Engineering, Arts and Mathematics to solve problems and innovate. At the non-profit sites, I observed the instructor's role as that of a facilitator. The two non-profit cases also appeared to use *low floor, high ceiling, wide walls* activities. However, there were some differences as described below.

**Non-Profit Case Study 1:** Case Study 1 refers to Non-Profit 1's program and site. Non-Profit 1 is an urban STEAM center in a metropolitan area catering to K-7 children and with programs for teens/adults. Non-Profit 1 offered students K-7 the option of after-school clubs or weekend programs. Parents registered and paid for a class for their children in advance. The two classes I observed were part of a weekend program that runs on Sundays, 2 hours per week for 7 weeks. During a session, there were one instructor and 3-5 volunteers in the room. I was told by both the director and instructor that the number of volunteers depended upon the class size.

The physical learning environment at Non-Profit 1 was non-conventional in that it was set up for small group work, with desks and chairs, as well as floor mats, in a large space that is divided by movable walls as shown in Figure 6. In all six lessons I observed, the students moved freely and independently from the floor mat to a specific work station depending on the task. The pedagogy appeared to be designed to support the making process versus an emphasis on completing the final product at the end of the session. For example, some students took on a project that was more complex and did not finish their final product by the end of the course. Every student was encouraged to continue making and building after the course ended.

I also observed the teaching style of play and discovery learning in which the students constructed their own knowledge through their experiences at this site. A case in point was students learning through their senses by physically touching and seeing how the motors of a remote-controlled car worked, then using this motor in the project that they individually designed (see Figure 7).

*Figure 6.* The physical learning environment of the Non-Profit 1 STEAM Centre.


*Figure 7.* Play and discovery learning with motors and parts in the Non-Profit 1 STEAM Centre.

Students at Non-Profit 1 went through multiple designs by testing the robotic dog and redesigning their prototype from a simple design (i.e. numerous wires and two basic remote controllers) to a more complex design (i.e. a single push-button mechanism and robotic tail that wagged) as shown in Figure 8. The student had to test and adjust their design multiple times (i.e. multiple cycles of design) to get the legs and tail to move on the ground without assistance for a prolonged period.

**a)** 

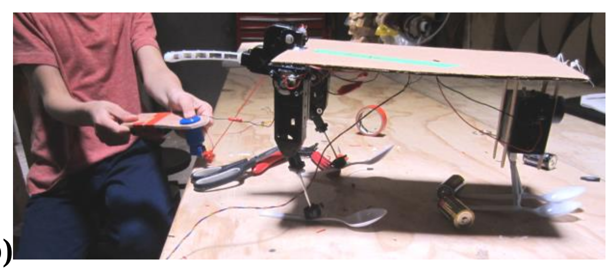

**b)** 

*Figure 8.* At Non-Profit 1, the student started with a design of a robotic dog that was a) simpler with a basic remote controller then b) a more complex version with a single push-button mechanism.

**Non-Profit Case Study 2:** Case Study 2 refers to Non-Profit 2's program and site. Non-Profit 2 is an urban STEAM center in a metropolitan area catering to K-7 children and with programs for teens/adults. Non-Profit 2 offered students K-7 workshops after school on Tuesdays, Wednesdays and Thursdays. Parents registered and paid for a class for their children in advance. During a session, there was one instructor and 3-5 volunteers in the room depending upon the class size. The two classes I observed were on Wednesday and Thursday, 1.5 hours per week for 5 weeks.

Non-Profit 2's learning environment is relatively conventional because it is set up as a computer laboratory for students to work individually or in pairs at desks, as seen in Figure 9. I observed that the pedagogy seemed designed to support individual students to create a STEAM product by the end of the course. This STEAM center, as evinced in the two introductory classes I observed, supports the framework of hands-on learning and design thinking. Students in the first class I observed were given the opportunity to explore and discover 3-dimensional (3D) shapes kinaesthetically using modeling clay (i.e., hands-on learning), specifically looking at the geometric shapes that make up an animal.


*Figure 9*. The physical learning environment of the work area at Non-Profit 2.

In the same class, design thinking was evinced as the students were asked by the instructor to design a prototype of the pencil topper using the modeling clay and/or sketching their design. Students were then asked to apply this knowledge to reproduce the 3D images in Tinkercad as shown in Figure 10. This pencil topper project did not appear to include “low floor, high ceiling, wide walls.” Although this was a simple task for the students to execute, the instructor engaged students in thinking about how living and non-living things are constructed from geometric shapes and students were encouraged to think about the image for the pencil topper in terms of 2D and 3D geometric shapes. Students created designs in Tinkercad which ranged from simple (i.e., the pencil topper) to more complex (i.e., the castle) as seen in Figure 11. The complexity of the tasks depended whether it was an introductory or advance-level course.

Similarly, in the creative coding course, the tasks started off with students learning how to create their own video game in Scratch by remixing the code “low floor” to “high floor” in which students use green screen technology to superimpose an image of themselves into the video game. This task also included “wide walls” as the students took multiple ways to approach a problem to design their own personalized video game.

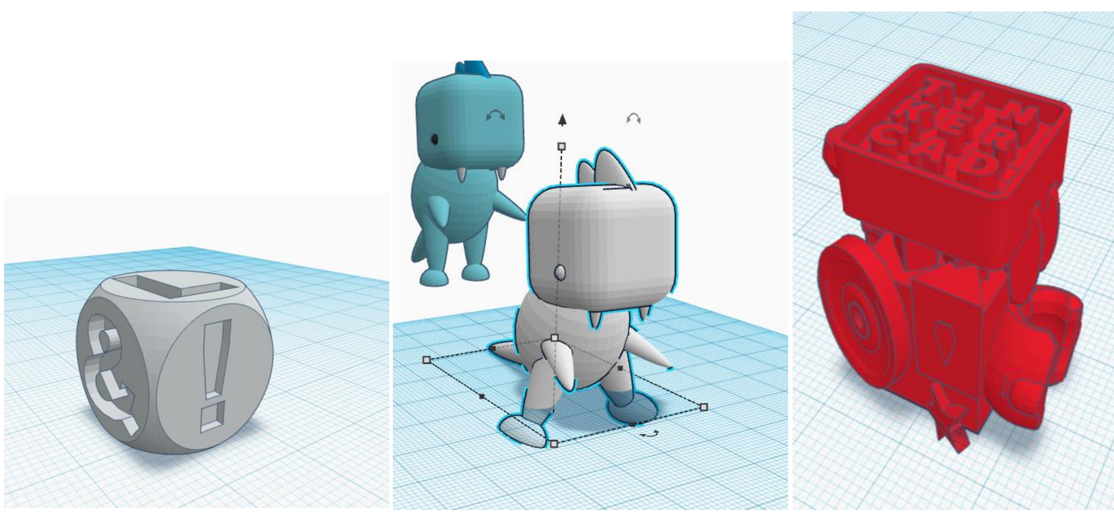


*Figure 10.* At Non-Profit 2, students used 2D and 3D geometric shapes to design these images in Tinkercad. The designs appeared to be both creative and innovative, since each design was personalized.


*Figure 11.* At Non-Profit 2, students created objects ranging from a simple pencil topper to an intricately detailed castle with a winding staircase.

Table 3 provides more details about the instruction, pedagogy and environment at the non-profit sites. The details of the instruction are organized by the teaching methods, class discussion, differentiation, assessment and documentation. The pedagogy section is organized by teacher-student interaction and teacher's values. The physical environment focuses on the learning stations and arrangement of the physical learning space (e.g., tables and desks). The social environment includes details on how students interact with one another and the types of learning (e.g., project-based learning).

*Table 3.* Type of Instruction, Pedagogy and Environment in the Case Study 1 and 2

| **Observation: Classroom/Workshop Activities**<br>**Instruction** | | |
|---|---|---|
| | **Non-Profit Case 1** | **Non-Profit Case 2** |
| Teaching Method<br>The instructor used: | • Group discussions rather than conducting a mini-lesson at the beginning of class. | • Mini-lesson at the beginning of class with a presentation on a screen. |
| Class Discussion<br>The instructor: | • Facilitated discussion, such as to discover how robots work, share what they created, and give other students feedback (e.g., to fix a problem or create a better design). | • Asked students to brainstorm questions, share ideas to whole group and explain how to fix or debug their code. |
| Differentiation<br>The instructor used: | • multiple ways to approach a problem<br>• low floor, high ceiling, wide walls (simple to complex) approach to learning<br>• flexible lesson plans (i.e., lesson plans were adapted at that moment depending on the students' interests and needs) | |
| Assessment and documentation | For documentation, the instructors utilized a website where they uploaded the student learning environment of the case through photographs and videos for each of the different programs offered. | |
| **Pedagogy** | | |
| Teacher-Student Interaction.<br>The lessons were design/inquiry-based learning, and: | Student-driven/centered. For example, students were guided through four stages of the Maker Education Model: (1) Play/ Discovery, (2) Design, (3) Build/Failure, and (4) Celebrate. | Both teacher and student driven. As students became more familiar with new software and technologies, then they were given more opportunities to explore. The main pedagogy used was hands-on learning, inquiry-based and design thinking. |
| Teacher values<br>The instructor: | • was not as concerned with the product, but more with the process.<br><br>Students may not finish the project within the scope of the course. The process was dependent upon the individual. | • valued both the process and the product. Each student had a final product at the end of the course.<br>• was flexible and allowed students the flexibility to modify a task or use a different method. |
| **Physical Environment** | | |
| Learning Centers/Stations | All stations (e.g., the Glue station, cutting station and the craft station) were in one room. | Stations (e.g., the computer room, the Laser/Wood cutter room, and the 3D printing room) were located in multiple rooms on different floors. |

| | | |
|---|---|---|
| Programmable software and technology: | Several including micro-controllers, a 3D printer, laser cutter, programmable robots, and other technologies. | |
| Small group work | Students worked at the table or on foam mats in groups of 2-3, when learning a new skill or technology. | Students worked individually or in pairs at desks. |
| **Social Environment** | | |
| Project-Based Learning. Student designed: | • their own projects and were given freedom to select and use the materials available. | • their own projects within the given parameters of the activity designed by the instructor. |
| Hands-on activity Student work involved: | • hands-on activities all the time including the interactive class discussions in which students explored and experimented with the technology. | • hands-on activities much of the time, such as modeling 3D figures from clay. |
| Cooperative Learning During the class: | • on the foam mat or desks, students worked together to solve a problem or to plan a design. | • students worked together and helped each other.<br>• students were given group challenges (e.g., the marshmallow build challenge to build the tallest free-standing structure). |

Although the instruction, pedagogy and environment appeared to be similar at both non-profit organizations, the physical learning environments were quite different. From the sessions I observed, students were encouraged to work collaboratively, problem solve, engage in hands-on activities and create individual STEAM projects. Non-Profit 1 was more unconventional and Non-Profit 2 was more traditional. The most noticeable difference was that the teacher-student interaction in Non-Profit 1 gave students complete autonomy when planning their design, selecting the materials to use, the technology, and deciding the level of difficulty of the design, whereas Non-Profit 2 set specific parameters, such as the materials, technology and final product produced (e.g., prompting all students to make a 3D pencil topper). I shall return to this difference at Non-Profit 2 giving the students specific material, direction and time constraints when I elaborate on group challenges, projects or mini assignments in the section on student learning. The in-school research sites also show some similarities and differences to the non-profit cases.

### 5.1.2 In-School Case Studies: Physical Environment, Pedagogy and Examples

Both in-school cases served students ages K-8, were in urban settings, used inquiry-based models and had similar instructional pedagogies with lessons aligned with the Ontario curriculum. However, there were some differences as described below.

**In-School Case Study 3:** Case Study 3 refers to In-School 1's program and site. In-School 1 is an urban public school which caters to K-8 students in a metropolitan area. The STEAM program is offered in a specific space where a teacher or teacher librarian takes students for specific lessons on a STEAM cycle in the Maker Lab on a weekly or biweekly basis.

In-School 1's learning environment for STEAM was set in the Maker Lab, located in the Library Learning Commons. It appeared unconventional for a public school, as it was comprised of work benches and stations on which students could make and build, as seen in Figure 12. The Learning Commons was double the size of a classroom and divided into two parts. One section was for the Maker Lab, which has most of the technology, tools, and software. The other section has the computers, tables and carpet area used for working on the computers and for small group activities.


*Figure 12*. The physical learning environment for the In-School 1 Maker Lab

The lessons were all aligned with the Ontario curriculum and, as indicated in the documents that were shared with me, used the Balanced Model in which the teacher models first, then the student has a shared experience with the teacher, a guided one and then an independent one. The main pedagogy for the STEAM programs is the Guided-Inquiry Model: Ask, Collect Ideas, Plan and Make. For example, the Grade 5 students in the first lesson I observed asked the question: “How can we get our robot to see?” (i.e., Ask). There were different ways that the students could answer the inquiry question using multiple ways to approach a problem and multiple entry levels depending on the student’s skill set or proficiency with a particular technology. A case in point is that students answered this question by figuring out how sensors work, how self-driving cars work, and how to make the robot’s movements more precise through research, building a robot with colour sensors and/or testing the LEGO EV3 robot (i.e. multiple pathways) by creating simple to complex codes (i.e. multiple entry levels) to program the robot to follow a specific path. In their groups, they collected ideas by researching online, viewing images and reading books (i.e., Collect Ideas). They planned their designs by drawing a blueprint and listing the materials (i.e., Plan). Finally, they used coding to program the robot to travel outside the perimeter of an irregular 2D geometric shape, made with black tape, on a team generated challenge mat as seen in Figure 13 (i.e., Make). Students wrote anecdotal notes about programming their robot, including a picture of the map, the code and their feelings about the process (i.e., Reflect).

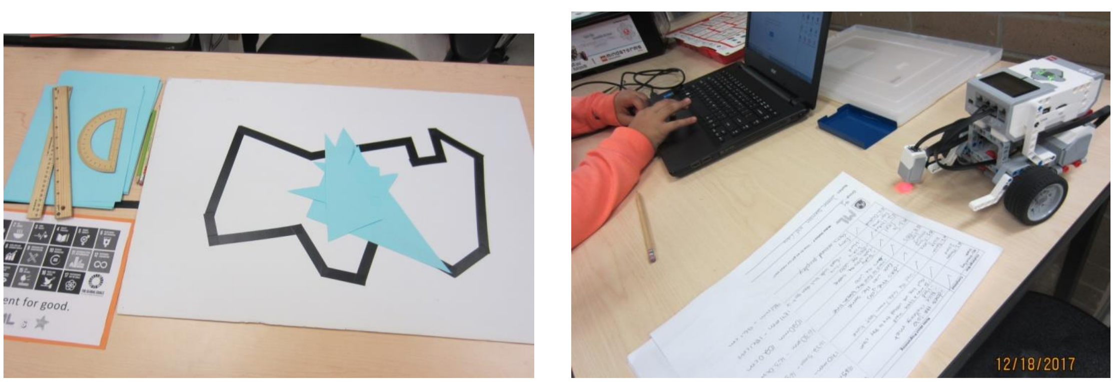



*Figure 13.* Students in Grade 5 programmed a LEGO EV3 robot to travel outside the perimeter of an irregular 2D geometric shape at In-School 1.

**In-School Case Study 4:** Case Study 4 refers to In-School 2's program and site. In-School 2 is an urban public school in a metropolitan area catering to K-8 students. STEAM programs are offered in a specific space where teachers or the teacher librarian take students for specific lessons on Science, Technology, Engineering, Arts and Mathematics in the Makerspace on a weekly or biweekly basis.

At In-School 2, the learning environment in the Makerspace —the Library Learning Commons— was somewhat unconventional for a public school given its stationary and mobile stations, as seen in Figure 14. The Learning Commons is double the size of a classroom, and the entire space is used as the Makerspace. Some of the lessons happened outside of the Makerspace, such as the Science and Technology Application Centre (S.T.A.C.) room or a regular classroom.


*Figure 14*. The physical learning environment of In-School 2, showing the stationary and mobile stations.

As indicated in the interviews, the curriculum documents that the teacher and teacher librarian shared with me were all aligned with the Ontario curriculum. The main pedagogy of the Learning Commons is a Partnering Model in which the teacher learns alongside the students. The teacher is not the expert, but a facilitator and collaborator with the students. In the first lesson I observed, students were given the opportunity to tinker, experiment and explore how to program the Micro:bit using Java Script. I had the opportunity to see the teacher learn alongside the students since the technology of Micro:bit was new to the teacher. Then the Grade 5 students used the Design-Inquiry Process (Define, Sketch, Prototype, Test, and Feedback) to create a product that, as the teacher explained, entertained a target audience or served a function or purpose in their lives. Some students chose to build a model of a rocket made out of a pop bottle for this project, as seen in Figure 15 (i.e., designed a prototype and tested it), others made a solar-powered oven out of cardboard, and another group made an entertainment system with the Micro:bit. The open-ended nature of the Design-Inquiry project allowed students multiple entry points "low floor" to make simple to complex designs "high floor" and multiple pathways "wide walls" in the design, materials and execution of their plan. Table 4 provides more details about the two in-school case studies:

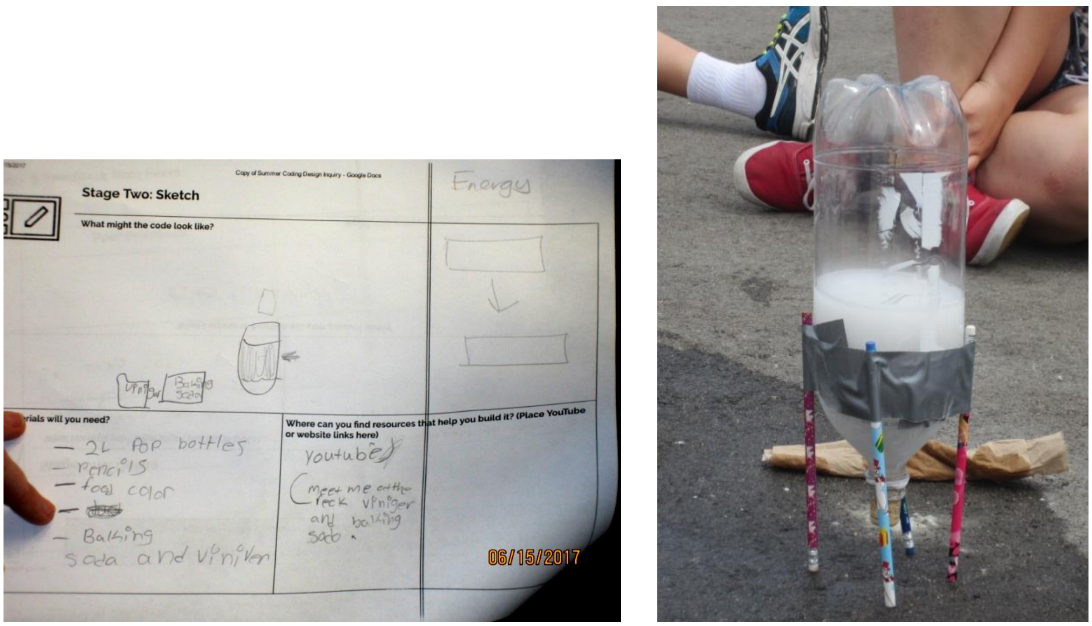



*Figure 15.* Students planned, designed and built a pop bottle rocket at In-School 2.

*Table 4.* Type of Instruction, Pedagogy and Environment in Case Study 3 and 4

| **Observation: Classroom/Workshop Activities<br>Instruction** | | |
|---|---|---|
| | **In-School Case 3** | **In-School Case 4** |
| The instructor used: | • Mini lesson at the beginning of class with a PowerPoint presentation. | |
| Class Discussion | Students talked in groups or with their partners at a center. | |
| Differentiation<br>The instructor used: | • multiple ways to approach a problem<br>• low floor, high ceiling, wide walls (simple to complex) approach to learning<br>• open-ended problems with multiple outcomes and flexible lesson plans | |

| | | |
|---|---|---|
| Assessment and documentation | The teachers documented the process through anecdotal notes. The two in-school teacher librarians created a website with their personal observations, blog posts, and social media stories (photographs and videos). | |
| **Pedagogy** | | |
| Teacher-Student Interaction.<br>The lessons were design/inquiry-based learning, and: | A balanced model: model, shared experience, guided and then independent activities.<br><br>Centers were student-driven because students choose their level and center. Guided-Inquiry Model: Ask, Collect Ideas, Plan (Design) and Make. | A partnering model: the teacher learned alongside students. The teacher was not the expert, but a facilitator and collaborator. Student-centered and -driven based on a student's individual needs. Students could choose their own level and explore their own ideas. Also, students used the Design-Inquiry model. |
| Teacher values,<br><br>The product is important because: | • both the process and the product.<br>• it helped the teacher assess what the student has learned from the activities.<br><br>Students were encouraged to keep building and making in a club or during the summer break. | |
| **Physical Environment** | | |
| The Library Learning Commons had:<br><br>Makerspace Learning Centers/Stations: | • A wall dividing the Makerspace and the library section.<br>• Work benches, scroll and band saws, sewing machine, Green Screen, LittleBits, E-textiles and Chibitronics bins.<br><br>The library section had large collaborative tables, a carpet area and a computer lab. | • Movable centers so it can facilitate both the classroom activities and the clubs.<br>• Collaborative tables, a mobile computer lab, Soldering and sewing, a Wood shop in the lower level, a Craft/loose parts bin, a Paper circuits bin, Squishy circuits, Remodeling computers and Green screen/stop- motion center. |
| Programmable software and technology: | Several including micro-controllers, a 3D printer, Green screen, programmable robots and other technologies. | |
| Small group work | Students designed, built, tested and redesigned their projects at the table or work benches in groups of 2-3, when collaborating and working as a team. | Students worked in groups of 2-3 at the collaborative tables or stationary centers. |
| **Social Environment** | | |
| Problem-Based Learning | Students were given a challenge that they must complete through programming and/or designing a model. | |

| | | |
|---|---|---|
| Project-Based Learning. | Student designed their own projects within the parameters of the activity and the materials available. | |
| Hands-on activity. | Lots of hands-on activities during the building and making stage. | |
| | During my observations, students engaged in many hands-on activities, whether they were programming a robot, making a physical object or creating a pattern in Minecraft. | Many of the activities provide students with the opportunity to tinker/explore a new technology or skill. |
| Cooperative Learning. During the class: | • students worked in groups or pairs to solve a problem. | • students worked in pairs. The teacher encouraged students to consult with a student expert first before asking the teacher. |

### 5.1.3 Differentiated Instruction with "Low Floor, High Ceiling, Wide Walls"

At all four sites, the lessons or units were differentiated with "low floor, high ceiling, wide walls" approach to learning, open-ended problems with multiple outcomes, multiple ways to approach a problem, and flexible adaptable lesson plans that were based on the interests and needs of the students. In the observations and interviews, it was evident that the instructors at the non-profit sites did differentiate their instruction, but examples of differentiation were not seen in the curriculum documents. There were several examples in the curriculum documents of differentiated instruction at the in-school sites. During the observation of the Little Red Hen lesson, there were many opportunities for the teacher to differentiate instruction through "low floor" (e.g., alternative recording sheet, one-to-one instruction, and length of the lesson) and "high ceiling" (e.g., reduce the timeframe, use extension menu and have students try this challenge at home) as seen in Figure 16.

Differentiation Options:
-There are several recording sheet options. Choose the one that works best for your students. It's ok if some students have a different one.
-For students who need extra help, you can have them work at a station with you and guide them through the first try. Note: many times, students who struggle in other areas of the curriculum may excel with STEM challenges.
-For students who need additional challenges, you can give them a copy of the extension menu to work with.
-Adjust the time allowed for construction to meet students' needs. For students who can handle it, give them shorter time and require them to work quickly which adds to the challenge.

Extension Ideas:
-For individual students, the extension menu provides choices for early finishers or students who need a little more.
-Parent Letter—send home the included letter for students to try this challenge at home. Encourage students to bring in pictures or share their experiences at home.

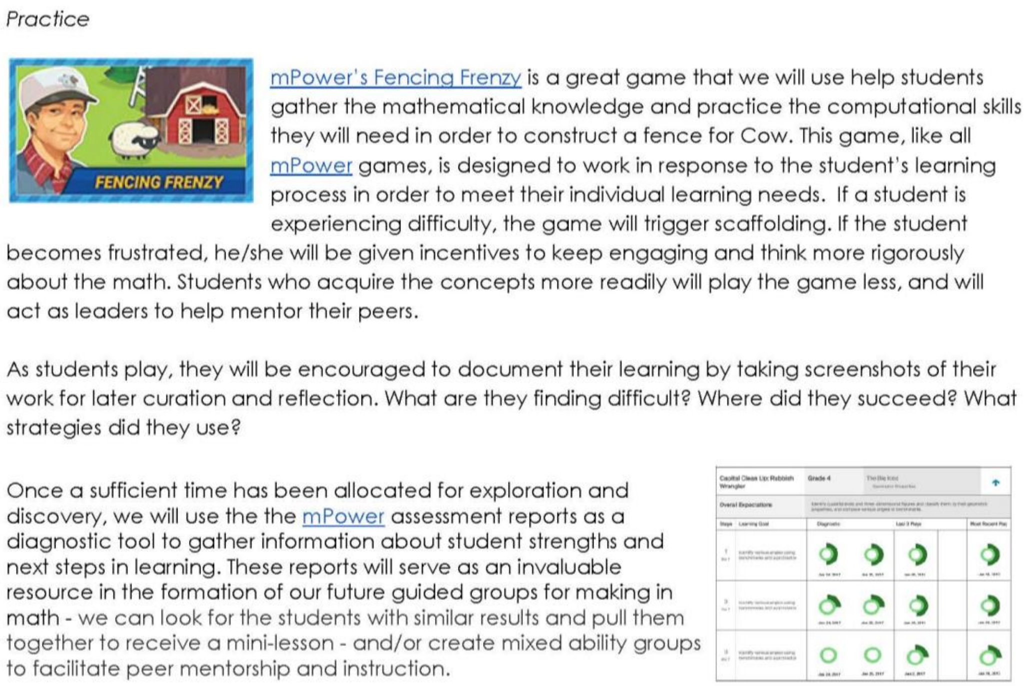
*Figure 16.* Possible suggestions for differentiation and extensions in the Little Red Hen lesson at In-School 2.

Similarly, in the Rube Goldberg unit Grade 2 students answered the question: “How can we use simple machines to make creative contraptions?” (see Figure 39 and Table 9 in section 5.4.2). The following accommodations were listed for students: strong peer partnering, one-to-one instruction and redirecting the students’ focus (see Figure 17). For example, the authors of the document stated in the teacher guidelines “this task could seem overwhelming, so model a quick sketch, . . . refocus the students’ minds on Rube Goldberg machines by showing this video, . . . students collaborate with the teacher to prototype a flat Rube Goldberg machine on a peg board or piece of foam board, . . . build the machine together, getting children to create components along the way, . . . and they [the students] must present their plans to the teacher before proceeding [to the next stage]” (Curriculum Documents, In-School 1). The teacher seemed to include specific directions that would help with students who were feeling overwhelmed, unfocussed or who needed extra guidance. There were opportunities where the teacher provided “low floor” when the teacher and students created the Rube Goldberg prototype together or “high ceiling” when students were challenged to incorporate more complex tasks, such as creating a cardboard arcade in which students had multiple ways to approach the problem (i.e., wide walls) as seen in Figure 17. In the challenge section, the authors mentioned that “the teacher should authorize plans that students present so they can evaluate the ambitiousness of [the] designs and weigh it against [the] material/time limitations" (Curriculum Document, In-School 1).

| | | |
|---|---|---|
| **Stage 5 Rational:**<br>Give students more freedom to create using their knowledge from all 4 stages | **Plan:**<br>- If time permits, allow teams who have completed Stage 4 to begin planning and creating a cardboard arcade.<br>- They can collect ideas and create a plan based on this film - http://bit.ly/ML-CainesArcade. Students can use standard *MakerLab* planning sheets for this task.<br>- The teacher should authorize plans that students present so they can evaluate the ambitiousness of designs and weigh it against material/time limitations.<br>- *Skeeball, Table-Top Soccer*, and *Catapult Basketball* are all good suggestions for students.<br>- The products from this task, plus the products from the previous task can be used for a 'STEAM Inspired Carnival' where the class hosts visitors in a unique science fair to broadcast their creations. | |
| **LLC Materials:**<br>Masking Tape<br>Scissors<br>Cardboard<br>Paper Towel Tubes<br>Brass Fasteners<br>Dowels<br>Popsicle Sticks<br>Cups<br>Straws<br>Balls of different weights<br>Rulers<br>Pizza Cutter (for perforating cardboard) | **Accommodations:**<br>Strong peer partnering<br>One-to-one instruction<br>Redirecting focus | **Reflections:** |

*Figure 17.* Challenge in Rube Goldberg unit for students to create a cardboard arcade.

In contrast, the teacher librarian at In-School 1 used the software mPower to differentiate the instruction for the student through a game (i.e., mPower's Fencing Frenzy) that will trigger scaffolding and the mPower assessment diagnostic tool (see Figure 18).



*Practice*

mPower's Fencing Frenzy is a great game that we will use help students gather the mathematical knowledge and practice the computational skills they will need in order to construct a fence for Cow. This game, like all mPower games, is designed to work in response to the student's learning process in order to meet their individual learning needs. If a student is experiencing difficulty, the game will trigger scaffolding. If the student becomes frustrated, he/she will be given incentives to keep engaging and think more rigorously about the math. Students who acquire the concepts more readily will play the game less, and will act as leaders to help mentor their peers.

As students play, they will be encouraged to document their learning by taking screenshots of their work for later curation and reflection. What are they finding difficult? Where did they succeed? What strategies did they use?

Once a sufficient time has been allocated for exploration and discovery, we will use the the mPower assessment reports as a diagnostic tool to gather information about student strengths and next steps in learning. These reports will serve as an invaluable resource in the formation of our future guided groups for making in math - we can look for the students with similar results and pull them together to receive a mini-lesson - and/or create mixed ability groups to facilitate peer mentorship and instruction.



*Figure 18.* The teacher librarian at In-School 1 used the software mPower to scaffold and differentiate the instruction.

The teachers and teacher librarians at the in-school sites used different methods, such as accommodations, lesson modifications, educational games and software to scaffold the learning, assess the students' understanding and differentiate the instruction.

### 5.1.4 Summary of the Pedagogy, Instruction and the Physical Environment for All Sites

Although the physical structure of the STEAM programs varied depending upon the structure of the learning space and the resources available, I observed that the learning environment was meant to cultivate the students' creativity and innovation. I wonder: Do the instructor's/teacher's pedagogies, such as guided-inquiry and prescribed tasks, limit the student's creativity and innovation? The lessons or units from the in-school research sites seemed to be more structured than the non-profit cases because they included specific expectations from the Ontario curriculum, goals and objectives, and a section for assessment. The teachers at both in-school research sites practice the pedagogy of a shared learning responsibility among students in which the teacher was a facilitator or collaborator. At Non-Profit 1, students were given more freedom to select their own centers, designs, materials to use and levels of difficulty. However, at Non-Profit 2 and the in-school sites, the instructor/teacher librarian invited students to engage with defined tasks with more constraints. All the STEAM programs in the research study used multiple ways to approach a problem with "low floor, high ceiling, wide walls" activities and used flexible lesson plans. Each research site used photographs and videos to assess and document the students' learning. The assessment and documentation consisted of anecdotal notes, taking pictures and posting through a social media platform such as Twitter or a sharing media such as Seesaw.

### 5.1.5 Social Environment Involving Collaboration and Community

Besides the STEAM programs' physical environment, I also observed the social environment between students and between the teachers and the students. In the four STEAM programs, I observed that the instructors/teachers created a collaborative environment that promoted creativity and new ideas. The director at Non-Profit 1, stated that there is "always an open-ended creativity built into every curriculum" for each course. The teacher librarian created an environment that encouraged students to have a maker attitude, and those students who had that "maker mindset, they're willing to be creative, they're willing to make mistakes [and] they are willing to take risks" (In-School 2). The teacher librarian at In-School 2 described the environment as a "communal teaching environment" for both teachers and students and "giving the students choice and voice in their learning." Students were learning how to talk, listen, share ideas, teach one another and provide feedback to their peers. The teacher in the focus group, Teacher B, recalled a situation of a communal teaching environment in which students "gather feedback or things from other teams [students] . . . It's neat that they [the students] see how other students think about things." For a Grade 2 teacher, "collaboration is [the] absolute key, because in a society where we are moving towards autonomy . . . [students should have the] skills to talk with people, listen, share . . . , not just sharing ideas" but communicating their ideas with one another (In-School 1). The director at Non-Profit 1 saw collaboration as a team-building skill and teaches “kids more about their own personal strengths and challenges and . . . that’s connected to the collaboration. Because you need to make a good team, you need to know your role in the team, what your strengths are, and how do you cover for other people’s challenges.” The teacher librarian at In-School 2 described a collaborative environment as “a community where we talk to each other, we stay positive, we embrace growth mindset, [and] we make sure everybody’s ideas are heard” (Post Interview). Teacher C mentioned an important pedagogy that influences his teaching practice. “For me now [I incorporate] a lot of empathetic design, so how that makes the students feel. And that’s kind of where a lot of my interests really lie within that [research] field” (Focus Group). The instructors/teachers discussed the value of community, collaboration, student voice and choice in these STEAM programs.

The instructor believed that “the most important thing . . . is creating a safe space . . . everyone’s got a place and everyone does fit in . . . Building a safe community that doesn’t care about the way you look, [or] the way you act” (Instructor 1, Non-Profit 1). The In-School 2 teacher librarian, Teacher Librarian 2, asked “how do I build a community of ‘makers’ beyond our school?” (Post Interview). For example, the Non-Profit 1 site got their students to run a STEAM activity or talk about their projects at the Maker Festival (organized by another not-for-profit) in Toronto. In this case and some other cases, the student community developed in these STEAM programs and/or Makerspaces was seen to go beyond the boundaries of a traditional classroom or school. For example, students visited Sheraton college and participated in a workshop “for robots, robotics use, so basically a maze set up where the robot had to navigate through” (Grade 7 teacher, In-School 2).

### 5.1.6 Classroom Teachers’ Views on Pedagogy and Instruction of STEAM

During the focus group discussion, the teachers shared their thoughts on pedagogy and instruction with respect to the preliminary findings after I shared with them about the four STEAM programs. When the participants in the focus group were asked “What do you like about the STEAM models presented?" Focus group Teacher C expressed that he likes the "fully integrated approaches that is cross-curricular, not just about technology or a program or a specific device . . . [but] the best pathway for students and creating multiple pathways to success" (Focus Group).  Teacher C from the focus group also reflected on the pedagogies that influenced his teaching practices in STEAM education:

> I kind of gravitate towards the design-inquiry process, but I also think that almost like indirectly that we all kind of do some of the partnering model where the teachers are really partnering with students … I think we are all kind of moving around and partnering with students at certain times and it may be like the whole lesson that day or it might be three students one day and four students the next . . . I don't necessarily want for me to use one specific model I kind of like blend it, in models and approaches. And it all comes back to needs of the students, which is kind of ironic cause design thinking is like [what the student] . . . needs and that's where I try to go, I try to gravitate to where the needs are.

During the interviews and observations, the directors, instructors and teachers mentioned several pedagogies that influenced the curriculum and instruction in the STEAM programs, such as design thinking and inquiry-based learning. All four teachers in the focus group said that design thinking or the design-inquiry process was the main pedagogy that they used when teaching STEAM lessons and activities. Teacher B said, "in terms of models I tended to look at . . . the design-inquiry process model and I like the prototype aspect of it and definitely the feedback from peers" (Focus Group).

In contrast, the Grade 5 teacher at In-School 2 explained how the open-ended nature of the design-inquiry process can be a challenge with some students:

> I have a student over here, like academically he's very good, he is working at a level, a higher level in the class also, but what I've seen with him whenever he is working over here in the Makerspace he is just wandering here and there because he has so many ideas popping up in his head and he wants to go and he wants to help other people rather than focusing on what he's doing.

Focus group participants also commented on the importance of creating a social environment for students that involves collaboration and community, student voice and feedback from their peers. Teacher B mentioned the benefits of allowing students to have a voice: "They remember those projects because it had student voice and . . . they felt a part of the project because they did a lot of planning, even though it might have been structured to the unit they still feel like they had a say in creating the unit so they retain it for a long time" (Focus Group).

In summary, the pedagogy, instruction, and the physical and social environment of the four sites evinced that the instructors/teachers have an important role in creating a learning environment that encourages student creativity, collaboration and community. At the non-profit research sites, there was a focus on creating a safe community where students felt free to take risks and make mistakes. In all the STEAM programs, I observed collaboration and the instructor/teacher providing students with the opportunity to share ideas, teach one another and give feedback to their peers to contribute to the overall learning experience of the students. This idea of student collaboration, communication and community were discussed in the interviews, evinced in my observations of the sessions and evident in the curriculum documents. I elaborate upon the main findings in Theme 1 about student collaboration, communication and community in greater detail in subsequent themes, such as Theme 2 Curriculum Models of STEAM, and Theme 3 Student Learning and Transferable Skills.

## 5.2 Theme 2: Curriculum Models of STEAM

In the STEAM programs, I observed that the physical and social environment promoted creativity and innovation. This set the stage for implementing the planned curriculum and instruction as articulated in the policy and planning documents for the programs. In this section, I report the cross-case findings from the curriculum documents which are organized based on the stages of a lesson or session. I provide a detailed analysis of the curriculum documents focusing on the parts of the curriculum units such as the lessons, the commonalities, differences and interconnections. Table 5 provides more details on the four stages of a lesson and the parts of a lesson:

*Table 5.* Main Sections of a Lesson Plan or Stages of the Instructional Design Model

| Site/Stages | Non-Profit 1: Maker Education Model | Non-Profit 2: Launch Cycle (bolded letters L.A.U.N.C.H.) | In-School 1: Guided-Inquiry Model | In-School 2: The Three (Four) Part Lesson |
|---|---|---|---|---|
| Stage 1<br><br>Initial<br><br>Building Curiosity | **Play/Discovery** – Students explore a new technology, experiment and take things apart. Tinker and have fun. Students participate in activities that teach learning skills through games and storytelling. | **L**ook, Listen and Learn – Students are given activities that elicit a sense of wonder.<br><br>**A**sk Tons of Questions – Spark the students' interest and curiosity. | **Ask** – Students begin the inquiry process, choosing the topic, developing questions and exploring. | **Minds-On** – Students are given a picture to look at and ask/answer inquiry-type questions. Begin the inquiry process. |
| Stage 2<br><br>Data and Facts | **Design** – Students plan and brainstorm ideas that connect to students' own interests. Make a plan and critically analyze the plan for the purpose behind the plan. | **U**nderstand the Problem or Process – Through finding out more information.<br><br>**N**avigate Ideas – Students apply knowledge to solve a problem or create something new. | **Collect Ideas** – Designing an outline, selecting information (notes, images, websites, people you should talk to), and formulating a focus. | **Let's Read**, Practice and Plan– Students read the book, sort ideas and information, collect ideas, create multimedia artifact to communicate and share their thinking. |
| Stage 3<br><br>Making and Refining | **Build/Failure**– Failure and iteration. Test it and refine the design. Students use picture book to introduce effective outcomes and make connection to this stage of building (such as connect growth vs. fixed mindset to mistakes). Do activities that encourage persistence. | **C**reate a Prototype – Digital or tangible product.<br><br>**H**ighlight and Fix – Students note what works well and what needs modifications. Students are told each mistake takes them closer to success. | **Plan**- Draw a blueprint or storyboard, list materials needed, assign jobs to group members, and organize & synthesize the information. | **Let's Make**, Tinker and Modify – Students determine the materials needed and plan how to test the prototype. They create a prototype and test it. They make using different tools such as loose parts, robots and coding software, knitting, textiles, etc. |

| | | | | |
|---|---|---|---|---|
| Stage 4<br><br>Real World and Thinking Forward | **Celebrate** – Students showcase what they have made to each other and their parents. Opportunities for students to share/display their projects/ inventions in the community. | Now it's ready to **L.A.U.N.C.H.** it to an audience. Students share their work with an authentic audience such as their parents and might even share it on the center website. | **Make** – Creating, assessing product & process, making & presenting product, extending & transferring learning. | **Let's Connect and Reflect** – Both students and teachers reflect on what worked well, what would need to be changed, and what could have been done differently, and on where might we go next. They reflect on what they wonder, what students are learning, and what was noticed. |

The lessons and unit plans of the in-school research sites were more detailed, and the main sections of the lesson were clearly labeled. The non-profit organizations posted their instructional design model on the walls or in a written document separate from the lesson plans. Similarly, In-School 1 posted the four stages of the Guided-Inquiry Model on the walls and on the computers. All the parts of the lesson were labeled with different headings depending on the research site and their program objectives. For example, as displayed on the bulletin board, In-School 2 adapted Marian Small's (2018) three-part lesson into a four-part lesson by adding the section "Let's Read" to encourage student literacy, whereas the Non-Profit 1, as mentioned in the document the Maker Education Model, was inspired by connected learning, experiential learning and inquiry-based learning models. I have included the different pedagogies and curriculum models utilized at each research site, as seen in Appendix K.  I also included sample curriculum documents from each research site in the appendices section for Non-Profit 1 (Appendix L), Non-Profit 2 (Appendix M), In-School 1 (Appendix N) and In-School 2 (Appendix O) to show the stages of a lesson/session as seen in Table 5.

### 5.2.1 Stage 1: Building Curiosity

Each research site started with a section that engages the students to make them wonder and to pique the students' interest. Non-Profit 1 got their students to engage with the technology through play and discovery, whereas the other research sites got students to wonder and the instructors/teachers sparked their interest by getting them to ask and "answering [answer] the questions that arise in their minds by giving them prompts" (Grade 5 teacher, In-School 2), as seen in Figure 19.

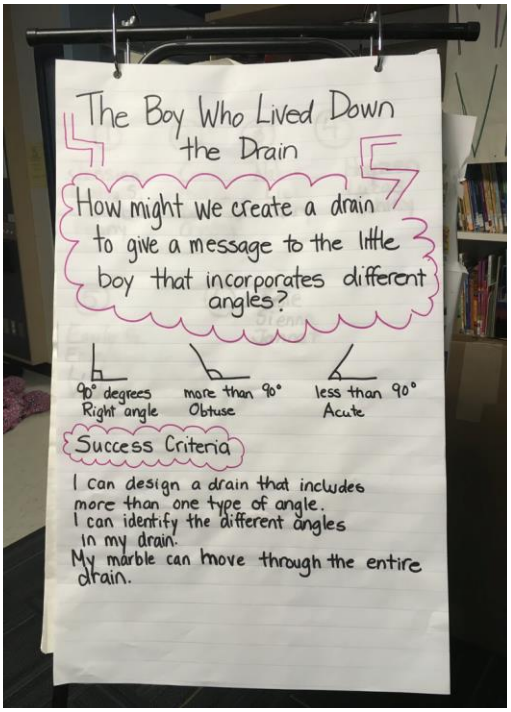
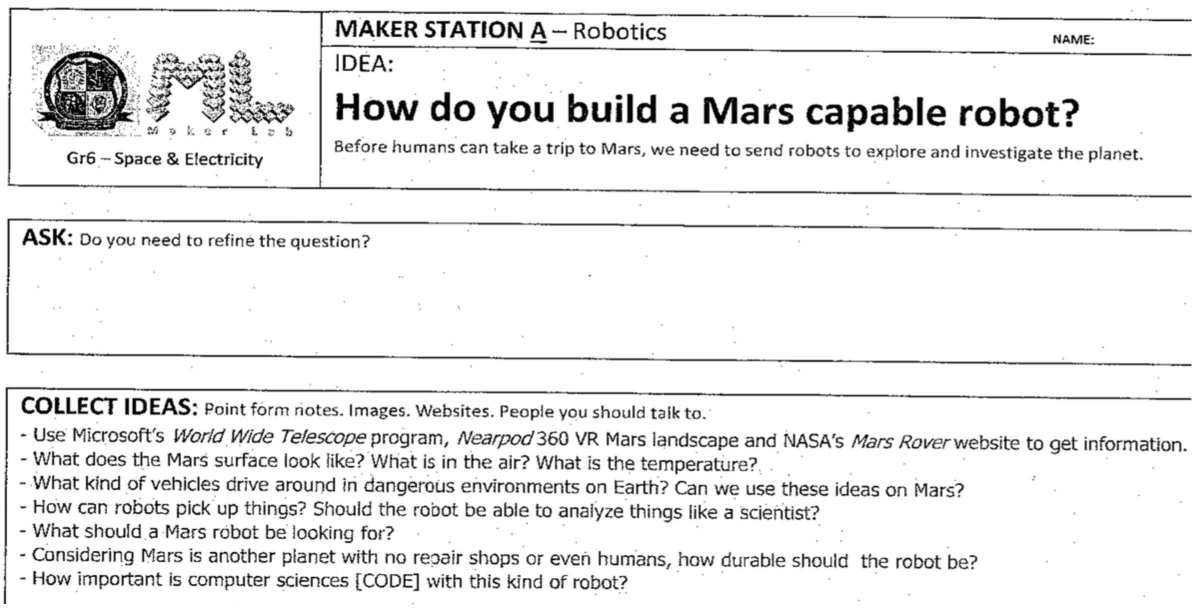



*Figure 19.* In-School 2 students were asked to answer an inquiry-type question to pique their curiosity and interest.

### 5.2.2 Stage 2: Data and Facts

The second stage appeared to be about gathering facts, whether it was using these facts to design a plan in Non-Profit 1, or to navigate their ideas and apply their knowledge in Non-Profit 2 to solve a problem or create something new. The two in-school research sites allowed students more time to research and collect ideas in this second stage. At In-School 1, students collected data from several sources, such as books, images, people and websites, which were decided by the group members as seen in Figure 20. In contrast, In-School 2 got students to focus their attention on a specific book that was selected by the teacher. The lesson was based on this book, and students used the book to gather facts and resources.



MAKER STATION A – Robotics NAME:

Gr6 – Space & Electricity

IDEA:

**How do you build a Mars capable robot?**

Before humans can take a trip to Mars, we need to send robots to explore and investigate the planet.

**ASK:** Do you need to refine the question?

**COLLECT IDEAS:** Point form notes. Images. Websites. People you should talk to.
- Use Microsoft's *World Wide Telescope* program, *Nearpod* 360 VR Mars landscape and NASA's *Mars Rover* website to get information.
- What does the Mars surface look like? What is in the air? What is the temperature?
- What kind of vehicles drive around in dangerous environments on Earth? Can we use these ideas on Mars?
- How can robots pick up things? Should the robot be able to analyze things like a scientist?
- What should a Mars robot be looking for?
- Considering Mars is another planet with no repair shops or even humans, how durable should the robot be?
- How important is computer sciences [CODE] with this kind of robot?

*Figure 20.* A hand-out with instructions for students to collect ideas and images from websites to think about building a robot to navigate and explore on Mars at In-School 1.

### 5.2.3 Stage 3: Making and Refining

The third stage was the making stage where the students got to create a prototype, test it and refine their design as seen in Figure 21 and Table 5 for the Non-Profit 1, Non-Profit 2 and In-School 2. In contrast, In-School 1 took one more step after collecting the ideas to make a detailed plan by drawing a blueprint or storyboard, listing the materials, organizing and synthesizing the information, whereas the other research sites combined the collecting ideas stage and planning stage. In this paper plane example, the following create-improve-reflect prompts on the hand-out encouraged students to reflect on why their first design was more successful than the second. They used this information in order to improve their designs.

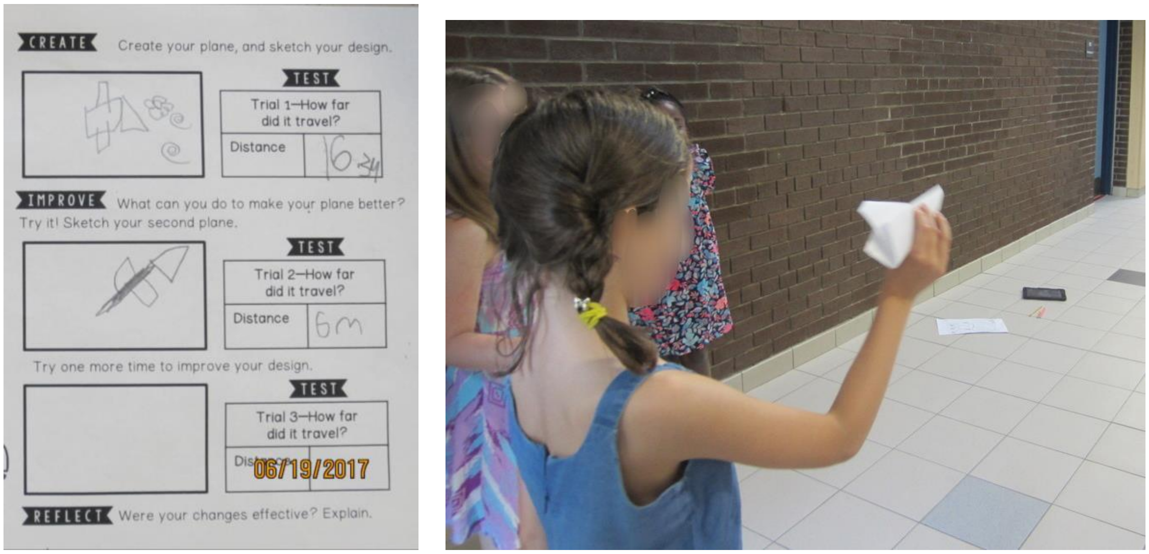



*Figure 21.* A hand-out with instructions for Grade 1, 2 and 3 students when they designed a paper airplane, tested it and refined their design at In-School 2.

### 5.2.4 Stage 4: Real World & Thinking Forward

The fourth stage is the most diverse section among the four research sites. The two non-profit organizations ended each course with a celebration where the students shared their work with an authentic audience, which included their peers, parents or the community. In the fourth stage, In-School 1 allowed their students to make their prototype, test and redesign it, and then present their product to an authentic audience. This audience included the class, school, parents or community and transfer their learning to another context, such as solving a problem at home, in high school, in post-secondary education or in a future career.

Similarly, In-School 2 provided students with the opportunity to reflect on what worked well, what they would change, and what they would do differently, as seen in Figure 22. In this fourth stage, teachers at In-School 2 took the opportunity to reflect and think about what they wonder, what they think the students are learning, what they still question and what they still notice.

**Stage 5: Feedback from Peers**

| Date | Peer Feedback | Moving Forward.... |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

*Figure 22.* Design-Inquiry Lesson: Students completed a log as they tested and redesigned their prototype based on feedback from their peers at In-School 2.

### 5.2.5 Summary of the Curriculum Models of STEAM for All Sites

Where and how the STEAM programs stated their curriculum varied from detailed and explicit outlines of curriculum objectives at the in-school sites to displays on walls at the non-profit sites. The lessons or units from the in-school research sites seemed to be more structured than the non-profit cases because they included specific expectations from the Ontario curriculum, goals and objectives, and a section for assessment. Lesson structures, as outlined in the curriculum documents (as seen in Appendices K, N and O), differed by STEAM sites depending on a research site's program objectives. Each one of the sites followed different stages in its instructional design.

What was common nonetheless was that each model could be seen to have four major stages: building curiosity, data and facts, making and refining, and thinking forward through sharing. At the building curiosity stage, only Non-Profit 1 differed as students immediately explored the tools and technology during this stage. The other three sites focused on sparking interest about the context of the lesson. At the planning stage students gathered facts in Non-Profit 1, or applied their ideas in Non-Profit 2, or got time to research and collect ideas in this second stage through gathering ideas from several sources at In-School 1 or focusing on a specific book at In-School 2. At the making and refining stage, only In-School 1 differed from the other three sites because it engaged students in one more sub-stage of making a detailed plan or a blueprint or storyboard in addition to prototyping, defining, testing and refining.

At the last stage, which was most diverse among the four research sites, students shared their work with an authentic audience, consisting of peers, parents or the community at the non-profit sites; the class, school, parents or community at in-school sites. Also, students received peer feedback on their product or prototype and reflected on the "making process" at In-School 2. After students shared their product with an authentic audience, the teacher librarian at In-School 1 encouraged students to use that knowledge and understanding in another context. In-School 2 provided students with the opportunity to reflect on what worked well, what they would change, and what they would do differently to drive the thinking forward.

### 5.2.6 Classroom Teachers' Views on the Curriculum Models of STEAM

During the focus group, the teachers discussed their views on the stages of the instructional curriculum models in the four STEAM programs. They were asked: "In what ways could some of the models/stages presented be used to meet curriculum and teaching goals in a school classroom?" In the focus group the teachers commented that they much valued the celebration stage (Stage 4 in Table 5). Teacher D explained "I like that piece here where you said the celebrating [stage]. So I think that it is so important that you have that time, that you have that moment with the kids to talk about what worked and the challenges and you know looking at all the different designs and testing it out and you know finding a real life connection to what they are building" (Focus Group). Teacher D further provided an example from her own teaching where students created their own video and how they celebrated their success:

> We showed them like a movie theatre we got candy and popcorn little thing and we had this thing here and this one kid asked me three weeks ago, can he use a different form of animation software . . . so he came in with his CGI [meaning Computer Generated Imagery] and his program called Blender [a 3D software for stop-motion animation] and it was incredible, probably the most surprising thing I've ever seen as an educator in 14 years. This thing was I don't know was just above and beyond anything I can imagine . . . It's really mind blowing, he had different voices and sound effects and it was just incredible. And there you go and that's just an example if you limit and if you open up those possibilities for them. I mean the ceiling was off the roof, I don't even know what to say to you.

Teacher A said "they constantly surprise me" when they go beyond my expectations (Focus Group). So, the celebration stage is an opportunity for the students to showcase their work and share with others. Besides the celebration stage, Teacher D in the focus group expressed the importance of the following stages:

> The planning piece where they are sketching out a variety of models before designing and building. I did really like the collaborative piece in a lot of them and them asking questions . . . I liked that they were asking a lot of questions. Even in the pencil toppers that they did first a design in plasticine before and they looked at it in Tinkercad before even getting into a third model, like this testing and building process as well.

The classroom teachers shared the stages they preferred as well as what they saw as the valuable enablers in these stages, such as student voice and choice, and students sharing their product with an authentic audience. Besides the stages of a lesson, the focus group participants commented on the scope and sequence of the lesson stages. That the curriculum models had "a scope and sequence too . . . there's things that the primaries do and there's things that the juniors do . . . I need to sit down and have a scope and sequence" for the different grade levels at my school. For example, In-School 1 there were specific projects for each grade level that builds upon the skills taught in previous years. Teacher D noticed that the curriculum models had "a lot of metacognitive pieces inside the curriculum and so using one of these models there's a lot of self-reflection and there's a lot of looking at different ways [methods] and different models and different procedures [that] could have been done" (Focus Group). Stage 4 at In-School 2, the "Let's Connect and Reflect Stage," provided both students and teachers with the opportunity to self-reflect on the "making process" and the learning experience, as seen in Table 5.

All four STEAM programs had some sort of task model that incorporated these four stages: building curiosity, data and facts, making and refining, and thinking forward; these were reinforced by students constructing their own knowledge and designing a prototype. Among the instructors/teachers in the STEAM sites and at the focus group, all of these curriculum and instructional models of STEAM education were referred to as the design and inquiry-based model. In most activities, all the STEAM programs integrated the design process where students created a plan and designed a prototype that was tested and then redesigned. It appeared that all four research sites used the fourth stage to drive the thinking forward for the students so that the learning continued after the lesson or unit had finished.

## 5.3 Theme 3: Student Learning and Transferable Skills

The curriculum documents that were shared with me from each of the STEAM programs showed that students learned character-building skills, which are transferable skills that can be used in another context, such as post-secondary education and the workforce. These encompass skills learned beyond the STEAM content curriculum. During my session observations, I noticed and took field notes on learning skills. Participants also commented about these skills when responding to interview questions on benefits of STEAM education. At In-School 1, for example, the teacher librarian said "I'm all about giving them skills to express their ideas, transferable skills so they can take with them to the next grade level. Keep practicing those skills, keep developing those skills and hopefully bring some of those skills together in unconventional ways."

In the following section, I report the findings from the curriculum documents and the interview data. This theme is organized based on the character-building skills that were found in the curriculum documents and the interview analysis. To show the character-building skills are developed within an out-of-school and in-school context, in this section I will provide details on the non-profit and in-school research sites separately. Then I will talk about the skills with respect to all the research sites.

**Character-Building Skills**

The curriculum documents refer to character-building skills, such as a sense of curiosity, collaboration, communication, perseverance (growth mindset), critical thinking and problem solving, several of which I noticed during the observations and came up during the interviews. In the field, the directors, instructors, teachers, teacher librarians, focus group teachers used the word “soft skills” to describe the character-building skills. Some of these character-building skills, such as critical thinking and problem solving, require higher-order thinking in which students have to analyze, evaluate and create new knowledge. In this study, the term critical thinking is used in a professional context in the curriculum documents and interview transcripts.

### 5.3.1 Non-Profit Case Studies

Both non-profit organizations approached the development of the students’ curiosity, communication and collaboration skills through games, storytelling and inquiry-type questions. But there were some notable differences in how each non-profit site approached perseverance and adaptability, collaboration, critical thinking and problem solving, which I also elaborate on in the following subsections.

#### 5.3.1.1 Curiosity

Both non-profit cases used games and storytelling to pique the interest and curiosity of their students in Stage 1 of a lesson. At Non-Profit 1, the director explained that “the first stage is play so that they can experiment with the technology [to] get an idea of what it can do, [and] get excited about it.”

At Non-Profit 2, students were given the opportunity by the instructors to tinker and play with the craft materials and technologies to spark their interest and curiosity as seen in Figure 23 (Stage 1 of the L.A.U.N.C.H cycle in Table 5).

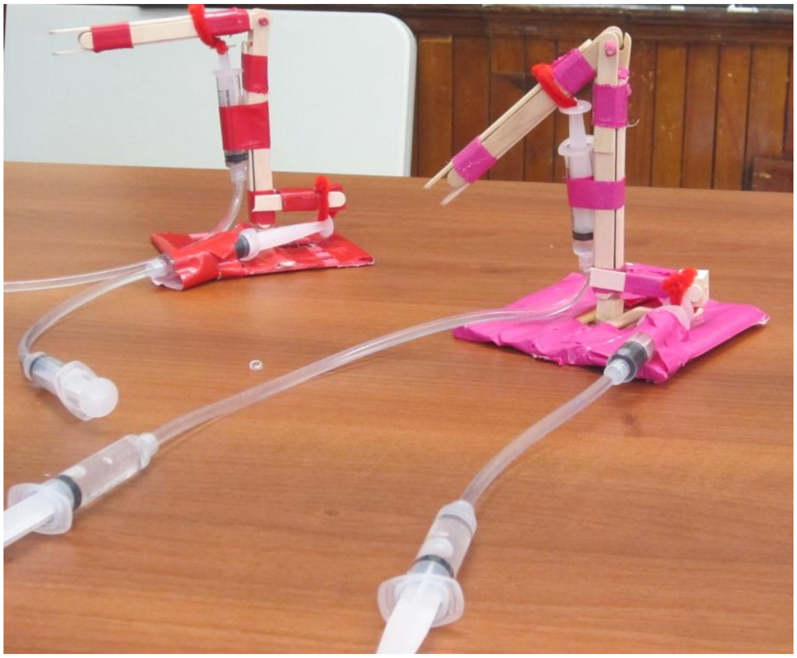


*Figure 23.* At Non-Profit 2 students played with the invention made by the instructor out of popsicle sticks and syringes to learn how changes in pressure can make the contraption move.

#### 5.3.1.2 Oral Communication

As described in Section 5.2, on the four stages of a lesson and unit, all sites included the initial stage that builds students curiosity and interest in Stage 1. At Stage 1, Non-Profit 1 and 2 facilitated group discussions with their students and prompted them to answer inquiry-type questions as a class, as seen in Table 5 on stages of a lesson. A case in point was after the students had been reading a book, they engaged in a whole class discussion on abstract concepts, such as logic. This class discussion on logic allowed students to synthesize new knowledge on algorithms by communicating and sharing ideas on a system or set of principles. Non-Profit 1 also provided students with several opportunities to communicate their ideas verbally in Stage 4 with the celebration stage. This was demonstrated through creating a video commercial for their product or making a video to share what they learned with others.

### 5.3.1.3 Written Communication

The two non-profit sites provided students with the opportunity to write during the activities. Non-Profit 1 clearly indicated specific tasks in their lesson plans where students communicated their ideas in writing. An example was when students were given a mini-lesson on how to write a good story and how this was very similar to the coding process. Students were then asked to write a story for their characters by creating a plan and a sequence of events. At Non-Profit 1, students sketched their ideas and expressed their thoughts through writing and drawings as seen in Figure 24.

Non-Profit 2 allowed their students the freedom to make a plan or sketch their ideas using multiple mediums. For example, some wrote it out, used modeling clay to create their 3D figures and designed it digitally. There was, however, no explicit part in the lesson plan that mentioned that students needed to write out their thoughts and ideas.

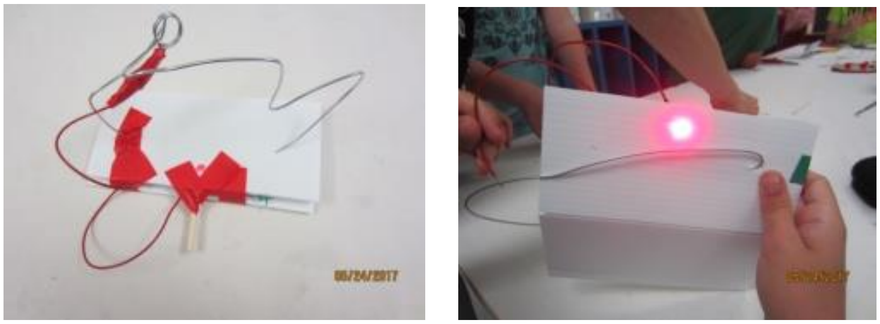

*Figure 24.* At Non-Profit 1, students expressed thoughts through writing and drawing. The student wrote the words “alarm,” “movement” and “tracking system” to describe the robot’s functions.

#### 5.3.1.4 Perseverance and Adaptability

At Non-Profit 1, the instructors also used picture books to get kids (6-9 years old) to discuss the topic of growth mindset, adaptability and persistence. Teaching perseverance is exemplified in the picture books *The Boy and the Airplane* with finding multiple solutions to a problem and in *The Girl Who Never Made a Mistake* with students' attitudes on making mistakes and learning from their mistakes as seen in Table 6. These picture books allowed students to visually understand these skills and to discuss their views on making mistakes. The instructor at Non-Profit 1 said she wanted her students to "not be afraid of making mistakes and trying new things." When asked about "what type of curriculum or instructional models do you commonly use in the STEAM lab/centre?" the director at Non-Profit 1 responded that he has built into the third stage "failure and iteration" as seen in Table 5 and "the main thing I want them to learn is perseverance."

After discussing the picture book, the instructor at Non-Profit 1 got students to identify their mindset on making mistakes, developing a growth mindset and learning from their mistakes. Both non-profit cases got students to plan, design, make a prototype, test, redesign and repeat the design-inquiry process as seen in Figure 25. Students at Non-Profit 2 followed the Design-Inquiry model: plan, design, make a prototype, test, redesign, and repeat to design a buzz wire game that lights up when the metal key touches the wire. When their prototype was unsuccessful, they had to persevere and find another way to make it work.

Prototype: test and redesign



Final product:

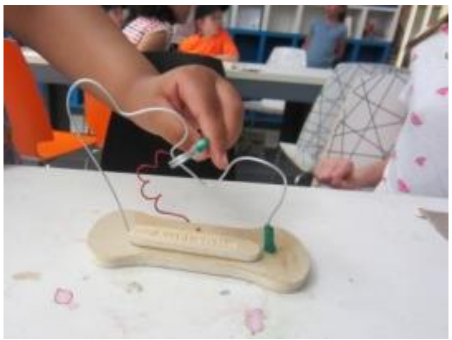


*Figure 25.* At Non-Profit 2, students designed and built a prototype to make their own buzz wire game.

#### 5.3.1.5 Collaboration

Both non-profit cases encouraged students to collaborate and work as a team when they were given group challenges. For example, in the spaghetti challenge, students had to build the tallest free-standing structure, or in the class mascot challenge where students had to design an innovative character using wood and the laser cutter (mentioned in Table 6 and seen in Figure 26). On the other hand, the two in-school sites provided students with the opportunity to work collaboratively in groups on a project or mini-assignments rather than a group challenge.


*Figure 26.* As a class, students sketched, designed and created a team mascot using the laser cutter at Non-Profit 1.

In the interview, the director at Non-profit 1 explained that their goal was to teach the students' "personal skills . . . which are collaboration, knowledge about themselves, . . . [knowledge] about their own personal strengths and challenges . . . that's connected to the collaboration because . . . to make a good team you need to know your role in the team what are your strengths and how do you cover for other people's challenges." In the group challenge, Non-Profit 2 gave the students specific constraints, such as 40 sticks of spaghetti, 5 marshmallows, 1 strip of tape, and 10 minutes to complete the task on 3D shapes and structural design. Non-Profit 2 instructors were detailed and specific when it came to the directions, while Non-Profit 1 gave students complete autonomy when they created the design of the team mascot as seen in Figure 26. Not every research site included these detailed constraints in their group challenges, projects or mini assignments.

#### 5.3.1.6 Critical Thinking

Non-Profit 1 was not as concerned with the product as much as the process. The director said that one of the student learning objectives "is critical thinking, so that they can make a plan . . . We want them to understand that in order to have an outcome that's close to what's in your head you need to make a plan and critically analyze your plan to make sure that it is awesome and doable, so the design ["the process"] always come before the building" (Non-Profit 1). This was also evident at Non-Profit 1 in the "explain-experimenter's reasoning" activity where students were encouraged to think about and explain someone else's reasoning. This can be a valuable task used for advancing students' critical-thinking skills by explaining their own thought process and developing a deeper understanding of "spatial and numerical transformations" (Waters & Schneider, 2010, p. 91). For example, in the chapter titled the Experimenter's Reasoning by Waters & Schneider (2010), the students had to explain the experimenter's reasoning when he or she lengthened the row, shortened the row, added an item, subtracted an item, or did not change the length or number of items at all. This activity taught students how to think critically, which was important when critically analyzing their plan in the Design stage (Stage 2 of a lesson as seen in Table 5).

At Non-Profit 2, students were given various tasks that would prompt them to use critical-thinking and problem-solving skills. For example, when students were creating a conditional (if then) statements in Scratch or Java script, they would have to use critical-thinking and problem-solving skills to write the code and debug their program when it was unsuccessful, as shown in Figure 27.

**General code for if statement**

```
if (expression) {
        // code executed if expression is true
} else {
        // code executed if expression is false
}
```

**For example,**

```
 if (buttonState == HIGH) {
   // turn LED on:
   digitalWrite(ledPin, HIGH);
 }
 else {
   // turn LED off:
   digitalWrite(ledPin, LOW);
 }
}
```

*Figure 27.* Students created an 'if statement' in Java Script. The code, except for annotations proceeded by "//," is very specific and one wrong character determines whether or not the program runs successfully.

*Table 6.* Character-Building Skills in the Curriculum Documents for Non-Profit Case 1 and 2

| Soft skills | Non-Profit Case 1 | Non-Profit Case 2 |
|---|---|---|
| Curiosity & Imagination<br><br>Students: | • Take part in activities that teach 21st century skills through games and storytelling<br><br>For example, students explore sections in Scratch, play games, take apart the code and build their own video game.<br><br>• Experiment and hook up whatever sensors and outputs they want<br>• Brainstorm group ideas for their project that connects to their interests | Ask questions and explore their curiosity. Activities that encourage creative play leading to learning 21st century skills.<br><br>For example, Creative Coding: Intro To Coding With Scratch (Kids 6-8) is all about fun games and playful learning. |
| Oral Communication<br><br>Students: | • Have open discussion on topics like logic/logical thinking after they have read a book as a class | • Answer the 'minds-on' questions in PowerPoint as a class or in a group |

| | | |
|---|---|---|
| | • Make a video commercial and present their pitch for their product in front of the class<br>• Make a video to share their product/invention with others | For example, what is 1-D, 2-D, 3-D and 4-D? |
| Written Communication<br><br>Students: | • Make a plan and sketch their idea, label the parts, list materials and highlight important information needed<br>• Create a story that has dialogue between 2 characters in Scratch. Try to answer as many of the 5 W's (who, what, when, where, why) in each game as possible. Create a plan (sequence): Who are the characters? What are they trying to accomplish? What are the features? The process of coding is very similar to writing a story. | No explicit part in curriculum documents or lesson plans that specifically mentions students writing to communicate their thoughts and ideas. |
| Growth mindset/ Adaptability/ Persistence<br><br>Students: | Instructor uses wordless picture books to discuss growth mindset, adaptability and persistence.<br><br>For example, the wordless picture book: *The Boy and the Airplane*. When a little boy's prized toy airplane lands on a rooftop, he makes several rescue attempts before devising an unexpected solution.<br><br>Another example is the Picture Book: *The Girl Who Never Made Mistakes*. Students: Identify their mindset on making mistakes; make connections between mistakes and the growth mindset; and learn from their mistakes. | • Design and engineer a prototype. For example, how to make their own buzz wire game. Plan, design, make a prototype, test, redesign, and repeat<br><br>• Learn from their mistakes and learn not to get frustrated when the prototype doesn't work the first time |
| Collaboration | Take part in activities that teach 21st century skills, such as collaboration.<br>For example, students brainstorm as a group and come up with 3-5 ideas of inventions they want to make.<br>For example, students create a Mascot; as a class, they draw, design and laser cut the mascot out of wood. | Group activity e.g., the spaghetti challenge to build the tallest free-standing structure.<br><br>Constraints: 40 sticks of spaghetti, 5 marshmallows, 1 strip of tape, 10 minutes. |

| | | |
|---|---|---|
| Critical Thinking/ Problem Solving | The instructor comes up with activities that encourage critical-thinking skills.<br><br>For example, students create a hypothesis to draw out preconceptions and misconceptions that they may have. Students also play games that get them to think critically. For example, in "*explain-experimenter*'s *reasoning"* groups were given corrective feedback by an experimenter, then asked to explain the experimenter's reasoning e.g., "Actually the two rows are the same. How do you think I knew that?"<br><br>The instructor encourages children to think about and explain someone else's reasoning, which is a valuable teaching method for advancing students' critical thinking and learning. | Students will start to develop 21st century skills: digital literacy, creative problem solving and teamwork in all of the STEAM Maker courses.<br><br>Students learn essential design and engineering skills to build their digital vocabulary and technology skills.<br><br>For example, Creative Coding Intro to Coding with Scratch (Kids 6-8): Students learn about variables, sprites, script, loops, conditional statements, programming, basic animation, sprite cloning, character import, game testing, how to create strategy games, among other technical skills. |

#### 5.3.1.7 Summary of Student Learning and Transferable Skills at the Non-Profit Sites

In this section, I have given examples of the transferable skills students learned at the non-profit sites; in Table 6 I summarised the character-building skills as evinced in the curriculum documents. Although both non-profit organizations functioned similarly, there were some notable differences in their approach to developing the students' curiosity, imagination, communication and collaboration skills (Stage 1 of a lesson in Table 5 and the character-building skills mentioned in Table 6). Non-Profit 1 used more games and storytelling as an opportunity for students to discuss difficult topics like logical thinking.

In contrast, Non-Profit 2 mainly used inquiry-type questions to get students talking, such as what is 3- and 4- dimensional? Or what does it take to design a video game? Each non-profit organization approached the group challenge differently. Non-Profit 1 described the challenge in general terms, while Non-Profit 2 included specific constraints for the given task. For example, the marshmallow and mascot challenge. This was not surprising because, during my observations, I noticed that students were given complete autonomy at Non-Profit 1 in the design, materials, technology and level of difficulty. Non-Profit 2 was more prescriptive, giving specific parameters for each activity. The in-school cases also showed some similarities and differences to the non-profit cases in their approach to learning, specifically in the development of the character-building skills mentioned.

### 5.3.2 In-School Case Studies

The in-school sites encouraged students to tinker and experiment with the technology. Both approached communication, collaboration, perseverance and adaptability, and critical thinking and problem solving similarly in most cases. In certain cases, perseverance was coupled with critical-thinking and problem-solving skills to find an alternative solution or navigate a robot through a maze. However, each teacher librarian at the in-school sites approached these character-building skills differently depending on the curriculum and instructional models used. This was evident in the differences that are mentioned in the following subsections.

#### 5.3.2.1 Curiosity

Both in-school cases used inquiry-type questions to get students to wonder, stir their imagination and pique their curiosity in Stage 1 of a lesson. In the post-observation interview, the special education teacher expressed that the "inspiring piece [is] . . . doing these type of learning activities . . . you are activating kids' natural curiosity, their natural interest in figuring out how things work and how they can make things better" (In-School 2). Both in-school cases allowed students the opportunity to tinker as they explored a new technology before using it to solve a problem or create something.

At In-School 2, some lessons were based on a children's book, such as *A Squiggly Story*, selected by the teacher librarian. The students were asked *minds-on* questions, shown in Figure 28, to focus their attention on a spiral drawing from the book. It appeared the teacher librarian used these questions —such as where the line started, ended and what happened on the way— to get students to think, question and wonder and in turn be curious and interested in the lesson on *A Squiggly Story* and sharing their own story in Stage 1 of a lesson.

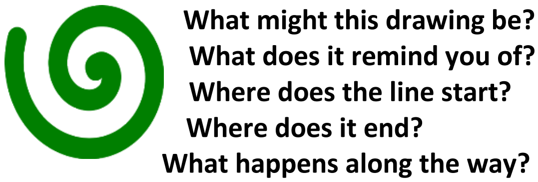



*Figure 28.* At In-School 2, the teacher librarian asked the students these inquiry-type questions for *A Squiggly Story*. The image in green represents a squiggly image that can be drawn with a pencil like the images in this book.

### 5.3.2.2 Oral Communication

At the in-school research sites, students documented the "making process" and expressed their thoughts verbally. At In-School 1, the students documented every stage of the "making process" in a video to capture their observations, creations and group discussions. In each lesson or unit, the teacher librarian offered students an opportunity to document the "making process" and share their thinking using photos and videos. The teacher librarian commented that the intent of the documentation was to "drive their thinking forward," as mentioned in Stage 4 of a lesson plan (Table 5). There appeared to be an opportunity for students to deepen their understanding as they shared their ideas on the planning, designing, making and refining stage rather than simply making a product. At In-School 1, a green screen room with several computers using video-making software and cameras was set up for students to free walk to and create a multimedia artefact, such as the short video, which they used to communicate and share their thinking.

Also, In-School 2 students documented the "making process," although, unlike In-School 1, this was done at the fourth and final stage of the lesson. Thus, students at both in-school sites were offered the opportunity to communicate and share their thinking in a video or short film. For example, at In-School 1, students used information from books and websites, and they created a video to sell their planet. The teacher librarian at In-School 1 said "we taught them some video editing, we taught them storyboarding [and] they wrote the script all this type of stuff and put it all together" using the green screen media production software Chroma Key Studio.

#### 5.3.2.3 Written Communication

In-School 1 also encouraged students to document the "making process" by writing and completing the handout. The handout provided space for students to write their answer to the inquiry questions about the activity, write notes from the results of their Internet research using the Chromebook. As shown in Figure 29, the teacher and teacher librarian at In-School 1 used questions on the handout to prompt the students to sketch out a plan and complete a written log on testing and redesigning their prototype. At In-School 1, I observed the Grade 5 students complete a log (see Figure 30), which included a section to write notes about programming the LEGO EV3 robot to navigate the perimeter and calculating the perimeter for each challenge mat. Each lesson and unit plan at the In-School 1 research site focused on a particular technology, such as LEGO EV3, and students would devise a plan to solve the problem or design their prototype given specific parameters (i.e. materials and technology).

In-School 2 used non-traditional ways of getting students to write using sticky notes and index cards, encouraging students to navigate their ideas by organizing those notes into categories. At In-School 2, the Grade 5 students completed a log during the Design-Inquiry lesson as seen in Figure 22 (Section 5.2). This lesson promoted multiple designs as they tested and redesigned the model of a solar-powered oven multiple times when the group experienced failure and the frozen food did not cook properly. They redesigned their prototype based on their observations and feedback from their peers. Students were also given a hand-out to complete, which documented every stage of the design-inquiry process labelled as define, sketch, prototype and test, and feedback.

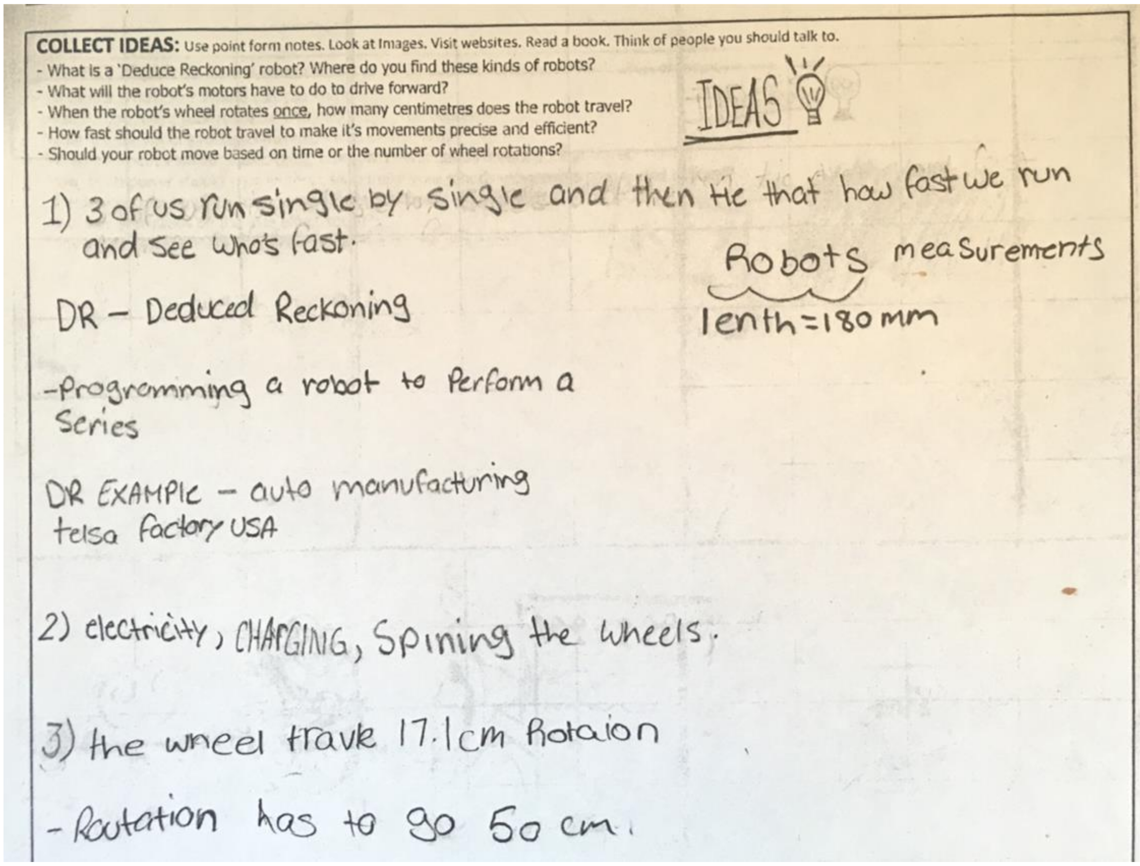



*Figure 29.* At In-School 1, students wrote information in the Collecting Ideas section to answer the inquiry-type questions that would help them build and program their robot.

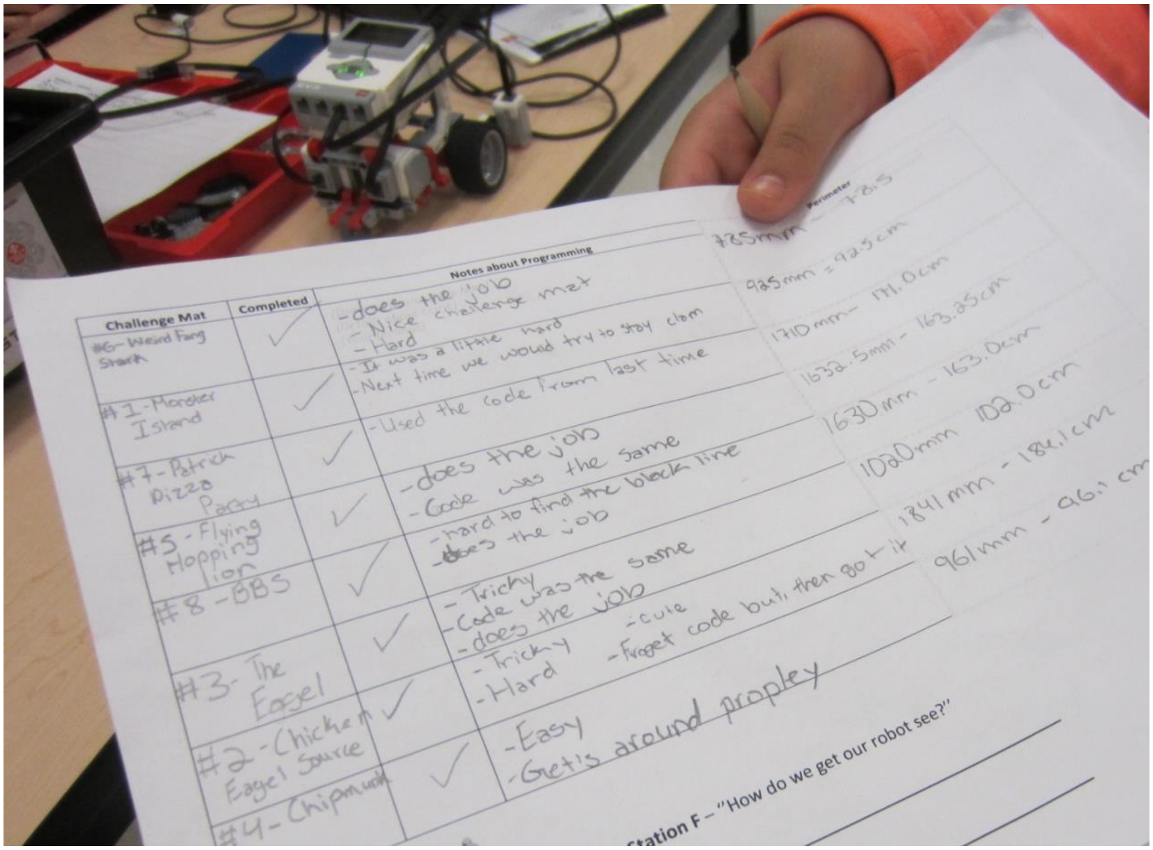



*Figure 30.* At In-School 1, students completed a log for each challenge mat that their LEGO EV3 robot successfully or unsuccessfully completed.

#### 5.3.2.4 Perseverance and Adaptability

In the interview, the teachers and teacher librarian discussed how students learned to develop a growth mindset, adapt to the situation and persist when going through the design-inquiry process: plan-design-make-test-redesign and repeat**.** At the in-school and non-profit sites, 12 out of 15 adult participants mentioned perseverance during the interviews when they were asked "what are some of the greatest benefits of this STEAM program that you have observed?" or "what do you think the students learned in the activity or lesson from your perspective?" For example, the teacher librarian at In-School 2 answered "developing mindsets, developing perseverance and grit in an openness to try new things." The teacher librarian explained "that's one of the things that we're trying to build is perseverance and risk taking and grit and I think it's more about the learning . . .

[and] the learning is more about the process" (In-School 2). The teacher librarian at In-School 1 talked about "growth mindset and persistence and keeping a positive frame of mind seems to be more difficult with some of the students." Similarly, the Grade 5 teacher mentioned that he "saw a lot of leadership skills . . . and problem solving even with robotics, they had to code the robot to move around a shape and escape the maze through using trial and error and you know they had to keep going and not give up" (In-School 1).

#### 5.3.2.5 Collaboration

The in-school STEAM programs provided students with several opportunities to work in groups whether they were designing a robot, creating a pattern in Minecraft, programming a robot such LEGO EV3, Ozobot or Sphero to move around a perimeter or to the beat of a song. At In-School 1, a Grade 2 teacher expressed that she "think[s] that collaboration is absolutely key." A Grade 5 teacher at In-School 1 found that "kids would be like I don't know what to do and after they explore[d] and collaborate[d] with their own teammates and then they would create these amazing things." Similarly, a *self-contained* special education classroom (for only students with identified special needs in mathematics and English) for grade 1, 2 and 3 students at In-School 2 worked collaboratively to design a paper airplane as seen in Figure 31. Students had to work as a group to improve their design to increase the distance that the airplane travelled. Students were able to use "inquiry and research skills, so they had ideas from their prior knowledge if they had any about it, but they also used the iPads to research and follow a video model [on making a paper airplane], which is awesome . . . and they collaborated with other partners too" (Special Education Teacher, In-School 2).


*Figure 31.* At In-School 2, students in Grade 1-3 in a self-contained special education classroom worked collaboratively to design a paper airplane using an iPad, or paper and pencil, to sketch and design their prototype.

### 5.3.2.6 Critical Thinking

I noticed that most of the sessions' objectives or questions on the handouts incorporated STEM subjects, such as science and mathematics. The objectives for science and mathematics appeared to provide students with the opportunity to use critical-thinking and problem-solving skills. Each lesson at In-School 2 focused on a question or set of questions, like "How might we get Georgie home [in the story book] and describe the path?" Students were given the opportunity to answer this question using multiple approaches to represent Georgie's path home. Students used unplugged methods (i.e., methods with no digital and screen technology, such as string stories, drawings, LEGO creations and arrow diagrams), as seen in Figure 32. In this example, students had to think critically about distance, direction, measurement, angles and scale factor for the arrow and the distance that one arrow represented. The teacher librarian facilitated a learning environment where students appeared to represent mathematical concepts such as distance, angles, measurements and scale factor in STEAM as they created a model or collage. They also used different digital technologies, such as Ozobots and Beebots to code Georgie’s path home. The students had to use problem-solving skills to decide how to program the robots to follow a specific path, or the LEGO EV3 in the example of challenge mats at In-School 2. As students were representing Georgie’s path home, they had to be both creative and strategic. Students integrated the arts with STEM when selecting different materials such as a plastic figurine, cardboard arrows and natural wood slices that made a clear visual representation of the path taken. Students also had to describe in written words the path that Georgie travelled.

*Figure 32.* At In-School 2, students made an arrow diagram or collage.

*Table 7.* Character-Building Skills in the Curriculum Documents for In-School Case 3 and 4

| Soft skills | In-School Case 3 | In-School Case 4 |
|---|---|---|
| Curiosity & Imagination<br><br>Students: | • Tinker with the technology or view online videos<br>• Ask inquiry type questions that will pique their interest<br><br>For example, when building a robot, students might ask: How do we become great robot makers? How do sensors help a robot work better? When a robot | Minds-on section used to peak the student’s interest by answering questions about a given image which is connected to a children’s story. |

| | | |
|---|---|---|
| | is working, should it know how to solve many little problems or one giant problem? | |
| Oral Communication<br><br>Students: | • Document their experiences with photos/videos.<br>• Tape a short film or Google slides on the "making process" with images, keywords, talking and highlighting important things. The film should capture their observations, their creations and group discussions.<br>• Discuss or debate their ideas with the group | • Answer the minds-on questions as a class or in a group<br>• Express their personal thoughts and feelings about what has been read<br>• Create multimedia artifacts such as a short video to communicate and share their thinking |
| Written Communication<br><br>Students: | • Write out their questions in the ASK section<br>• Write out notes from their research in the 'Collecting Ideas' section (Figure 26)<br>• Document their ideas in the PLAN section both written as well as oral communication | • Communicate by writing their feelings on paper or sticky notes<br><br>For example, "How does this picture make you feel?" Take a sticky note and draw a picture or write a word/ sentence that shows how they feel about sharks. Use cue cards to write/draw three things you learned about sharks.<br><br>Students showcase their shark facts by creating a game in Scratch Jr. They might also use the data to make a shark out of lose craft materials (referred to in the lessons as loose parts) or pattern blocks. Students will have an opportunity to communicate verbally their choices and thought process. |
| Growth mindset/ Adaptability/ Persistence<br><br>Students: | • Present a plan to their teacher and may need to make several iterations of revisions following the feedback from the teacher.<br>• Teacher encourages patience, precision and persistence among the students.<br><br>For example:<br>• Build Rube Goldberg Machine and the goal is to get the ball into the cup. This is a good moment to model precision and persistence. | • Have to create a plan, adapt and modify the plan to debug the code or create a successful stop-motion video<br><br>For example, "How might you create a drain from large loose parts or tape and code a rubber duck through with arrows? How you use a stop-motion app to make the duck move and arrows appear one by one?" |

| | | |
|---|---|---|
| | • Need to make several revisions to get their machine to complete the task successfully. | |
| Collaboration | Small group of students plan before making by drawing a blueprint or storyboard, listing the materials, highlighting the most important parts and assigning each group member a job. | Students can problem solve and work as a team. For example, "How might we get Georgie home and describe her path?"<br><br>Students worked in groups and described Georgie's path using markers and paper, arrows, LEGO and programming robots (e.g. Ozobots, Beebot and Cubetto) to answer the question. |
| Critical Thinking/ Problem Solving | If it doesn't work at first teachers tell students to go back in the process and figure out what you need to change/fix.<br><br>Students might have to problem solve, use experimentation, and trial and error to come up with the answers to these questions.<br><br>For example, how fast should the robot travel to make its movements precise and efficient? When the robot's wheels rotate once, how many centimeters does the robot travel? What speed is optimal for a robot to move precisely given the surface on which it is moving on? How do you make a robot turn 90°? … 180°? | Students use critical-thinking/ problem-solving skills when completing the objectives that the teacher has set out in the activity/lesson.<br><br>For example, in Math is mPower-ful!<br>Students:<br>● Engage in activities that involve problem solving and work as part of a team<br>● Learn how to estimate, measure, calculate a revolution, and record the perimeter of two-dimensional shapes, through investigation using standard units<br>● Learn how to create simple and/or complex coding scripts and understand coding algorithms; debugging scripts of code when they run into challenges |

### 5.3.3 Summary of Student Learning and Transferable Skills for All Sites

During the observations, all students learned character-building skills that were exemplified in the curriculum documents, such as curiosity and imagination, oral and written communication, perseverance and adaptability, collaboration, and critical thinking and problem solving. Every research site encouraged the students to tinker and experiment with the technology through play and discovery. Specifically, the Non-Profit 1 and In-School 2 used storytelling and/or answering inquiry-type questions to engage their students and to activate the students' natural curiosity. Non-Profit 1 and 2 used games to fuel the students' interest, imagination and curiosity. Both in-school cases also used the Ontario curriculum when creating some of the specific objectives and inquiry-type questions. Non-Profit 1 and both in-school cases, 3 of 4 sites, chose to document the "making process" through video. This allowed students to communicate and share their thinking. The two in-school cases allowed students to both share their thinking verbally in a video and in a written student log. The purpose of documenting the "making process" was to drive their thinking forward by reflecting on what worked well, what needed to be changed, what could have been done differently.

At the non-profit and in-school sites, students learned to develop persistence and adaptability when going through the design-inquiry process of plan-design-make-test-redesign and repeat**.** At Non-Profit 1, the director and instructor created a learning environment in which students were not afraid to make mistakes. To encourage perseverance, failure and iteration was built into the lesson or session at Non-Profit 1. All four research sites created group activities and encouraged students to collaborate with one another, whether students are working on a team challenge or a group project. Through collaboration, students learned their strengths and "after they explore[d] and collaborate[d] with their own teammates and then they would create these amazing things" (Grade 5 Teacher, In-School 1). Non-Profit 1 provided the students with more choice in materials and in how they designed their project. The other research sites were more prescriptive and gave students specific constraints in the lesson itself. These character-building skills in the curriculum documents were "all about giving them[students] skills to express their ideas, transferable skills" that can be used in a different context or to solve a different problem.

### 5.3.4 Classroom Teachers' Views on Student Learning and Transferable Skills

Besides the pedagogy, curriculum and instruction teachers from the focus group commented on STEAM education's goals following my presentation of the preliminary findings on the student learning at the four research sites. When responding to the focus group discussion prompt, "In what ways could some of the models/stages presented be used to meet curriculum and teaching goals in a school classroom?" Teacher C in the focus group answered:

> Well we're preparing them for a better world. The world I grew up in was a factory world. Some of my fellow students went to jobs where they would do the same job every day for the rest of their lives and that's not the case anymore . . . I really like the authentic experiences and the rich task. I think that in our world today there are a lot of problems to be solved.

Teacher D in the focus group gives an example of these authentic and rich tasks:

> Whether it's regards to sustainability or you know just compassion in the world, solving some of these food and hunger issues, water resources issues and I think that preparing our students to connect with their learning is a viable skill that they can take with them in the future. You know [for example collaboration and communication skills] where there are so many different entry level projects and contests [in these STEAM learning activities], where students are really creating things that are being used in our community and are being used to solve real-world problems. And I think that's when I find my kids the most engaged when they can actually see that thinking.

During the focus group discussion, there were also challenges mentioned in developing some of these character-building skills. For example, Teacher B described one of her challenges as "growth mindset . . . That's one of the biggest challenges when we're doing STEAM activities . . . it's like an unwillingness to try again or change the design even if it's not working." Teacher D suggested "that's why I think that it needs to start in the younger years and this idea of building, designing and trying again, being resilient, knowing how many prototypes something takes before [you get the final product] in the real world . . . You are never going to get a final product without going through that messy process of try-fail-start again" and repeat (Focus Group). This idea of failure and reiteration in Stage 3 of a lesson seemed to resonate with the focus group participants.

They all knew that it was important for student learning and was built into both Design-Based Learning and STEAM activities of the research sites.

At all the research sites, students learned character-building skills (21st Century skills). These skills seemed transferable because they could be used in real life, in high school, in post-secondary education and, eventually, in the workforce. When the teachers were asked "what are some of the greatest benefits in STEAM education?" The teachers saw the benefits of how the STEAM tasks connected to students' real lives, to the world in which students find themselves, and to how students may prepare for future jobs. A Grade 5 teacher at In-School 1 said "I think the biggest thing is it just speaks to kids, this is their language right now. This is their world if you think about like future job opportunities this is like 21st Century learning for kids, this is what they know and what they are interested in."

Instructor 2 at Non-Profit 2 said "giving them the tools to have a better life essentially and work life, that's where adding technology and adding these new features, new STEAM learning comes from." The director at Non-Profit 1 wanted his students to "think about, think of, look at the world around them as the place that can be changed by their ideas . . . [and] make this city a better place somehow." Both teachers and students in the STEAM programs considered the skills being learned as valuable and realistic. The director of the STEAM program said "what we are trying to do is to empower people [kids] to feel like they can have control over their lives, they can make things that they want, … that they need. They can make a difference in the world and these tools of technology and science and engineering are really a great way to do that" (Non-Profit 1).

## 5.4 Theme 4: STEAM Tasks and Learning Experiences

The following section talks about the academic skills that the students learned from the STEAM activities. The lessons and activities at the STEAM programs were described as rich and authentic tasks. For example, the In-School 1 Grade 2 teacher described these activities as "rich tasks . . . that connects to the overall experiences or draw a theme to the lessons [and] they naturally come with Science, Technology, Art, Engineering, Math, all those things naturally come out if you give them time." At Non-Profit 1 "the core strings of it for STEAM, for our investigations . . . it has to include some form of authenticity" (Instructor 1, Non-Profit 1). Students in these STEAM programs were constructing their own knowledge, as well as making and sharing their final product with an authentic audience. For students to experience rich and authentic tasks in STEAM education, the learner must not only have the opportunity to make an artefact but be able to share their thinking about the making process and how that fits into a social and real-world context.

This section is organized by the academic skills attained, specifically Science, Technology, Engineering, Arts and Mathematics. I share only the tasks as opportunities to learn specific curriculum content, processes or skills because this study did not assess the students on the skills they learned in the lessons/sessions I observed. As a result, I did not analyse any secondary data on the testing of the student participants.

**Academic and STEAM Tasks**

I also identified specific academic skills that students learned through STEAM education. These skills were analysed first in the curriculum documents from the four research sites, and then they were triangulated with interview and observation data. In the field, the teachers and teacher librarians at the in-school sites referred to the academic skills as "hard skills", which could be defined and measured. The hard skills included writing, mathematics, and reading. In the context of this research study, I was particularly interested in the skills related to each of the STEAM disciplines and the integrated learning opportunities (i.e., three or more subjects are integrated within a specific STEAM lesson or course) that the students gained from the STEAM programs.

### 5.4.1 Non-Profit Case Studies

Although students learned academic STEAM skills, I observed that the students at the non-profit research sites had difficulty articulating the specific Science, Technology, Engineering, Arts and Mathematics concepts learned. At the non-profit sites, students ages 6-12 were asked "what have you learned about Science, Technology, Engineering, Arts and Mathematics so far in the STEAM program?" and despite probing, many students could not answer the question, and this was left blank for 8 out of 14 students at these sites. On the other hand, the students had no problem describing their favourite activities and the interesting things that they learned in the STEAM programs when the researcher asked them during class. In this section, I mention the specific academic and STEAM skills found in the curriculum documents and examples of the academic skills learned that were mentioned in the student and teacher interviews.

#### 5.4.1.1 Science Tasks

Both non-profit cases taught their students about simple circuits, electricity and mechanisms. In the Ontario Science curriculum (2007), students learn about electricity and electrical devices in Grade 6. In Non- Profit 1, students learned how to create a simple circuit, use a remote controller with a motor or a LED with a coin-cell battery to power their inventions (e.g., toilet paper shooter) or robots (e.g., cardboard robot with wheels to carry toys).

Similarly, Non-Profit 2 used reactive materials, such as squishy circuits, LittleBits or Makey Makey kits, to create inventions and learn about circuits and electricity in the STEAM 101 class. When commenting on the LittleBits kit that they had used to create an entertainment system with lights and sound. A student said, “it was neat how it went together, how light and energy work together” (Student 3, Non-Profit 2). These science tasks appeared to be designed to teach students about electricity, circuits, energy, simple machines in an authentic way through play, discovery, exploration and experimentation. One student said her favourite activity was “making a circuit game” and she said, “I like making stuff that I could play with.” The student further explained “I learned how to make a light go on when the metal [key] hit” the wire (Student 1, Non-Profit 2). Students appeared to learn how to create a simple circuit with an Arduino microcontroller, battery and cable, a servo (controllable motor) and power source in the Inventioneering class I observed, as shown in Figure 33. Students could add a sound button, fan, and LEDs so that their simple machine had served a purpose or performed an action, such as to make music, act as a fan, or light up.

I also observed students use of scientific thinking when researching, experimenting and testing their prototypes, such as designing and building programmable robots. Grade 4-8 students at Non-Profit 1, In-School 1 and In-School 2 designed and built a programmable robot using Arduino, breadboard, connector wires, among other electronic parts. Students had to test their prototype and redesign their robot to function more efficiently. In these activities, I observed the students learning specific concepts in the Ontario Science curriculum (2007), such as the Light and Sound unit in Grade 4 and Electricity and Electrical Devices unit in Grade 6.

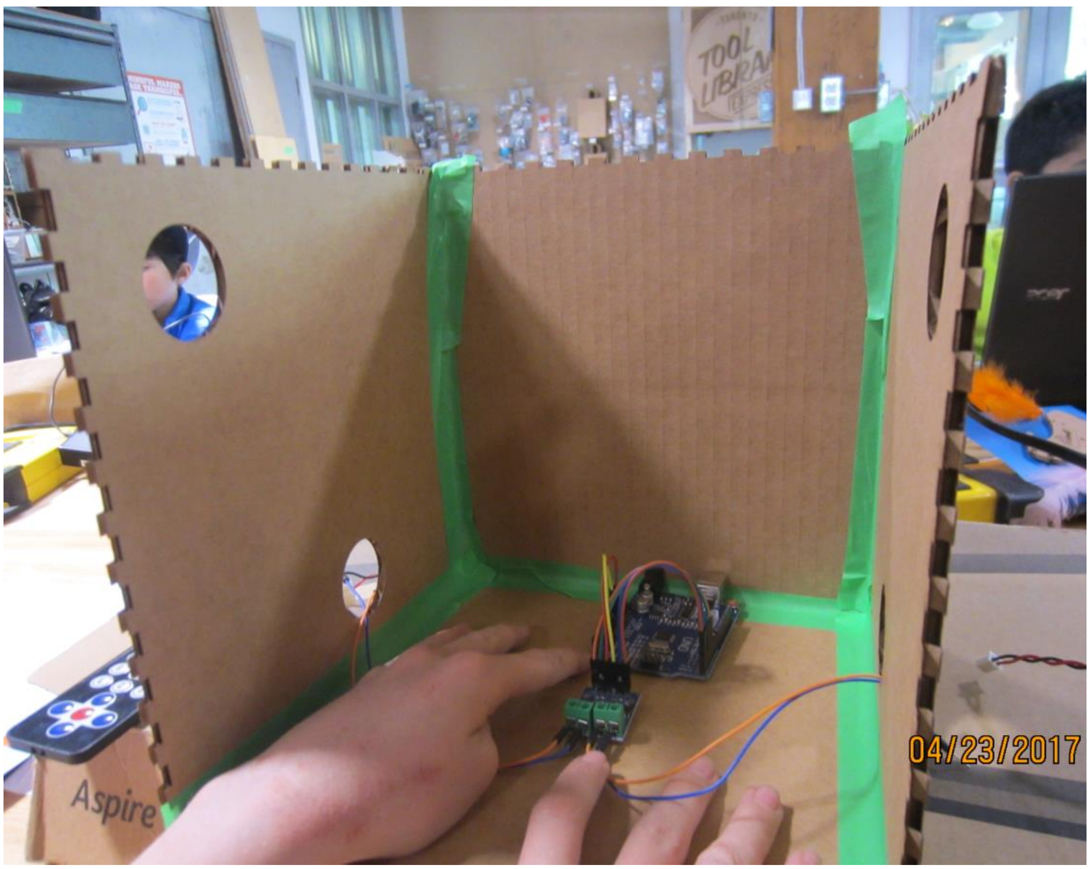



*Figure 33.* A student created a circuit with an Arduino microcontroller, cables and a servo to power the wheels on his robot designed and built at Non-Profit 1.

#### 5.4.1.2 Technology Tasks

Both non-profit organizations used similar technology for their STEAM tasks and activities. At the non-profit sites, the STEAM tasks included computer programming, 3D modeling, laser cutting, video and digital tools. Student 1 at Non-Profit 1 mentioned that "laser cutting was very impressive how it works." At Non-Profit 1, student 4 mentioned some technologies learned, like "3D printing, programming, laser cutting and building robots." Instructor 2 discussed at the beginning of each course "they [the students] still need foundational tools to get started, so the basics of how Scratch works or how Python works and then you lead them to a point where they can then do whatever they want to do" (Non-Profit 2). In the introductory courses, students learned how to program using the Visual Programming Language (VPL), like Scratch, Makecode Minecraft, Ozoblockly, etc. In more advanced courses, such as the Inventioneering program for 9 to 12-year-old children and other programs, as evinced in the curriculum documents, offered for teens or adults, students used text-based programming languages like Java Script and Python.

At Non-Profit 1, students learned how to create their own Arduino [a microcontroller] robot or robot creation using simple circuits and mechanisms. Students were given the opportunity to learn the main components of robots, such as sensors, control systems, and effectors. The students enjoyed the technology. One student expressed that "it was cool programming the lights on the neopixels" strip as seen in Figure 34 (Student 2, Non-Profit 1).

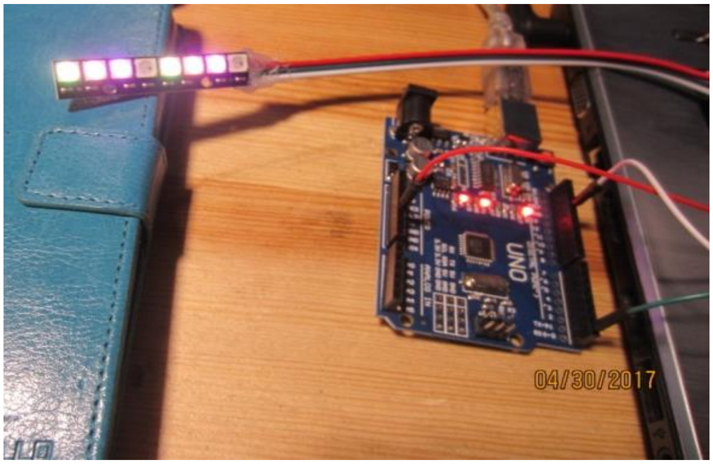



*Figure 34.* Grade 4-6 students at Non-Profit 1. Some used a technology called a neopixel strip in their project and programmed the LEDs to sequence the colour pattern.

In contrast to Non-Profit 1, which designed, built and programmed the robots, Non-Profit 2 taught students how to program robots, such as Ozobots, Spheros and LEGO EV3s to move using the VPL. This finding was evinced in the lessons I observed and in the curriculum documents that I analyzed. The students learned the "main components of robots, various ways that objects can move, [and] programming and logic for robotics components" (British Columbia Ministry of Education, 2016, p.7). At both non-profit sites, students learned about robotics in an authentic context through building, programming, exploration and experimentation. The students at Non-Profit 2 also enjoyed the technology as evinced in the comment from a student explaining why she enjoyed the 3D printing of the house "because it was like fun, you got to create your own thing" (Student 2, Non-Profit 2).

#### 5.4.1.3 Engineering Tasks

Both non-profit cases appeared to have seamlessly integrated the engineering process in most of their courses, as evinced in the curriculum documents, observations and interviews. Non-Profit 1 offered courses that emphasised engineering, such as the *Robotics Playground* course for ages 6-13 in which girls learned about architecture and design in a meaningful way and real-world context. As stipulated in the curriculum documents and on their website, students in this course appeared to be offered a learning outcome that aligns with an engineering curriculum to “define a design problem that can be solved through the development of an object” (Robotics Playground, Non-Profit 1). As specified in its curriculum documents, the course at Non-Profit 1, offered students the opportunity to reimagine, remix and recreate a green space and build a prototype to scale using multiple ways to approach a problem and tools such as robotics, laser cutting, 3D printing and woodworking. This robotics playground can be described as an interdisciplinary project that seamlessly integrated Science (i.e., environmental, recreate a green space), Technology (i.e., robotics, laser cutting, 3D printing), Engineering (i.e., plan, design and build a prototype), Arts (i.e., aesthetics) and Mathematics (i.e., scale factor, dimensions, measurement, distance, angles, surface area, perimeter) in a real-world context. In the Non-Profit 1 program for students ages 6-9, they got to design their own basic robot and create a detailed plan as seen in Figure 35.

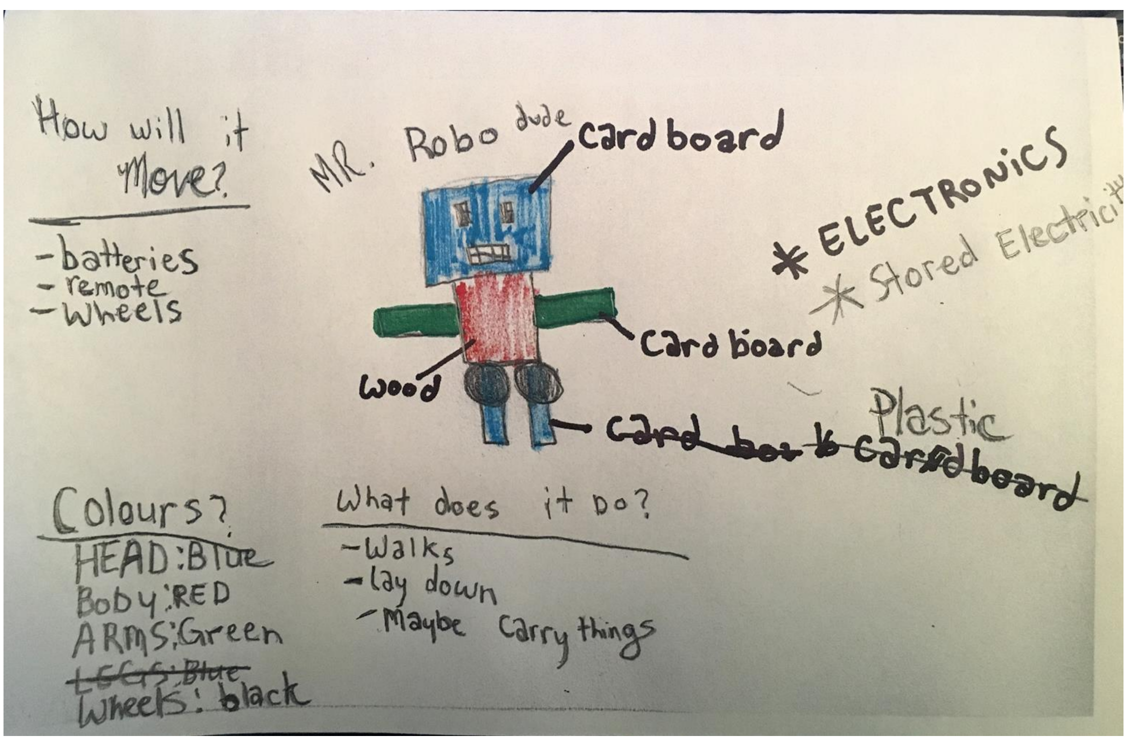



*Figure 35.* A student at Non-Profit 1 planned and designed a blueprint of a robot by listing the materials, robot’s purpose, ways to make it move, and electronic supplies needed.

Non-Profit 2 incorporated engineering into all their courses that I observed and those outlined in the documents that were shared with me by the director and the instructors. Specifically, in the STEAM 101 course students ages 6-8 were offered learning opportunities to plan, design, make a prototype, test, redesign, and repeat the process. Student 2 at Non-Profit 1's favourite activity was "Tinkercad [a 3D CAD design software] because you got to invent your own stuff" and design a character using the software. Students went through several designs and drafts before deciding on the final sketch in Tinkercad.

#### 5.4.1.4 Art Tasks

Similar to engineering, art has also been seamlessly woven into the structure of each course at the two non-profit research sites. The creative process aligned with design thinking and inquiry process that was used at the non-profit sites. At Non-Profit 1, the physical learning environment had a craft station with a variety of materials and a woodworking station with a scroll saw and laser cutter. Non-Profit 1 offered a two-day workshop for ages 6-13 on Lantern Emblem Making to encourage students' artistry and creativity. Similarly, the Non-Profit 2 offered courses that were specifically designed for the STEAM kid Artists, like *Printmaking and Jewellery* making courses. At Non-Profit 1, students designed and made a team mascot using the laser cutter as seen in Figure 26 (Section 5.3). Specifically, when making the team mascot students learned the elements of design; they used a variety of lines (thick and thin), symmetrical and asymmetrical shapes and created different textures with the laser cutter. A student in the *Creative Coding with Scratch* class described the "computer as a canvas" as they created a multimedia work of art (Student 5, Non-Profit 2) as seen in Figure 36. Specifically, the students at Non-Profit 2 were creating a geometric spiral using rotation, colours and geometric shapes in Scratch.

Students at Non-Profit 2 learned about the elements of design in the *Creative Coding-Intro to Coding with Scratch* course for ages 9-12 that I observed: they used lines for expressive purposes, used repetition of lines to create visual rhythm, and combined different colours for or to create a pattern. They also learned the principles of design through repetition of colours, shapes, textures, lines, alignment and proximity. For example, I observed in the *Creative Coding with Scratch* class that the geometric swirl created by the students used mathematical properties and showed the distance/perspective, drawing the eye further away as it spiraled into the center of the computer screen as seen in Figure 36. The art tasks appeared to be designed to seamlessly integrate mathematics, arts and technology in a meaningful way. This was evident as the students used mathematical concepts such as distance/perspective, symmetry, asymmetry, patterns, geometry and rotation to create this multimedia work of art by coding and designing the image in Scratch, as seen in Figure 36.

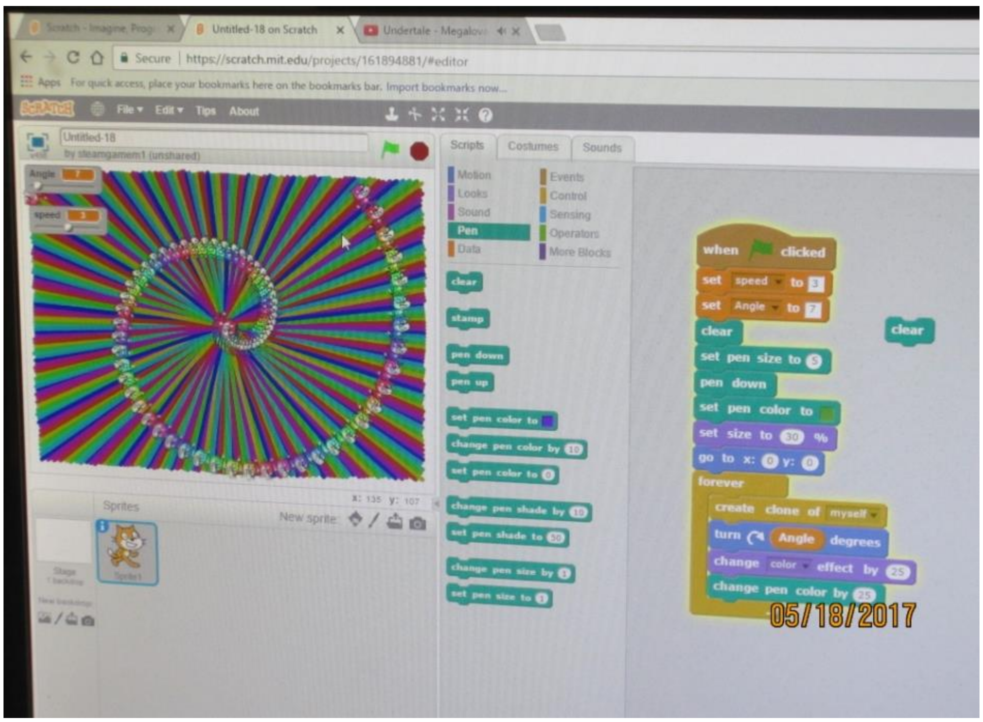



*Figure 36.* Students designed a multimedia work of art in Scratch at Non-Profit 2. Students used repetition of lines, colours and shapes to create a geometric spiral.

### 5.4.1.5 Mathematics Tasks

Every course at the non-profit research sites had a lesson, activity or particular concept that lended itself to mathematical thinking. For example, in the Non-Profit 1 students learned about budgeting, finances and money management. A student at Non-Profit 1 said “we could have used math like in [the] calculating” of the budget (Student 3). At both non-profit sites, students learned about algorithms, coordinate planes, functions, variables, geometry, spatial reasoning and other mathematical concepts when programming in Scratch or Minecraft. Students seemed to be enacting or bringing the mathematical concepts to life using digital animation in Scratch, video game platform in Minecraft and 3D imaging in Tinkercad. One student said "I learned about x- and y-coordinates, speed and axis" when programming the character in Scratch (Student 6, Non-Profit 2). Students learned about coordinate geometry and spatial reasoning as they moved the character in Scratch from one position, a specific coordinate, to another using transformations such as rotation, translations and reflections. For example, in an unplugged activity at Non-Profit 2 the students pretended to be a sprite in Scratch and the instructor verbally coded the student to move from one position on the coordinate plane to another as seen in Figure 37. In this unplugged activity, students appeared to enact and embody mathematical concepts such as coordinate geometry and transformations by adding and subtracting integers when moving up, down, forwards and backwards along the x- and y-axis. Student 2 at Non-Profit 1 described "all programming as having math" as they learned algorithms (e.g., step by step procedure), order of operation and conditional statements (e.g., if-then). Students also learned  how to represent geometric shapes, angles (i.e., set angle to 7), rotations, translations, scale factor (i.e., set size to 30%), variables (i.e. create a clone of "myself"), speed (i.e., set speed to 2) and distance using code to represent the mathematics and movement in the geometric spiral as seen in Figure 36 and 38. Students ages 9-12, in the *Introductory Coding* course, appeared to learn advanced level concepts, such as conditional statements in their multi-level program as they created the code as seen in Figure 38. I observed that students in the Inventioneering program have difficulty articulating what they had learned. When students were asked "what have you learned about Science, Technology, Engineering, Arts and Mathematics so far in the STEAM program?" Student 5 said "we could have used math [when] like calculating velocity, but we didn't" and he did not elaborate or give a specific example of when he did use mathematics (Non-Profit 1).


*Figure 37.* In an unplugged activity where the students at Non-Profit 2 learned about coordinate geometry and how to move their sprite from one position to another.

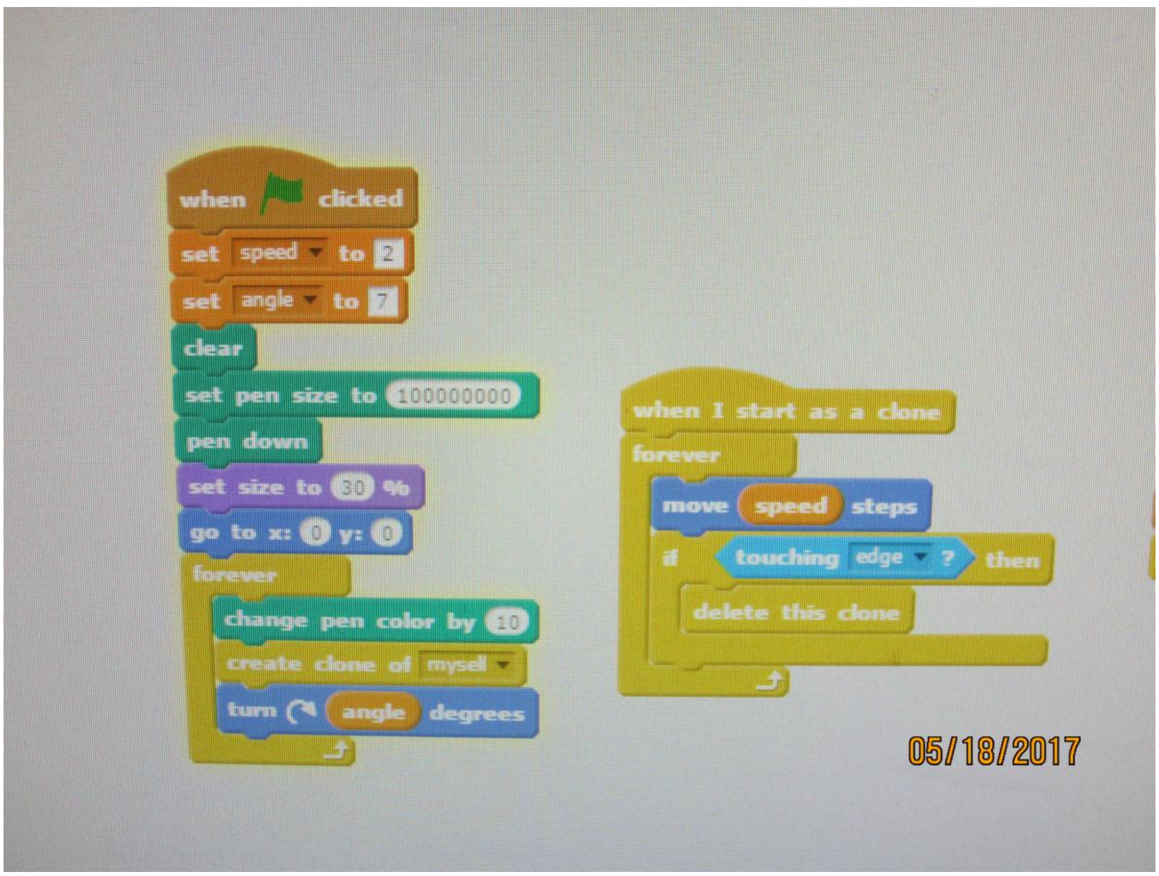



*Figure 38.* At Non-Profit 2, students learned to code a geometric spiral (see Figure 36) by setting a numerical value for the speed, angle and scale factor. Students also created a variable for the image that they desired to be cloned.

At Non-Profit 2, Student 4's favourite activity was the "3D printing of the house because it was like fun, you got to create your own thing" and "you could make anything you wanted in Tinkercad." Creating a 3D image in Tinkercad, the students learned about 2D and 3D geometric shapes, measurements, scale factor, rotations, translations and flips as shown in Figure 10 and 39. The students were able to see the image from different viewpoints as they rotated and flipped the image. The technology appeared to be an extension of the students' thoughts and actions, which allowed them to manipulate an image in Tinkercad to better understand abstract concepts such as viewpoint, scale factor, rotations and translations.

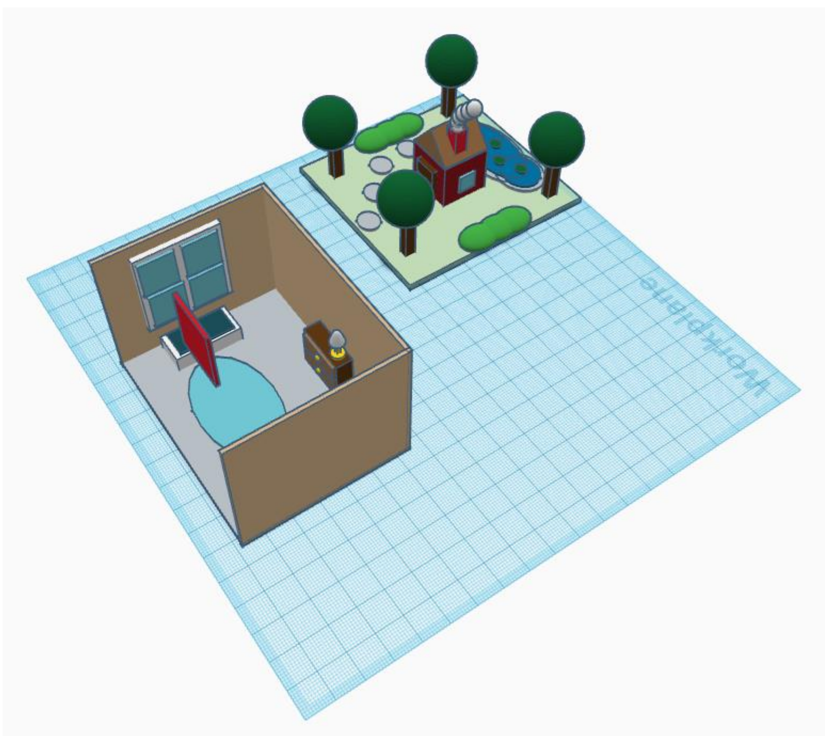


*Figure 39.* Student created this 3D image in Tinkercad, using 2D and 3D shapes at Non-Profit 2.

The text in Table 8 is from the curriculum lessons and units shared at the non-profit research sites and class/session overviews are quoted verbatim to exemplify what is in the documents and the STEAM content represented. The adult participants in this study referred to these as “Hard skills.” The curriculum documents include the Science, Technology, Engineering, Arts and Mathematics standards mentioned in the lessons/sessions in Table 8 and 9. However, the curriculum documents do not specifically section or label the standards based on the subject area.

*Table 8.* Academic Skills in the Curriculum Documents for Non-Profit Case 1 and 2

| Hard Skills | Non-Profit Case 1 | Non-Profit Case 2 |
|---|---|---|
| Science<br><br>Students use scientific thinking in the following classes/sessions | **Robotics Playground:** The robotics lesson starts with the basics by explaining LEDs and batteries. Gets everyone to grab LED and battery to try it. Explain the flow of electricity and the positive versus the negative legs of the LED.<br><br>**Imagineering/Inventioneering:** Simple circuits and mechanisms (wired remote controllers with motors, LEDs with coin cell batteries) to power their inventions or robot creations. | **Squishy Circuits and Little bits:** Students design and build fun gadgets with LittleBits to learn about circuits/electricity such as how to create a basic circuit with a battery, cable, a servo (controllable motor) and power source.<br><br>**STEAM Artists Ultimate Slime Makers (Kids 6-8):** Lots of goopy, gloppy, gushy new creative ways to learn experimental science through making slime.<br><br>**STEAM Makers Little Engineer (Kids 6-8):** Little Engineers will discover the fundamental concepts of energy, materials, and movement. |
| Technology | **Computer programming:** Terminology, Visual Programming Language [VPL, Blocks], Scratch, ComputerCraft Mod, Makecode Minecraft, Arduino, Python/ RaspberriPi, Particle photon (i.e., micro-controller with wi-fi).<br><br>**3D Modelling/3D Printing:** Tinkercad, Octo-print<br><br>**Robots:** Arduino Robotics<br><br>**Laser Cutting:** Inkscape, Adobe Illustrator<br><br>**Video:** Vine video, Twitter video posts, YouTube Screencast | **Computer programming:** Terminology, Visual Programming Language [VPL, Blocks], Scratch, Stencyl, Ozoblockly, Arduino, Mico:bits, Python/ RaspberriPi, Python games library, Unity game development platform, Javascript.<br><br>**3D Modelling/3D Printing:** Tinkercad<br><br>**Robots:** Ozobots, Spheros, Microbits, LEGO EV3<br><br>**Laser Cutting:** Tinkercad, Gravit.io<br><br>**Video:** Green screen and stop-motion, stop-motion studio app. |

| | | |
|---|---|---|
| | **Digital tools:** Minecraft, Tinkercad (export 3D model to Minecraft), MCEdit, Worldedit, Mod Instillation, Pixlr (digital drawing), MaKey MaKey as game controller. | **Digital tools:** Makey Makey, Skanect (3D Scanning), LittleBits.<br><br>**Creative Coders: Get in the Game** Using drag-and-drop block coding and green screen technology, become the hero of your very own game that you code and design. Digital literacy has never been so fun! |
| Engineering<br><br>Students use engineering thinking in the following classes/sessions | **Robotic Playgrounds:** Hands-on program that explores themes at the intersection of architecture, design and making. In this program, girls will learn about architecture and installation design to re-imagine, remix and recreate green spaces and concrete landscapes. Participants will choose a space they'd like to transform and learn how to prototype and build their installation using Arduino robotics, laser cutting, 3D printing and woodworking. | **STEAM Makers Laser Cutting (Kids 9-12):** Learn essential design and engineering skills to build your digital vocabulary and technology skills. Create, design, prototype, test, redesign, and repeat! |
| Art | **Textiles:** Programmable and wearable technology (e-textiles).<br><br>**Paper:** Design an innovation/ artwork using cardboard, hot glue, scroll saw, laser cutter, etc. For example, students will learn and create their 2D designs in Adobe Illustrator for laser cutting to make a paper lantern.<br><br>**3D Modelling/3D Printing:** Tinkercad<br><br>**Woodworking:** Scroll saw station and laser cutter are used to create a product using wood.<br><br>**Crafts/Loose Parts Bin:** Craft station is similar to Loose Parts Bin, which has a variety of craft materials that kids can create with.<br><br>**Animation Art:** Scratch. digitally draw a main character and villain using Pixlr. Then import the saved image to Scratch. | **Textiles:** Programmable and wearable technology (e-textiles).<br><br>**3D Modelling/3D Printing:** Tinkercad<br><br>**Animation Art:** Scratch and stop-motion videos.<br><br>**STEAM Makers Stop-Motion Animation (Kids 9-12):** Students will create the storyline, backgrounds and characters in their original stop-motion film.<br><br>**Crafts/Loose Parts Bin:** There is a comprehensive set of craft supplies: Washi tape, glue sticks, paper plates, masking tape, wooden sticks, markers glitter, stickers, craft paper and children are encouraged to expand upon numerous projects adding a level of craft and art to whatever they are working on. |

| | | |
|---|---|---|
| | | **STEAM Artists Printmaking (Kids 9-12):** Learn spatial reasoning, the fundamentals of drawing and elements of design.<br><br>**STEAM Artist Jewellery (Kids 9-12):** Students use the laser cutter to make pendants, earrings and more! |
| Mathematics<br><br><br>Students use mathematical thinking in the following classes/sessions | **Inventioneering:** Introduce the budget and rules about their budget. Each kid gets a budget sheet and, on this sheet, they must check off what materials needed and calculate the total cost.<br><br>**Minecraft:** Makecode Minecraft uses a visual programming similar to Scratch. Students learn about functions, variable, data structures and control structures in this programming environment using different mathematical operations.<br><br>**Imagineering:** Students will be introduced to logical and collaborative thinking, basic programming, and using Algorithms. For example, an unplugged activity called "Happy Maps" where students learn about algorithms, coding and programming using cut out game pieces, grid map and a character called a Flurb.<br><br>**Scratch Video Game Programming:** Students learn about if, then statements (conditionals) and creating variables in their video game. | **Creative Coding Intro to Coding with Scratch:** During the observation students learned about coordinate grids and how to move their sprite from one position to another.<br><br>**STEAM Makers 3D Printing (Kids 9-12):** Design and print your own 3D creations! Have fun expanding your design skills while learning the secrets of creating in 3D. Students learn about 2D and 3D geometric shapes. During the observations, students see images from different viewpoints as they rotate/flip it as shown in Figure 10 and 39.<br><br>**Arduino for Makers:** Arduino code is based on Javascript. Students learn how to create variables in their code. For example: int ledPin = 13*<br>*int means any integer specifically link to LED Pin 13 |

This section mentioned specific STEAM tasks and learning experiences that were observed at the non-profit sites. During the lessons at the non-profit sites, the instructors did not identify the specific curriculum standards that students were learning. When asked "What have you learned about Science, Technology, Engineering, Arts and Mathematics in the STEAM program?" the students seemed to have more difficulty identifying the specific academic skills that were learned compared to students at the in-school sites. At the non-profit sites, courses were categorized into two categories that depended on age and skill level: introductory and advanced level courses. The STEAM tasks were briefly described by the directors and instructors as rich and authentic because student learning was placed in a real-world context or the tasks were authentic.

### 5.4.2 In-School Case Studies

Compared to the non-profit cases, the students at the in-school research sites were able to identify the specific science, technology, engineering, arts and mathematics skills/concepts in the lessons in more detail. Both in-school cases developed lessons and units that included specific expectations from the Ontario curriculum for Grades 1-8 Science and Technology, Mathematics and Arts. Units were developed with a series of lessons at the In-School 1 research site. At the In-School 2 site, on the other hand, individual stand-alone lessons were created for one or more days, and each lesson was based on a children's literature book.

#### 5.4.2.1 Science Tasks

At the in-school research sites, I observed that the scientific concepts were taught more in-depth because they were connected to a specific expectation from the Ontario Science curriculum (2007), Grades 1-8. For example, the teacher librarian at the In-School 1 site designed a unit for the Grade 4 students on Simple Gear Systems. In the robotics unit, Grade 5 and 6 students "learned about pressure and weight, [specifically the] heavier [the] weight it will be harder for the opponent to push us [the LEGO EV3 robot] off" the challenge mat in the competition shared in the section on Pedagogy, Instruction and Environment and illustrated in Figure 13 (Student 1, In-School 1). Similarly, students at In-School 2 learned about circuitry when they created their robots made from Arduino and connecting wires on a breadboard.

At In-School 2, Grade 5 students were asked to answer the following question: How might we design a product that transforms energy from one form to another and serves a purpose or function in our daily lives? This question connected to students' prior knowledge of matter, energy, physical and chemical change. For example, when the students designed and created their own model of a rocket, they used “vinegar and baking soda to make a chemical reaction” (Student 2, In-School 2) as illustrated in section on Pedagogy, Instruction and Environment with Figure 15. When testing the rocket, students learned that you “have to put [a] paper towel in the [pop bottle] rocket so it [the energy] would be released gradually” and launch successfully (Student 3, In-School 2). At In-School 2, students made a solar-powered oven out of a pizza box, and they described how the food was heated “as the light hits the metal and bounces into the food” (Student 4, In-School 2). Each lesson and unit plan in Table 9 of STEAM tasks is aligned with the Ontario curriculum. The science tasks appeared to be designed to learn science in a real-world context in ways that were meaningful to the students. For example, the Rube Goldberg Machine —where students explored simple machines from the Grade 2 Science curriculum— used inclined planes, levers and pulleys from the Grade 2 Ontario Science curriculum (2007), as shown in Figure 40. Students learned about matter, energy, chemical reactions, reflection and absorption of light, and simple machines through the design process of plan-design-make-test-redesign and repeat. Thus, students were seen to apply that scientific knowledge to design and build the prototype.

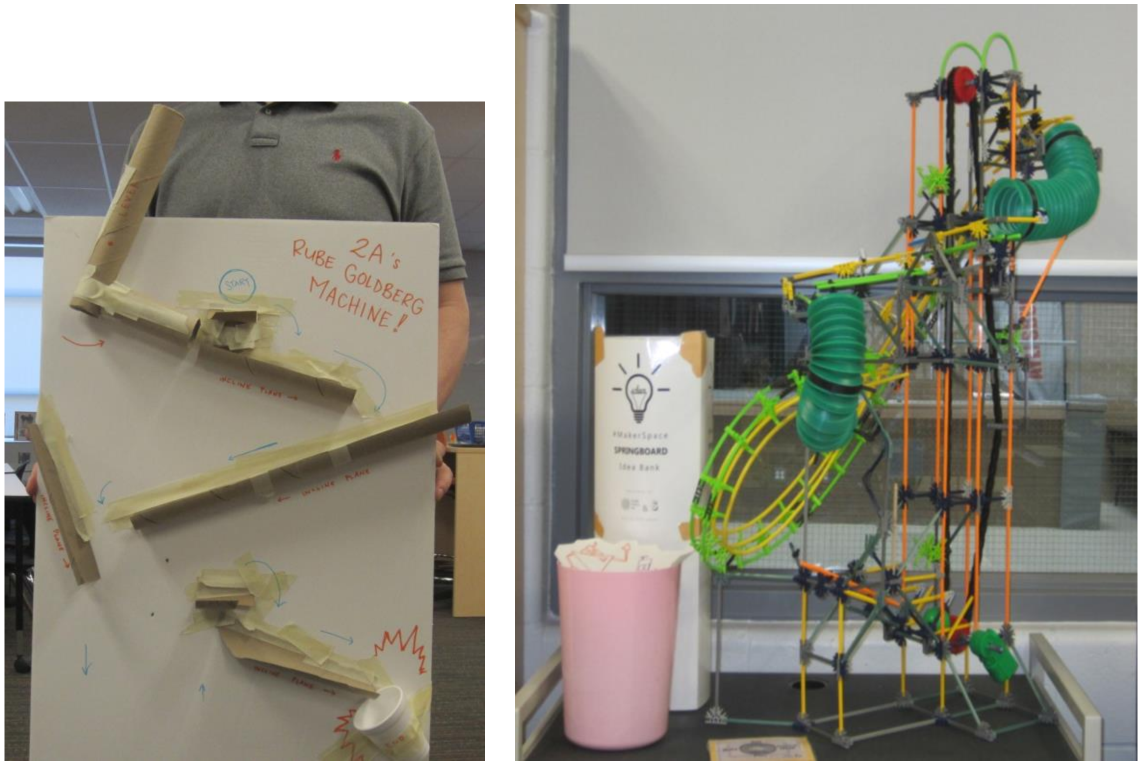



*Figure 40.* Students created a Rube Goldberg Machine together before creating their own machine at In-School 2. In small groups, students designed a more complex version made out of K'NEX.

#### 5.4.2.2 Technology Tasks

Both in-school cases used similar technology for computer programming, 3D modeling, robots, video and digital tools. At the in-school research sites, the primary and junior students learned to code using the Visual Programming Language (VPL) software, such as Scratch JR and Scratch. Students also learned to code robots with VPL, such as LEGO WeDo and Ozoblockly. The document analysis of the curriculum showed different levels of difficulty based on age. The intermediate students used text-based programming languages like Java Script and Python.

At In-School 1, students learned that "smaller gears make [the robot] go faster, if you want it to go fast [use] smaller gears or . . . slow [use], larger gears" (Student 6, In-School 1). They also learned through trial and error that the "code has to be precise and [you have to] use the right code blocks" (Student 5, In-School 1). Similarly, Grades 4 and 5 students at In-School 2 designed a music maker using the Micro:bit "making the code, learning something new that they had never done before and learning about a new technology" (Student 5, In-School 2). Students used computational thinking skills, such as programming (i.e., VPL), algorithms and debugging the code when they programmed the Micro:bit (British Columbia Ministry of Education, 2016, p.8). Further, Grades 6-8 students used the Arduino microcontroller to build a robot using connecting wires, breadboard, wheels, a motor, among other parts to assemble circuits as shown in Figure 41.

Students explored circuitry and electrical devices in an authentic context when they built this robot which they entered for a competition as a team at an offsite robotics competition in their district. In the competition, the robot was scored on aesthetics, precision and ability to complete robotic skills challenge (i.e., the track had a specific perimeter and multiple turns), and on the explanation of the design and making process. This task appeared to be an interdisciplinary project because students learned scientific (i.e., circuits, electricity), technology (i.e. Arduino microcontroller), engineering (i.e. plan, design, build prototype), arts (i.e., aesthetics) and mathematical (i.e., perimeter, distance, time, speed, measurement, direction, angles) concepts simultaneously as they designed, built, tested and redesigned their robot. Both in-school research sites used a variety of digital tools to make videos and stop-motion animation.

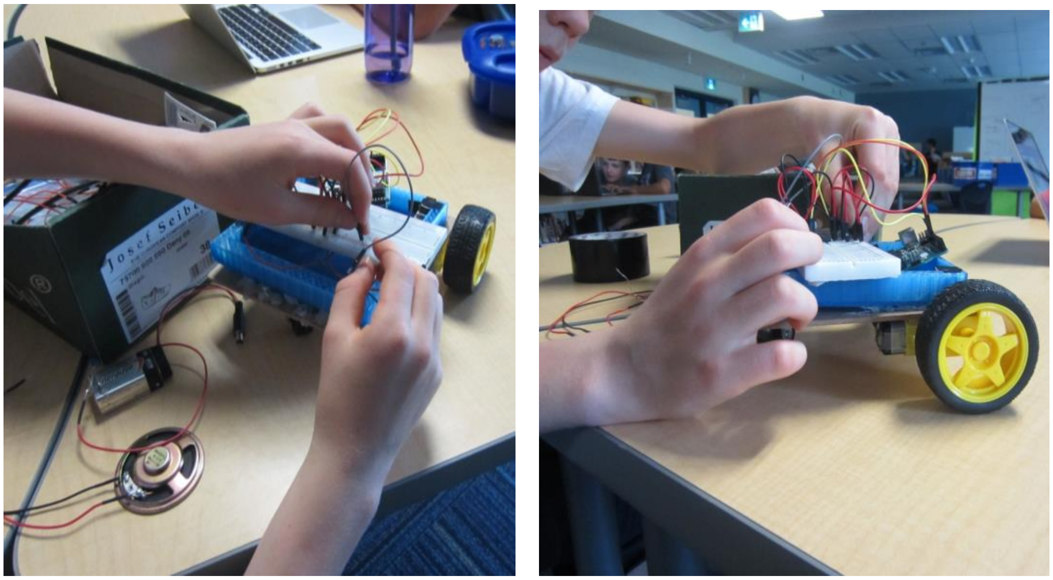


*Figure 41.* At In-School 2, students each designed, built, and programmed a robot using Arduino, breadboard, connector wires, wheels, motor and 3D-printed platform.

#### 5.4.2.3 Engineering Tasks

It was evident from the observations and curriculum documents that both in-school cases had seamlessly integrated engineering into each lesson and unit. Each site had adopted to use the design-inquiry process. For example, during the lesson of *The Little Boy who Lived Down the Drain*, students responded to the following question: How might you design and create a drain to help send a message down to the little boy? Students used more than one blueprint when they planned, designed, made a prototype, tested and redesigned their drain based on their reflections on what went well, what they would change and what they wish they could do differently as seen in Figure 42. The student in Figure 42 mentions “I would change it to have more materials and it to be more stable.” Students redesigned the drain and they had to evaluate their design solutions and determine how well they met the design problem’s criteria in the lesson. Similarly, students at In-School 2 learned the design process of plan-design-make-test-redesign and used “a little engineering to build it [the rocket] well with a good stand” (Student 3, In-School 2).

At In-School 1, students created a detailed plan for their challenge mat, which was a 2D irregular geometric shape as seen in Figure 43, and their robot had to go around the perimeter of this shape. Besides the design of the challenge mat, the Grade 6 students had to “think about the design of exterior [body], different LEGO parts used to do different tasks” and “actually [the] making [of] the robot, where to put the wheels,” etc. (Student 3, In-School 1).

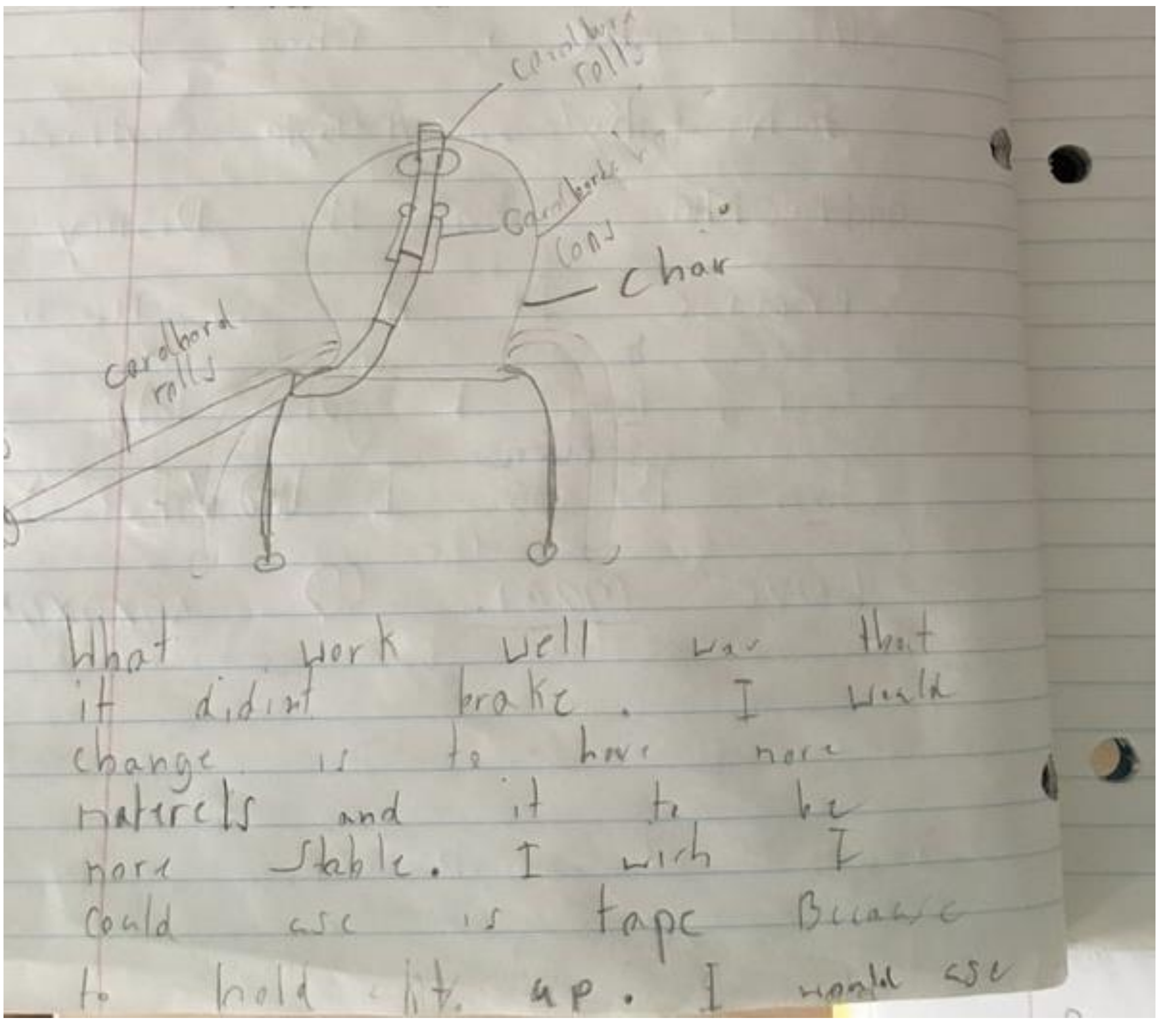



*Figure 42.* Students from In-School 2 reflected upon their initial prototype of the drain and how they might make the structure and design better.

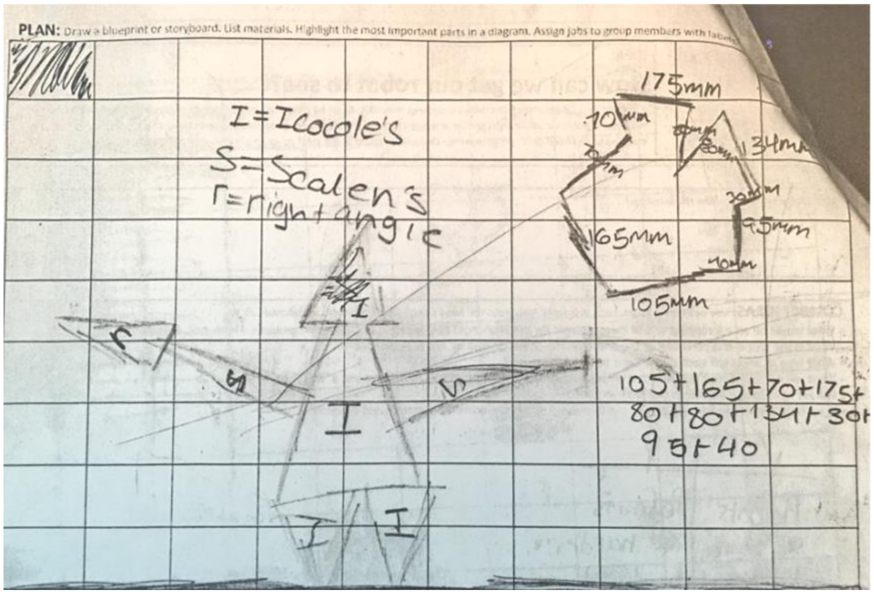



*Figure 43.* At In-School 1 the students created the initial sketch on the left of a 2D irregular shape. The students modified their design to a simpler shape on the right.

#### 5.4.2.4 Art Tasks

Similar to the engineering section, it was evident in the lesson plans that art had also been incorporated into the structure of every lesson and unit. At both in-school research sites, the students did activities that focused on art with unplugged activities such as hand knitting, crochet, sewing and origami. There were also art activities that used technology such as e-textiles, paper circuits, 3D modeling and animation. In-School 1 used “media art, green screen filming and animation” to bring their designs in Scratch and stop-motion to life in the STEAM program (Student 6, In-School 1). In-School 1 did not have a craft bin, but students used paper, electronic stickers and copper tape to explore from basic origami to more complicated designs with paper circuits that they referred to as inventions. Students were given a task to design an eco-friendly flip-flop made from paper, as shown in Figure 44. They had to draw from the techniques learned in previous lessons and apply that knowledge to make the origami flip-flop. Students had to think about art concepts such as aesthetics and symmetry, science concepts such as the environment and eco-friendly, and engineering design concepts such as comfort and practicality of the design.

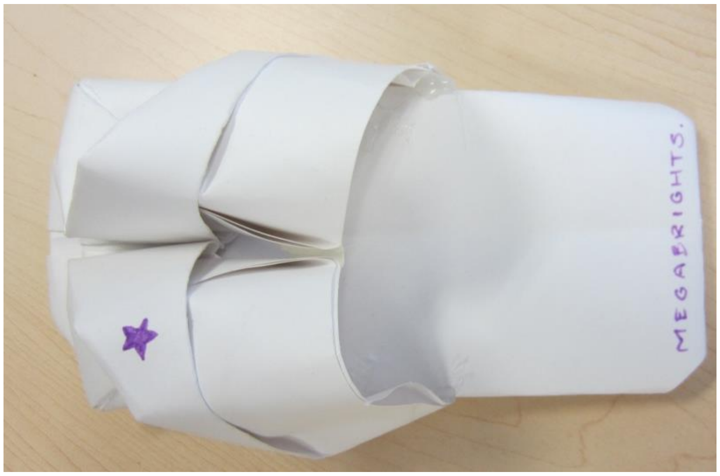


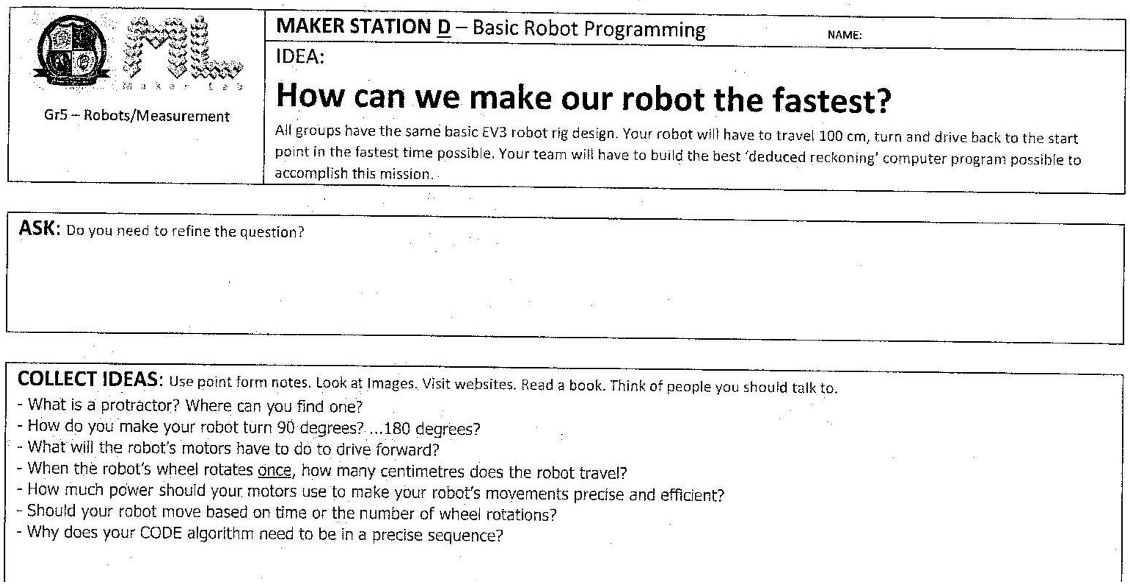

*Figure 44.* At In-School 1, students created and designed an eco-friendly flip-flop out of paper. To add to the aesthetics and design, students added copper tape and created a circuit to make the flip-flop light up as you walked.

A Grade 2 teacher at In-School 1 got her students to understand non-traditional forms of art during the lesson on Rube Goldberg machines. Students designed and built their own machine. The teacher explained “we had some interesting dynamics in regard to just how to create and when are we doing art? You are doing art, but they [the students] are like this [Rube Goldberg machine] isn’t pretty and this creates a connection does art need to be pretty? [To the students] art is very much a paintbrush, [and] crayons. And it’s like no, no it’s creating it doesn’t necessarily have to look beautiful” (Grade 2 teacher, In-School 1). I observed students at the two in-school STEAM programs create non-traditional art on a computer or an interactive sculpture using coding and computational thinking skills. A Grade 2 teacher at In-School 1 explained that there are different forms of art and the final product may not look beautiful or like a traditional piece of artwork. This Grade 2 teacher challenged her students to engage with and redefine what art is in a meaningful and authentic way that reflects Contemporary Art today, such as an interactive multimedia artwork as seen in Figure 36 and 38. At In-School 2, the teacher librarian used a craft bin to encourage students to be creative when telling a story. Students created a collage with mixed media with different colours, textures, layers, symbols, text and dimensions. They used both 2D and 3D shapes in their collage to add variety and depth.

#### 5.4.2.5 Mathematics Tasks

In contrast to the non-profit cases, the in-school sites included specific mathematics objectives. At In-School 2, specific mathematics objectives were clearly written in the Success Criteria, whereas In-School 1 embedded the mathematical concepts learned into the inquiry-type questions, as seen in Figure 45. The specific mathematical concepts mentioned in this section were from the Ontario Math curriculum (2005), as noted in the documents and during the interviews. The teacher librarian at In-School 1 said they got the students to ask and answer inquiry-type questions. They did this purposely to get the students to think about the problem critically, such as how do you make your robot turn 90 degrees? . . . 180 degrees? (see Figure 45). At In-School 1, Grade 5 and 6 students learned about “negative and positive numbers, [and how the] number effects the rotations, clockwise or counter-clockwise” (Student 2, in-school 1). These math tasks seemed to encourage students to conceptualize mathematical concepts, such as adding and subtracting integers, rotation of a specific degrees and direction of movement counter-clockwise (i.e., positive angles) and clockwise (i.e., negative angles), when designing and programming the LEGO EV3 robots. They also learned fact-based or procedural “mathematics when you had to divide, measure, measure rotations and have to add them up to figure out the path, figure out how many rotations by adding and multiplying” (Student 1, In-School 1) in which students used their math facts and skills to solve the problem. Student also needed “precise measurements and perimeter to program the robot” such as the length (i.e., 30 cm max), width (i.e., 30 cm max) and height (i.e., 30 cm max), weight of the robot (i.e., 1000 g max), diameter (i.e., 90 cm) and circumference (i.e., 282.74 cm) of the mat, the distance between the two robots (i.e., 10 cm apart) in the SUMO competition (Student 4, In-School 1) as seen in Figure 46. Students used mathematical facts, formulas (i.e., circumference) and these specific measurements stated in the SUMO competition guidelines to design and program their

LEGO EV3 robot to meet the requirements and compete in the SUMO event.



Gr5 – Robots/Measurement

**MAKER STATION D** – Basic Robot Programming NAME:

IDEA:

**How can we make our robot the fastest?**

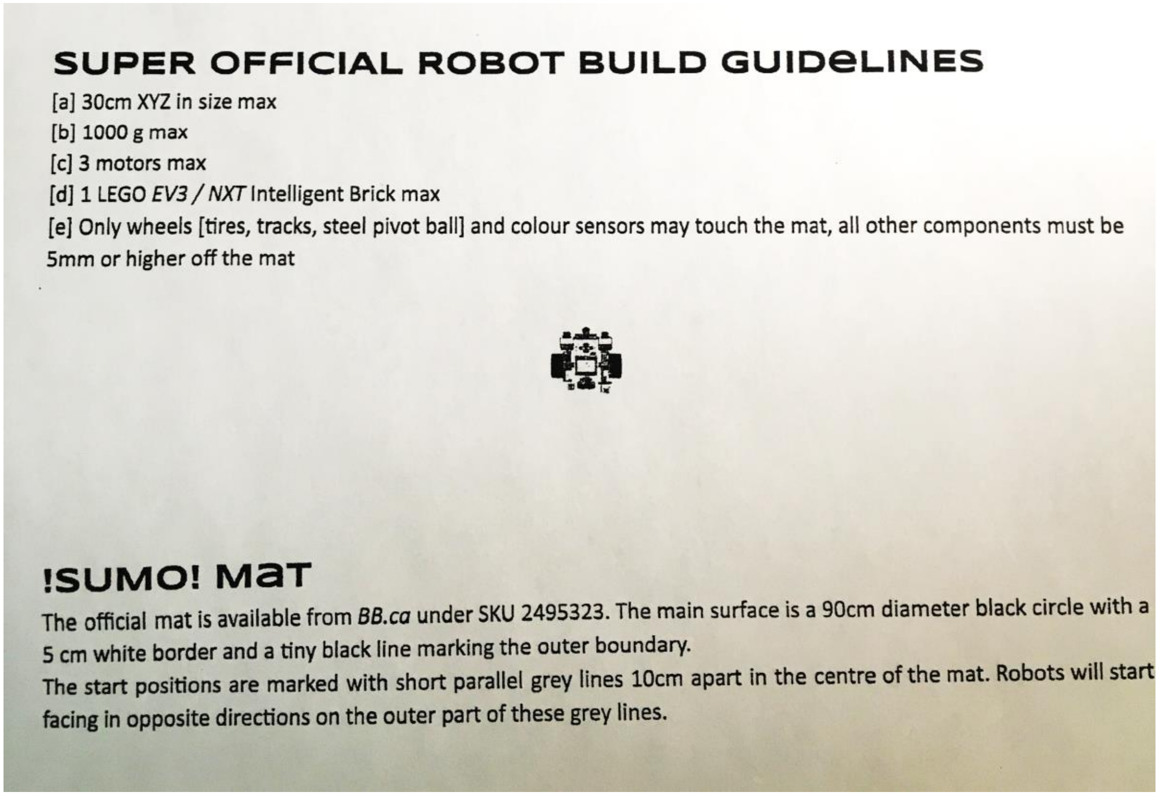
All groups have the same basic EV3 robot rig design. Your robot will have to travel 100 cm, turn and drive back to the start point in the fastest time possible. Your team will have to build the best 'deduced reckoning' computer program possible to accomplish this mission.

**ASK:** Do you need to refine the question?

**COLLECT IDEAS:** Use point form notes. Look at Images. Visit websites. Read a book. Think of people you should talk to.

- What is a protractor? Where can you find one?
- How do you make your robot turn 90 degrees? ...180 degrees?
- What will the robot's motors have to do to drive forward?
- When the robot's wheel rotates once, how many centimetres does the robot travel?
- How much power should your motors use to make your robot's movements precise and efficient?
- Should your robot move based on time or the number of wheel rotations?
- Why does your CODE algorithm need to be in a precise sequence?

*Figure 45.* At In-School 1, students were given a handout and were asked inquiry-type questions to think about angles, rotations and measurements to figure out how to make the LEGO EV3 robot go faster.



**SUPER OFFICIAL ROBOT BUILD GUIDeLINES**

[a] 30cm XYZ in size max
[b] 1000 g max
[c] 3 motors max
[d] 1 LEGO *EV3 / NXT* Intelligent Brick max
[e] Only wheels [tires, tracks, steel pivot ball] and colour sensors may touch the mat, all other components must be 5mm or higher off the mat

**!SUMO! MaT**

The official mat is available from *BB.ca* under SKU 2495323. The main surface is a 90cm diameter black circle with a 5 cm white border and a tiny black line marking the outer boundary.
The start positions are marked with short parallel grey lines 10cm apart in the centre of the mat. Robots will start facing in opposite directions on the outer part of these grey lines.

*Figure 46.* An excerpt from the official robot build and guidelines for the SUMO competition at In-School 1.

Similarly, students used procedural mathematics in the "measurements in millimeters to 3D print the base of the robot; measurement of the dimensions for the robot; and geometry, area, perimeter and x- and y- coordinates to program the robot" (Student 1, In-School 2) as seen in Figure 41. These math tasks seemed to have a real-world context as students used math skills in a meaningful way to design the base of the robot (i.e., measurement and volume) and program the robot to follow the path on the track at the robotics competition. Students used mathematics when "creating a robotic arm to measure someone's arm and the angles" for specific movements of the arm (Student 6, In-School 1).

Similarly, at In-School 1, the Grade 1 students used mathematics skills "to build a tower" and create "ab" and "abc" patterns in Minecraft. During my observation of this lesson, the students at In-School 1 appeared to learn about architecture and design while building their “ab” and “abc” pattern towers in Minecraft as seen in Figure 47. All the students I interviewed at this station said this was their favourite STEAM activity “because they got to choose patterns and shapes” and “building is fun” (Student 6, In-School 1). In these STEAM activities, the mathematics concepts and skills taught and applied, such as rotations, angles, coordinate geometry, circumference and volume, did not seem as daunting as math problems on a worksheet because the students appeared to be highly engaged in the activity and having fun.

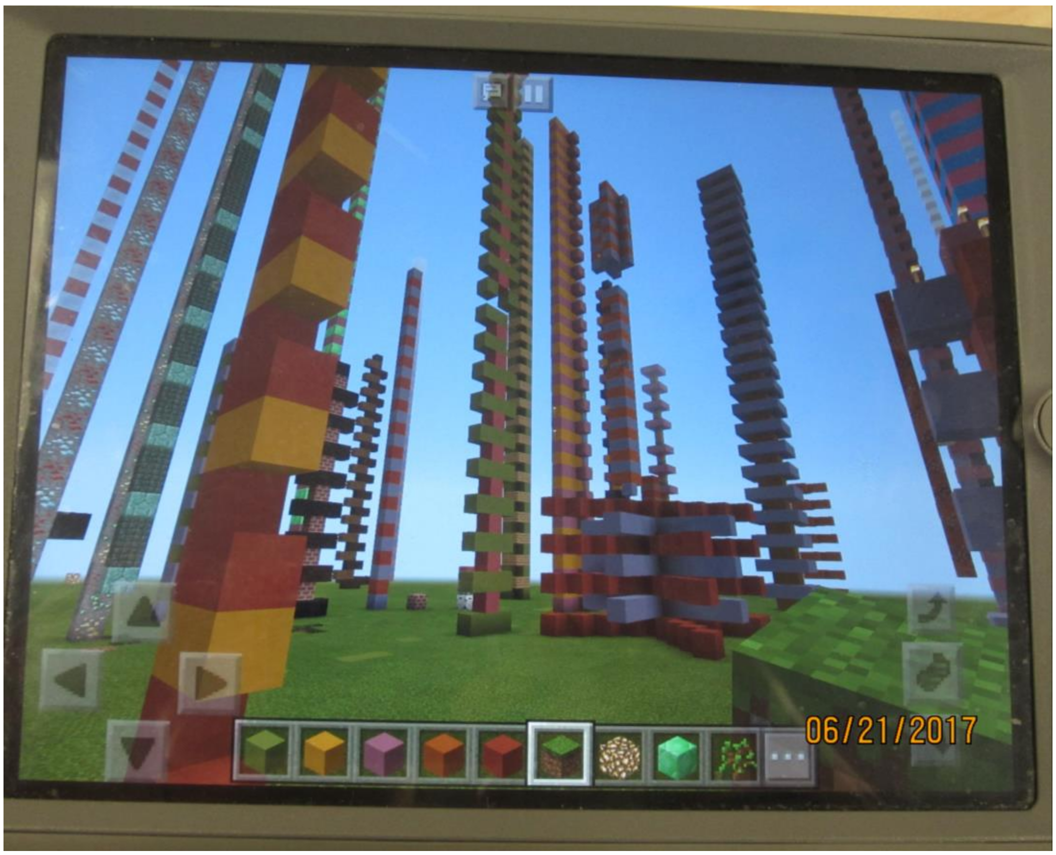



*Figure 47.* Grade 1 students created “ab” and “abc” patterns using different building blocks in Minecraft at In-School 1.

All the questions and bulleted points in Table 9 are from the curriculum lessons and units, and are quoted verbatim to exemplify what is in the documents and the STEAM content represented.

*Table 9.* Academic Skills in the Curriculum Documents for In-School Case 3 and 4

| Hard Skills | In-School Case 3 | In-School Case 4 |
|---|---|---|
| Science<br><br>Students use scientific thinking in the following lessons/units | **Grade 2 Rube Goldberg Machine:**<br>Explore and innovate with simple machines, using inclined planes, levers and pulleys to create a Rube Goldberg Machine.<br><br>**Grade 4 Simple Gears Systems**:<br>Investigate different types of gears used in a fishing rod. What is torque? Does it affect a gear's speed? Why does torque matter? Investigate complex gear system in a race car and build a basic model race car with a LEGO kit.<br><br>**Grade 6 Space and Electricity**:<br>Answer inquiry type questions: What does Mars surface look like? What is in the air? What is the temperature? What is the Mars environment like? How do you build a Mars capable robot? Students invent fun gadgets with LittleBits to learn about circuits/electricity and for entertainment purposes in space. | **Shark Lady:** Make some connections through research. Use the PebbleGo database to learn more about sharks (tool for educators with leveled text, read-aloud audio, easy navigation for younger students, videos, audio clips, printables and more. See http://www.capstonepub.com/library/ and click on PebbleGo tab). Use cue cards to write/draw three things they've learned.<br><br>**The Branch:** Students use the design-inquiry process to answer the following questions: How might you create a stable structure out of loose parts in order to withstand a storm? What materials might you need to use? How might you experiment to make it stable? How might you test it?<br><br>**Grade 5 Design-Inquiry Process:**<br>Students ask how we might design a product that transforms energy from one form to another and serves a purpose or function in our lives. Define what purpose or function their product will serve. Sketch a diagram, label the parts and list the materials. Design a prototype of your product and test it by conducting mini experiments. Get feedback from your peers and redesign it. |
| Technology | **Computer programming:**<br>Terminology, Visual Programming Language [VPL, Blocks], Scratch Jr./Scratch, Arduino, Micro:bits, CPX, Python/ RaspberriPi<br><br>**3D Modelling/3D Printing:**<br>Tinkercad<br><br>**Robots:** Code-A-Pillar, LEGO WeDo, Sphero, LEGO EV3. | **Computer programming:**<br>Terminology, Visual Programming Language [VPL, Blocks], Scratch Jr./Scratch, Arduino, Micro:bits.<br><br>**3D Modelling/3D Printing:** Tinkercad<br><br>**Robots:** Bee Bot, Ozobots, Sphero, Dash, LEGO EV3. |

| | | |
|---|---|---|
| | **Video:** Pre- and post-production, 3-part narrative, stop-motion filming, Chroma Key effects, computer animation.<br><br>**Digital tools:** LittleBits, Videolicious, Adobe Spark, Explain Everything, Google Education Suite, Minecraft, CoSpaces, iMovie, Adobe Flash, Aurasma, Podcasting. | **Video:** Green screen room and stop-motion filming.<br><br>**Digital tools:** iMovie, Pic Collage, Book Creator, Educreations, Google Docs with the Read & Write extension, app QuiverVision (3D Augmented Reality), app Skitch and Stikbot. |
| Engineering | In all of the following activities, students design a prototype. Create, design, prototype, test, redesign, and repeat.<br><br>Cardboard Challenge, Caine's Arcade, Rube Goldberg, LEGO Mechanics, LEGO EV3, Little Bits, Pneumatics. | In all of the following activities, students design a prototype. Create, design, prototype, test, redesign, and repeat.<br><br>**Design-Inquiry Process Lesson:** How might we design a product that transforms energy from one form to another and serves a purpose or function in our lives?<br><br>**Little Boy who Lived Down the Drain:** How might you design and create a drain to help send a message down to the little boy? |
| Art | **Textiles:** Hand knitting, Crochet, Sewing, e-textiles.<br><br>**Paper:** Origami (basic, kinetic, tessellation and modular), paper circuits such as Chibitronics, Kirigami.<br><br>**3D Modelling/3D Printing:** Tinkercad<br><br>**Animation Art:** Scratch and stop-motion videos | **Textiles:** Hand knitting, Crochet, Sewing, e-textiles.<br><br>**Paper:** Origami, paper circuits such as Chibitronics.<br><br>**3D Modelling/3D Printing:** Tinkercad<br><br>**Animation Art:** Scratch and stop-motion videos<br><br>**Crafts/Loose Parts Bin:** Students use items in bin to tell a story or create a character or invention. |
| Mathematics | **Grade 2 Rube Goldberg Machine:** Students will estimate, measure, and record lengths of materials in this project. Before building students will use a ruler and building materials to predict | **Shark Lady:** How might you create a shark out of pattern blocks? What geometric shapes have you used?<br><br>**Little Boy who Lived Down the Drain:** How might you design and |

| | | |
|---|---|---|
| Students use mathematical thinking in the following lessons/units | the dimensions of their Rube Goldberg Machine.<br><br>**Grade 5 Robots/Measurement:** What kind of geometric or organic shapes are the strongest? How can we make our robot travel 50 centimeters? When a robot rotates once, how many centimeters does the robot travel? How do you make your robot turn 90 degrees? . . . 180 degrees? How can your robot travel around the perimeter of a rectangle or a pentagon? What is the perimeter of the shape of your challenge mat? What angles will each of the turns be?<br><br>**Grade 6 Space and Electricity**: What is 3D modelling? Students will use 3D geometric shapes to design a food related product to be used in space (e.g. product to preserve or warm up the food). How do you stay entertained on those long space flights? How do they use electricity? Can you invent two fun gadgets that use basically the same LittleBits? Is the idea for your invention going to be too big? Is size a concern on a spaceship? Students must consider the size and dimensions of their gadgets. | create a drain to help send a message down to the little boy? How might students incorporate a right angle, an angle less and/or greater in their design?<br><br>**Milo and Georgie:** How might we get Georgie home and describe her path?<br>• Students: Describe movement from one location to another using a grid map<br>• Estimate, measure, and record the perimeter of 2D shapes, through investigation using standard units<br><br>**Math is mpowerful:** How might we recreate a big enough fence for Cow to graze? And build it so that he/she won't get stuck? How might we create a fence with a perimeter of _____? What math might we need to practice and use? |

### 5.4.3 Summary of STEAM Tasks and Learning Experiences for All Sites

All four research sites described these STEAM tasks as being rich and authentic tasks. The students shared their thinking about the making process and how that fits into a social and real-world context.

Students had fun learning how things worked together whether it was Science, Technology, Engineering and Math. Students were excited and engaged in the activities because it interested them. For example, Student 1 thought the "laser cutting was very impressive how it works" and Student 2 said "it was cool programming the lights on the neopixels" strip (Non-Profit 1). Specifically, STEAM is "a great way to engage people [kids] and learn new technologies" (Grade 5 Teacher, In-school 1). The special education teacher also said, "I find that they're naturally engaged [and] intrinsically motivated" (In-School 2). In the STEAM tasks, the curriculum documents, student interviews and observations showed me that students were transferring their knowledge across multiple disciplines. For example, the origami flip-flop used art concepts such as aesthetics, mathematical concepts such as symmetry, scientific concepts such as electricity and circuitry, and engineering design concepts such as comfort and practicality of the design. Besides the transdisciplinary approach to STEAM students also created non-traditional forms of art, such a multimedia work of art or an interactive sculpture. Students were transcending the traditional boundaries of individual disciplines at the non-profit and in-school sites.

### 5.4.4 Classroom Teachers' Views on STEAM Tasks and Learning Experiences

The focus group participants talked about the benefits and the challenges of integrated curriculum with Science, Technology, Engineering, Arts and Mathematics. Teacher B recognized that:

> Time is always a challenge and meeting all of the curriculum needs. And the struggle I have as a librarian is trying to bring teachers in to do some STEAM is that they don't always see that they are meeting curriculum expectations in all the strands. In all the areas, even language . . . so if we can unpack that for people [teachers] more, they might view a big STEAM project . . . that they have hit language, math, science, all sorts of curriculum expectations for the report card. I really find that . . . [teachers are like] I don't have time to spend two days on this project. So, I guess trying to find ways to encourage people to see all those curriculum connections that they make.

Teacher D discussed the importance of an integrative curriculum in STEAM education:

> I like to look at the whole picture when I'm doing, when I'm planning a STEAM activity. So, what's the art aspect and what's the mathematical piece because sometimes you can just jump into the technology piece. So, I like to consider you know what's the mathematical application of this piece of technology and how can

> I make it look prettier [which is the] art's elements, right? Because people who are building stuff for around the world for our environment design, that piece is an important matter . . . You always have the artists, the engineers, the scientists, the mathematicians, so it makes a nice group, really balanced so they all are sort of contributing.

Focus group participants were asked "In what ways could some of the STEAM stages presented be used to meet curriculum and teaching goals in a school classroom?" Teacher A, who is an instructional coach at four schools in the district, described how an integrative curriculum and STEAM education would influence how he taught mathematics:

> I think when I go back to the classroom I've now changed my math program from operating this idea of I'm doing my addition unit, I'm doing my subtraction unit, I'm doing my measurement unit, and I've looked at that we are doing all the math at once and we are just trying to build their level in mathematics. And I think with even the coding [lesson] today with Scratch racing game where we ran into variables, we ran into if-then arguments . . . we used the Cartesian plane. One kid had their car facing the wrong direction and had to figure out on their own that they had to put in a negative two [instead]. To make their car move in that direction, rather than this direction so we're into integers and they're learning all these things and having discussions about all these things. So not in isolation and that's where I think when I finally get back to my own classroom where having a makerspace, having a STEAM classroom to allow your students to cover the curriculum in a jumbled [interconnected] way.

Similarly, Teacher D reflected upon the interconnected nature of STEAM:

> I also think all the processes in math . . . you know the problem solving, the reflecting and the planning piece . . . it's been embedded into the mathematical thinking and processes that you do as well. It also ties into your science, it's an easy fit into your science and then the technology piece, the technology piece it's just a tool.

The classroom teachers in the focus group talked about the individual standards in STEAM (Science, Technology, Engineering, Arts and Mathematics) as well as STEAM's interconnectedness. They discussed the difficulty in getting other teachers to participate in STEAM activities and understand how one STEAM activity can incorporate so many curriculum standards from different subject areas. They also discussed the interdisciplinary nature of STEAM and how this has influenced their teaching practices. As evinced in the teacher interviews, one of the main goals of each STEAM program was authenticity. For example, students celebrated what they had created by sharing their product with an authentic audience, such as other students, parents, their community and globally. The Grade 2 teacher at the In-School 2 described authenticity as “these rich tasks that we are being encouraged to do and you know that connects to the overall experiences or draw on a theme to the lessons they naturally come with Science, Technology, Art, Engineering, Math. All those things naturally come out if you give them time.” Similarly, a Grade 5 teacher discussed how STEAM education can be a rich and authentic experience for students because “kids can use things [skills] that are valuable and realistic for them” (In-School 1). Teacher D from the focus group expressed a similar sentiment “Whether it’s regards to sustainability or you know just compassion in the world, solving some of these food and hunger issues, water resources issues and I think that preparing our students to connect with their learning is a viable skill that they can take with them in the future. You know where there are so many different [STEM/STEAM] entry level projects and contests where students are really creating things that are being used in our community and are being used to solve real-world problems.”

## 5.5 Theme 5: Assessment, Documentation and Sharing their Learning Experiences with a Wider Community

In this section, I look at assessment, pedagogical documentation, and sharing. Specifically, how the instructors, teachers and directors, took these aspects of teaching as a way for teachers to reflect upon the learning process and share their findings with other teachers, their school and the wider community.

### 5.5.1 Assessment

The main reason for assessment is to provide students with feedback and improve their learning experience.

#### 5.5.1.1 Non-Profit Case Studies

During an informal conversation with the director at Non-Profit 1, the director mentioned that the instructors conducted an informal assessment with their students to assess their knowledge before they started and evaluated their success by how well they communicated their understanding at the end of the course. Non-Profit 1's assessment was based on observations, questions and conversations with the students. All the information collected from the assessment data at this site was recorded in a shared document on a cloud drive. Similarly, during an informal conversation the teacher librarian at In-School 1 mentioned that he made anecdotal notes from the observations, conversations, pictures, videos, presentations and the final product that were organized based on the specific curriculum standards and recorded in a shared document on a cloud drive.

#### 5.5.1.2 In-School Case Studies

A Grade 2 teacher at In-School 1 explained her views on the curriculum and assessment "I'm not stuck on procedures and rules so you give me a curriculum . . . I can see where we can play with this, and it's the being okay to say you know what, 'I didn't check that box off, but we got a really rich experience checking off A, B, C.'" A special education teacher at In-School 2 describes how she assesses her students during a STEAM activity:

> I would be making notes and observations based on the photos that I took . . . [and] the videos I took . . . this would be an example of how I would assess . . . like here be able to see them understand that this is a meter it stops here and then it start there, like that would be an example of how I would take this to assess. I embed the assessment into it so I see it as a product right, product and observation. I use digital portfolios to document their learning so I'm able to capture their comments and their demonstration of things so I don't find it [assessment] that hard at all actually.

A Grade 2 teacher at In-School 2 described her challenges with assessing STEAM activities as "having to take such a rich experience that I've had this year and document it into such a dry, formal . . . [and] restrictive report card . . . is really challenging. So that was my biggest challenge, [and] has always been …. my biggest challenge is assessment." Each instructor/teacher approached assessment differently based on their pedagogies, instructional practices and learning environment whether the site was non-profit or in-school.

There were several examples of how the teacher or teacher librarian at the in-school sites assessed students' communication skills and what they learned. For example, in the Rube Goldberg unit (as mentioned in Table 9, Science section) "students create a short video to document their plan and Rube Goldberg machine working. They begin the film with the cue cards for assessment purposes [as seen in Figure 48 and 49]. The teacher will collect the videos via AirDrop or Lightning Cable" (Curriculum Documents, In-School 1).

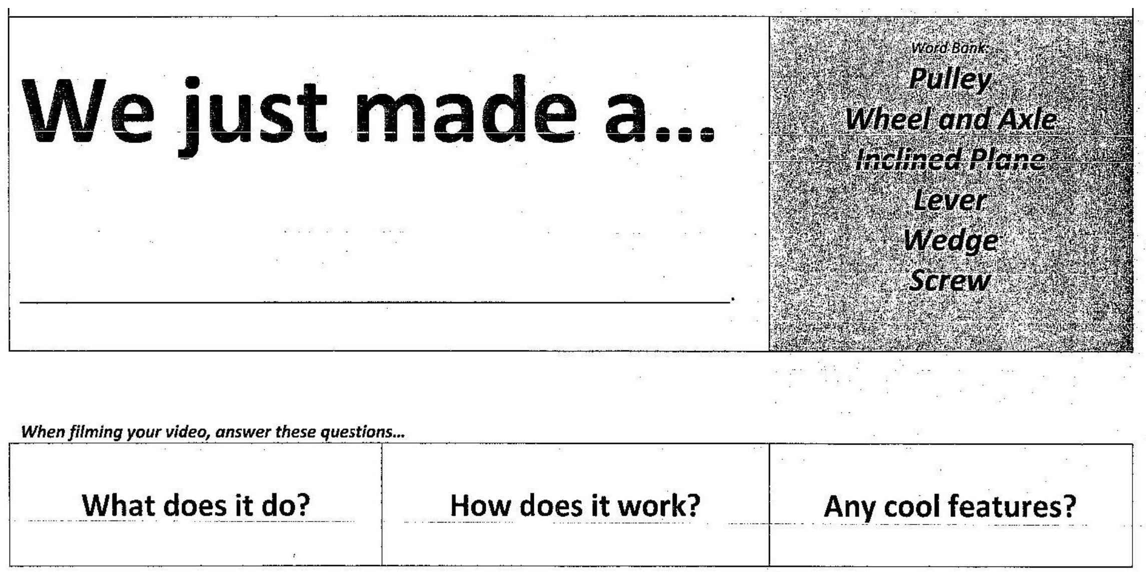



*Figure 48.* At In-School 1, teachers used this cue card to prompt students to talk about what the simple machine does, how it works and any cool features. Students created a video as they built and collected ideas in Stage 2 of a lesson (Table 5).

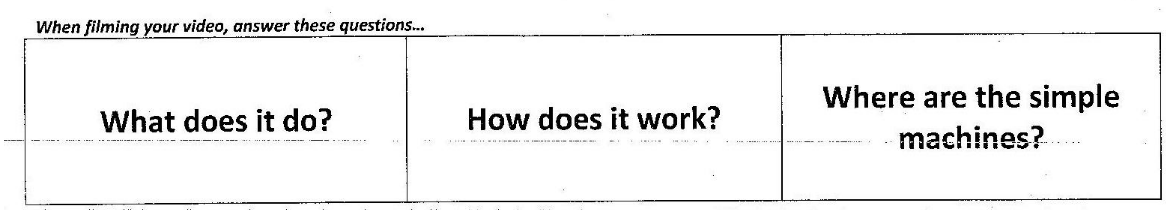



*Figure 49.* At In-School 1, teachers used this cue card to prompt students to talk about the "making process" of their Rube Goldberg Machine in Stage 4 of a lesson (Table 5).

The teacher librarian at In-School 2 assessed the lesson by documenting student learning based on the success criteria, as seen in Figure 50 and Appendix O. These were specific items that the teacher librarian was looking for as the students planned the structure of the fencing, measured the fence, calculated the perimeter and documented the learning process.

*Plan*

Based on the mPower reports we will create groups based on the current needs of our students.

After students are placed into groups, we will co-construct our success criteria for documentation and reflection. It is hoped that together we can come up with a list of success criteria similar to the following:

- I can document and explain some of my successes, strategies and difficulties calculating perimeter using mPower
- I can document my plan and how it may have changed
- **I can document the measurements of the fence**
- **I can document our calculations of the perimeter**
- **I can document our most important learning skill**

*Figure 50.* Teacher librarian and students co-construct the success criteria that will be used for documentation and assessment purposes.

The examples of assessment and documentation, as seen in Figure 48-50, demonstrated how the teacher or teacher librarian might approach assessment and documentation of student learning, character-building skills and academic skills of the STEAM tasks. The assessment and documentation appeared to be embedded throughout the lesson rather than at the end (as seen in Appendix O). In the following section, I will discuss the pedagogical documentation at the non-profit and in-school sites.

### 5.5.2 Pedagogical Documentation

Pedagogical documentation is a reflective process which allows the teachers to reflect on their own teaching practices and the students' overall learning experience.

### 5.5.2.1 Non-Profit Case Studies

During an informal conversation with the director at Non-Profit 1, he mentioned that his staff met four times per year to reflect upon student learning: what worked well, what did not work and what could be done differently for each course. Non-Profit 2 did not mention or discuss a specific process that they have in place for reflection on the courses offered or on student learning. Although the instructors at the non-profit sites appeared to use pedagogical documentation in their teaching practices, one educator (the teacher librarian at In-School 2) spoke about her understanding, use and valuing of pedagogical documentation.

### 5.5.2.2 In-School Case Studies

The teacher librarian at In-School 2 used the term pedagogical documentation to describe how she documented and assessed her students and spoke at length about what it is, what it entails and its value:

> I am documenting some of the learning . . . what's happening here, what does this mean about this child's growth, where can we take this next, how best are we to direct this child's learning in this direction?

Pedagogical documentation looks at "what worked, what didn't and how to move forward . . . that whole reflective process . . . is really important to know where should we go next" (Teacher librarian, In-School 2). The teacher librarian describes pedagogical documentation as a process to observe the students and understand the learning process and differentiate the learning experience for the students based on their individual needs. The teacher librarian at In-School 2 explains her interest in this area:

> And with my work on pedagogical documentation . . . it's really interesting how I'm learning to listen with all my senses . . . it really opened up my eyes as to how to listen carefully, how to observe, [and] how to reflect.

The teacher librarian continued to explain her thought process on pedagogical documentation and why documentation is so important in supporting the students' learning:

> I think it's, it's an attempt that we are trying to make it open-ended, we're trying to have it to be self-directed learning, really listening to the students to . . . [their] voice, and how we're documenting the learning. I always got my iPad around

documenting and taking videos and how do I share that, that's something we started this year, but I think we really need to discuss as a Staff, so if I am documenting some of the learning and I am taking videos how am I sharing that with you so we can reflect on it later and say what's happening here, what does this mean about this child's growth, where can we take this next, how best are we to direct this child's learning in this direction?

The teacher librarian added that she reflected after each lesson and pondered:

> I'm wondering how successful were we really, but looking back, even looking back at some of the documentation that I took, there is learning going on there, the kids were building, they were creating, they were talking to each other, they were talking about what worked, what didn't and how to move forward . . . that whole reflective process after you document the learning, it is really important to know where should we go next?

The teacher librarian explained that pedagogical documentation can allow the teacher to answer questions focused on the students' overall learning experience:

> What do I think the students are learning? How can we get students to document their own learning? How can we deepen or extend the learning process? (Curriculum Documents, In-School 2).

The educators at In-School 1 did not speak at length about pedagogical documentation. At the In-School 1, the teacher librarian met monthly with the school Maker Education team, comprised of the teacher librarian and maker education teachers assigned to a specific grade level, to plan STEAM tasks based on students' grade and experience level.

### 5.5.3 Sharing their Learning Experiences with a Wider Community

In my findings, the sharing of the student and teacher learning experience in STEAM varied from site to site from building community partnerships at the non-profit sites to sharing the learning experiences in STEAM both locally and globally at the in-school sites.

#### 5.5.3.1 Non-Profit Case Studies

The instructors and directors at the non-profit sites mentioned that the intention of sharing students' learning experiences was to develop and expand their STEAM program and build community partnerships.

At Non-Profit 1, they communicated the students' learning experience with others through several community partnerships, such as collaborations with the Science Museum and hosting a station at the annual Maker Festival. The director at Non-Profit 1 said that "incredible results from it [the collaboration] they're really looking to us to bring our culture and our pedagogy into the rest of their museum . . . to make their place more open-ended and experimental."

At the non-profit organization, collaboration was an important factor when creating community partnerships around the STEAM program. An instructor at Non-Profit 2 said:

> Perhaps the closest and tightest collaboration has been with the innovations team and we have had a series of Saturday sessions that turned into some sort of innovation [and] investigation sessions. And we designed this free session for teachers in the [geographical] area to do some STEAM programming, but it became this tight knit group that came each time and we more or less worked as a team . . . We discussed how it might work best in the class and what else we might do. It was [an] excellent … collaboration.

At Non-Profit 2, the STEAM lab/centre spoke about their continuing partnership with either one of the local school board and with the community in which it resides.

#### 5.5.3.2 In-School Case Studies

At the in-school sites, both teacher librarians shared the learning process with the wider community through their school websites and twitter accounts. They shared personal observations, pictures, videos, and blog posts and social media stories on Twitter. The teacher librarian discussed the benefits of collaboration: "So, it's like bringing more experiences, bringing more expertise to the table" (In-School 1). At the in-school sites, the teachers spoke about team-teaching, as well as documenting and assessing the "making process" with other teachers. In the curriculum documents, documentation and sharing the learning experience was noted in the question: "How might we document, share, reflect and connect with our learning communities in order to drive thinking forward?" (Curriculum documents, In-School 2).

The teacher librarian at In-School 2 explained why sharing the learning experiences of the students with another teacher can be beneficial:

> It's a different perspective because it's having an extra body in the classroom, but it's also having a different perspective because what they see maybe something that I totally missed. We may have different relationships with the students and it's the whole triangulation of data, you always want a different person or a different lens to help validate what you're seeing, so it's because you see something through a totally different way that another people will see it.

The In-School 2 teacher librarian reflected on how she could share the learning experience with a wider community.

> How do we take that learning that has happened in the Library Learning Commons and apply it to the curriculum and get the teachers to, to do this, how do we build capacity? How do we build partnerships, you know if we build partnerships between the teachers, the students are going to see that too, that's good modeling for them?

Similarly, the teacher librarian at In-School 1 expressed his thoughts on building teacher capacity in the school:

> Build capacity on their [the teachers'] end to embrace this kind of mindset of changing the way they approach subjects and learning, I think is important. And getting, giving them the ability to see kids producing [a product] in an unconventional manner in their opinion because then [the] hope is that going forward they'll give more options for kids to express their ideas which is important . . . it puts perspective into your practice and it might enlighten their practice too and in ways of dealing with people . . . So, in collaborating you open up their [the teachers'] minds and but maybe too, you share an insight between each other as to best practices and hopefully change things for the better going forward.

The In-School 2 teacher librarian elaborated on how educators share their learning experiences with a wider community:

> You know if we are sharing the documentation we have with each other, but where's the next step, where do we take that? It shouldn't just end there, we should be sharing it with the staff or sharing it with the other Grade 5 teachers, saying you know this type of approach with these kids, how we can make this a school-wide process or even sharing it outside in the community.

The teacher librarian at In-School 2 explained the connections she saw among pedagogical documentation, collaboration and capacity building, as well as sharing with a wider community. The reflection piece seemed to connect these elements because educators could reflect individually and collaboratively on student learning while engaging students in a shared learning experience and then sharing the knowledge gained from that experience with a wider community. For example, the teacher librarian at In-School 1 provided students with the opportunity to share their product with the community in a "STEAM Inspired Carnival where the class host[ed] visitors in a unique science fair to broadcast their creations" in Stage 4 of the lesson (Curriculum Documents, Rube Goldberg, In-School 1). Both teachers and students at the in-school sites had the opportunity to share the learning experience with the wider community.

### 5.5.4 Classroom Teachers' Views on Sharing Learning Experiences with a Wider Community

The focus group participants discussed how sharing their learning experiences within the school and community was a greater challenge. Teacher D responded to another teacher's comment about this challenge:

> I think you're right when you say everybody here is like sitting in the room with people who have been doing this for years and I still feel like a novice. And I think it's because it's an isolating world, so with technology at times [you can connect with others with] this kind of thinking . . . at the elementary level. Sometimes there are one or two people in a building, but sometimes . . . you have to go outside to meet like-minded people and sort of gather ideas and things like that.

Teacher B mentioned some benefits of sharing the learning experience and partnering with other teachers:

> I guess as a teacher librarian, teacher collaboration is really important. I have some teachers that are great at partnering and you know like student feedback they give me feedback and I give [them] feedback. And when we partner our lessons are amazing, right because I don't always know the class as well as the teacher does or

> even that grade level . . . So, it really starts to take on a whole new look with your STEAM projects when you have two people. Again, it doesn't have to be librarian – teacher [partnering], but it's just that collaboration part on the teacher's side of things, right.

Teacher B reflected on how she could share the learning experience with a wider community by bringing experts and guest speakers to the school:

> Getting out there to the community and talking to experts or talking to other people who are actually in industry like that and that's one of the things that we have to do for the robotics team . . . A couple of kids have mentioned game development and I'm doing CoSpaces 3D with the Grades 7's and 8's. I have …[invited] a professor from Fanshawe coming to talk to the team, but I thought I better include the 7's and 8's because they're designing this too. So just trying to find more of those connections I think is something that I would like to do more of for the whole school. As a teacher librarian I do have that kind of ability to try and get some guest speakers in the specific areas and interests that you know engage the kids more in our world. Because often they feel like they're isolated in the school and they are not having an impact . . .  on the world and these [world] issues.

Teacher B was reaching out to the community and bringing in experts and guest speakers to be a part of the students' learning experience. Teacher D had registered her students for "entry level projects and contests were students are really creating things that are being used in our community and are being used to solve real-world problems." These examples show how classroom teachers can share the learning experience with a wider community. The teachers in the focus group have, in their pedagogies and teaching practices, taken a similar approach to the teacher librarians at the in-school sites. For example, the focus group participants have also used Twitter and social media to share their students' learning experiences and gather ideas from others in STEAM education.

Some teachers struggled to assess STEAM activities and incorporate assessment of rich learning experiences on a formal report card. At each research site, instructors/teachers collected anecdotal "notes and observations based on the [conversations], photos [and] the videos" of the process/product that captured the student's learning.  The curriculum models included "a lot of self-reflection and there's a lot of looking at different ways [methods], different models and different procedures [that] could have been done"

(Teacher D, Focus Group). The in-school sites used this as an opportunity to share ideas with other educators and researchers beyond their own school.

To expand the learning experience beyond the physical STEAM lab/centre, the non-profit sites wanted to build community partnerships with school boards, industries and non-profit organizations. The focus group teachers shared additional ways of expanding students' STEAM learning experience, including bringing in experts and guest speakers, and registering their students for entry level contests and projects. No matter the method or the reason for sharing the learning experience with a wider community, the sharing appeared to provide students with a more authentic experience which "engage[d] the kids more in our [their] world" (Teacher B, Focus Group).

# Chapter 6

# 6 Discussion

Within the context of STEAM education, I discuss how teachers facilitated a creative learning environment, what skills were taught, what experience learners were offered, and how learners were engaged beyond their individual learning —such as with a wider community. The discussion in the following sections is organized according to the four research questions posed in Chapter 4: 1) What curriculum and instruction models of STEAM education are implemented in non-profit and in-school contexts in Ontario, Canada? 2) What do students learn through different models of STEAM education? 3) What types of assessment of student learning is happening in STEAM education? 4) How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals? Each subsection below summarizes and discusses the main findings.

## 6.1 Research Question 1

What curriculum and instruction models of STEAM education are implemented in non-profit and in-school contexts in Ontario, Canada?

**Curriculum and Instruction Models of STEAM**

STEAM education is being implemented in non-profit organizations and schools through art integration in STEM, and through other pedagogical approaches such as Design-Based Learning as described in Chapter 3. Several curricular and instructional models for STEAM education are noted in the literature in Chapter 2, such as art-integration, design-based, inquiry-based, project-based and problem-based models. In this section, I discuss the findings on the pedagogy, instruction, physical and social environment, teacher-student interactions, teaching style, teacher's values, and method of assessment and documentation at each research site. Data were collected and analyzed from the interviews, observations and curriculum documents to better understand the STEAM curriculum and instruction models. The findings from the observations suggest that the instructor/teacher can create a learning environment that encourages creativity and innovation through the physical and social environment, instruction and pedagogy, and the teacher-student and student-student interactions. I discuss both within the case findings as well as the cross-case findings.

### 6.1.1 Theme 1: Pedagogy, Instruction and Environment

Five primary findings illustrate how the STEAM programs organized the learning environment as seen in Table 3 and 4. 1) Students were offered the opportunity to learn through play and discovery. 2) Similarly, the design or orchestration of the learning activities focused on the students' interests (student-centered). 3) Instructors' and teachers' extensive use of, what I —based on Gadanidis (2015)— saw as, *low floor, high ceiling, wide wall* activities. 4) The structuring of the physical environment supported the nature of STEAM education. 5) While the utilization of the social environment supported and extended individual students' STEAM learning.

The physical learning environment of each research site was unique and depended upon the layout, space and resources available. One thing that surprised me was how the physical and social environment of the STEAM programs appeared to greatly affect the teacher-student interaction and the overall students' learning experience. Specifically, for the latter the physical environment of the STEAM programs was set up to support the possibility of student creativity, student collaboration and community among their peers.

#### 6.1.1.1 Fostered Creativity

I observed students learning through play, experimentation and tinkering when they were exploring a new technology. For example, students learned kinaesthetically by physically touching, playing, tinkering and seeing how the motors and parts of a remote-control car worked (see Figure 7). This finding supports that "it is important that learning activities are open-ended, giving students the freedom to explore and experiment within their own interests and learning styles, rather than just encouraging recipes to right answers" (Ejiwale, 2012, p.91). The four research sites used design-based and inquiry-based models, which focused on the students' interests (student-centered). Connor et al. (2015)

stated that projects that were student-centered motivated “students to take ownership of their own learning experience” (p. 45) and to be actively engaged in the learning process.

For example, Non-Profit 1 had more open-ended activities that allowed students to select the materials, design their own project and choose the level of difficulty. Similarly, the teacher librarian at In-School 2 believed in “giving the students [both] choice and voice in their learning,” and this was reflected in the Design-Inquiry lesson in which students were given more freedom compared to other lessons I observed in the selection of materials, design and product. At Non-Profit 1, I observed that the students moved freely and independently from the floor mat to a specific work station depending on the task. This freedom of choice was evident in the fact that students had complete autonomy when it came to planning their design, selecting the materials to use, choosing the technology and deciding the level of difficulty of the design.

The other three research sites also allowed students the opportunity to choose how they would plan and design their project, but they appeared to place more constraints on students’ interests by prescribing the materials selected and the final product the students would make at the end.

I observed that the physical structure of the work stations consisted of multiple work stations in one room at Non-Profit 1, different stations in different rooms at Non-Profit 2, of one room separated into two parts, which consisted of the maker lab with work benches and stations, and the other section with computers, tables and carpet area at In-School 1, and of Makerspace with a technology application room or regular classroom at In-School 2. It was evident that the physical set-up at each site, such as the digital and craft materials, the computer and cutting tools, and sample artefacts, as well as the spaces on the floor or on the table, encouraged students to create different artefacts ranging from simple paper airplanes and pencil toppers to more sophisticated artefacts such as origami paper flip-flops that had a working LED light.

So, it appeared to me that the physical and social environment supported the instructor's/teacher's pedagogies and instructional practices. It appeared that, by cultivating a creative learning environment, students felt safe, they were willing to communicate and share their ideas with others because "everybody's ideas are heard" (Teacher librarian, In-School 2). At Non-Profit 1, Instructor 1 said "the most important thing is creating a safe space" where everyone is accepted and encouraged, and students are not "afraid of making mistakes and trying new things."

#### 6.1.1.2 Tensions of Prescribed Tasks on Students' Creativity and Innovation

Do prescribed tasks and constraints in the lesson limit the student's creativity and innovation? In a non-profit or in-school context, there can be several constraints, such as time and resources. At the in-school sites, the teacher librarians saw a class only once a week or once every two weeks, so the length and frequency of the sessions per week was a constraint. At the in-school sites, "the teacher should authorize plans that students present so they can evaluate the ambitiousness of [the] designs and weigh it against [the] material/time limitations" (Curriculum Document, In-School 1). Blikstein (2013) stated that if "the aim is efficiency . . . it could have undermined students' willingness to persist through difficult problems" (p. 15) or encouraged "prematurely aborted design elements that they deemed too difficult" (p. 14). It appeared that the teacher librarians included goals, objectives or inquiry questions to guide the students and reduce the time needed to complete the STEAM tasks. At Non-Profit 2, some of the tasks were more prescribed possibly due to the time constraints of a 1.5 hr session per week, such as the 3D pencil topper in which the "students seemed to be in charge of the creative part of their design" (Blikstein, 2013, p.15), but the student did not have the opportunity to use different materials or methods to complete the task. In this lesson, students' creativity and innovation may have been hindered because of the constraints that the instructors gave. Blikstein (2013) describes this as a "quick demonstration project" that "might generate aesthetically pleasing products with little effort" (p. 18) and in which the product produced does not include "any computation or complex constructive challenges" (p. 9).

It appears that this type of activity encouraged students to put more value on the product over the process. In the four STEAM programs, this was not the case because the instructors/teachers at each site appeared to value both the process and the product which was evident during the observations, interviews and analysis of the curriculum documents as students document the "making process" in a video and/or student log.

Another factor that might hinder a student's creativity and innovation is how much assistance the student received throughout the "making process." In the balance or partnering model at In-School 1 and In-School 2, respectively, it can "easily turn into a disempowering arrangement when students realize that they are too dependent on the facilitators and cannot create the more complex designs by themselves" (Blikstein, 2013, p. 16). During my observations, the teacher librarians and teachers dealt with this issue by getting students to troubleshoot on their own or ask a peer for help before asking the teacher or teacher librarian. At In-School 1, the teacher librarian expressed "once you have given them the guidance to and the expectations on what needs to be done it's kind of much let them go off and figure things out on their own." The teacher librarian at In-School 2 echoed this by saying "we want to create context where the kids want to learn, where we're engaging them with things that, it's moving more towards that self-directed learning rather than the teacher-directed." This self-directed learning encourages students to construct their own knowledge indicative of constructionism.

#### 6.1.1.3 Tensions of Physical and Social Environment

The physical and social environment of Non-Profit 1 appeared to support student autonomy with the one room STEAM centre/lab separated by a movable wall, where students had the freedom to move from the floor mat to a station independently (section 5.1.1). This is not always possible in an environment such as Non-Profit 2 which had stations in multiple rooms on multiple floors in which there may be little or no choice in the location or physical layout (section 5.1.1). There may be tensions in the school curriculum and administration that may impede the teacher's ability to give students complete freedom and autonomy when it comes to the design, selecting the materials, choosing the technology and timeframe. The physical and social environment at Non-Profit 1 may not be replicable in a school-based institution or another non-profit organization. The instructors/teachers at the other three research sites appeared to find ways to give students both "choice and voice," as well as freedom in the design of the prototype or product within the parameters and constraints of the physical and social environment.

#### 6.1.1.4 Support Collaboration and Community

The instructors/teachers designed activities and an environment that provided students with the opportunity to work collaboratively, problem solve, engage in hands-on activities, and embark on both individual STEAM projects that were completed quickly, as well as more complex ones. All four research sites created group activities and encouraged students to collaborate, whether students were working on a team challenge at the non-profit sites or a group project at the in-school sites. Through collaboration, students learned their strengths and "after they explore[d] and collaborate[d] with their own team mates . . . they would create these amazing things" (Grade 5 Teacher, In-School 1). The physical environment was set-up in a way that included floor mats, work stations, collaborative tables and freedom of movement within the STEAM Centre or Makerspace. The social environment consisted of positive teacher-student interactions that were described as a "communal teaching environment" (Teacher librarian, In-School 1) in which I observed "students were learning from instructors, instructors were learning from students, students were learning from students" (Clark & Button, 2011, p. 41). The physical and social environment were extremely important in cultivating a learning environment that encouraged creativity in the students' learning processes as well as innovation in the design and products produced by the students. There were also several opportunities for hands-on activities all the time at Non-Profit 1, and most of the time at Non-Profit 2, In-School 1 and In-School 2. Each research site approached collaboration differently, such as when students were working at the collaborative tables and in small groups on team tasks at the in-school sites, the group tasks when planning a design at Non-Profit 1 and the group challenges at the non-profit sites. Students collaborated through shared activities in small groups of 3-5 answering questions and gathering information as they worked on these tasks, and this was especially evident at In-School 1 and In-School 2.

Several components appeared to support a community where students felt free to make mistakes and share their ideas, and by doing so, they were more creative. This was particularly evident through the following elements: positive teacher-student interactions by instructors, volunteers, teacher librarians and/or classroom teachers; the balanced and partnering learning models between teacher-student at In-School 1 and In-School 2 respectively; the design of students own projects without restrictions at Non-Profit 1 and within parameters at the other 3 sites; as well as the instructor/teacher valuing or more concern about the process at Non-Profit 1, both process and product at Non-Profit 2, In-School 1 and In-School 2.

#### 6.1.1.5 Design of the Physical, Pedagogical and Social Learning Environment

The findings on physical, pedagogical and social learning environment at all sites showed that both the pedagogy and the physical set-up were designed to support creativity, collaboration and a classroom community. This relates to Ghanbari (2015), Gross and Gross (2016), Harris and de Bruin (2018), and Madden et al. (2013) who studied the physical (Gross & Gross, 2016; Harris & de Bruin, 2018) and social environment (Ghanbari, 2015; Gross & Gross, 2016; Harris & de Bruin, 2018; Madden et al., 2013), as well as the student community in STEAM programs.

#### 6.1.1.6 Low Floor, High Ceiling and Wide Walls

Harris and de Bruin (2018) studied the idea that teachers were able to promote a creative learning environment for their students in the context of STEAM education. In order to cultivate a creative learning environment “teachers utilized class activities that engaged and developed curiosity/independence, empathy, analytical skills, resilience, complexity, and communication in thinking aloud and sharing problems” (p. 160).

All of the STEAM programs used differentiated instruction to provide students with multiple ways to approach a problem, "low floor, high ceiling, wide walls" activities (Gadanidis, 2015), and flexible adaptable lesson plans that were tailored to the student's interests and needs (see Table 3 and 4). These activities tended to be open-ended problems that allowed students "multiple entry points", provided "multiple ways to approach a problem" and encouraged both creativity and curiosity (Gadanidis et al., 2011). Most of the lessons observed at each site there were low floor activities because they provided *multiple entry points* for students, were high ceiling because students worked on group projects/challenges and showed sophistication in the products produced, as well as wide walls because they provided *multiple pathways* for the student to accomplish the task.

### 6.1.2 Theme 2: Curriculum Models of STEAM

The main findings on the curriculum models, as analyzed in the curriculum documents and as observed in the lessons at the STEAM programs, focused on: the use of the design thinking, building curiosity among learners, and driving the student thinking forward by reflecting on what worked well, what they would change, and what they would do differently. It was evident that, at all four sites, the written curriculum was based on the STEAM models. The instructors/teachers adopted STEAM curriculum models —more commonly the design thinking model, but also other similar models— appropriate for integrating the arts with engineering in STEAM. The instructors/teachers also implemented lesson stages in the models that built curiosity among the students at an early stage in the lesson.

#### 6.1.2.1 Four Stages of Instructional Design Model

The sites varied in how they structured and displayed their curriculum. Some were detailed and some were explicit with how they outlined the curriculum objectives referenced to the Ontario curriculum documents at the in-school sites to displays on walls at the non-profit sites. Despite these variations, it was evident that each site followed a curriculum in the implementation of their lessons. The lessons or units from the in-school cases seemed to be more structured than the non-profit cases because they included specific expectations from the Ontario curriculum, goals and objectives, and a section for assessment. Even when lesson structures differed depending on a STEAM site's program objectives and the instruction models adopted, each site structured their lessons into four major stages: building curiosity, data and facts, making and refining, and real world and thinking forward, as shown in Table 5.

These stages were reinforced by students constructing their own knowledge and designing a prototype. At the building curiosity stage, only Non-Profit 1 differed as students immediately explored the tools and technology. The other three sites focused on sparking interest about the context of the lesson. At the planning stage, students gathered facts at Non-Profit 1, or applied their ideas at Non-Profit 2, or got time to research and collect ideas in this second stage through gathering ideas from several sources at In-School 1 and focusing on a specific book at In-School 2. During the making and refining stage, only In-School 1 differed from the other three sites as it engaged students in one more sub-stage of making a detailed plan of a blueprint or storyboard in addition to prototype defining, testing and refining. During the interviews, the adult participants mentioned the word *make* and its variant *making* 224 times, *build*/*building* 107 times and *model*/*modelling* 106 times, these key words can be associated with the making and refining stage (Stage 3 of lesson). This finding was evident during the observations as all students were learning-by-making as they modelled and built a prototype. Non-Profit 1 and both in-school sites encouraged students to document the "making process" through video to communicate and share their thinking. This finding may indicate that the instructors/teachers valued the process, as well as the making and refining stage of lesson/session.

The last stage of the session was the most diverse among the four research sites with respect to students sharing their work with an authentic audience, student reflection and transference of knowledge. The two non-profit organizations ended each course with a celebration in which the students shared their work with an authentic audience, which included their peers, parents and/or the community. Similarly, students at the in-school sites shared their work with the class, school, parents and/or globally. After sharing their product with an authentic audience, the teacher librarian at In-School 1 encouraged students to use that knowledge and understanding in another context, such as solving a problem at home, in high school, in post-secondary education or in a future career. In contrast, In-School 2 provided students with the opportunity to reflect on what worked well, what they would change and what they would do differently. It appeared that all four research sites used the fourth stage to drive the thinking forward for the students so that the learning continued after the lesson or unit had finished.

#### 6.1.2.2 Curriculum Models and Design Inquiry

Among the instructors/teachers at the STEAM sites and at the focus group, all of these curriculum models of STEAM education were referred to as design-based and inquiry-based models. Both non-profit and in-school cases mentioned using some sort of design-based or inquiry-based model in their STEAM programs, which gave students the opportunity to problem solve and use critical-thinking skills to approach a problem that has multiple solutions. For example, the adult participants mentioned the word *design* 120 times during the interviews, 15 out of 19 adult participants talked about design inquiry, process or phase. Similarly, the adult participants mentioned the word *inquiry* 74 times during the interviews, 12 out of 19 adult participants talked about inquiry-based process, model or learning. In most activities, all the STEAM programs integrated the design process where students create a plan and design a prototype that is tested and then redesigned. Instructors/teachers said they activated students' natural curiosity in figuring out how things work and how they can make the prototype better. Students learned through games, storytelling and inquiry-type questions.

Many STEAM programs in this study, through their focus on hands-on activities/ learning, their mention of design thinking, and their adoption of maker education pedagogies appeared to adopt constructionism, which is "learning-by-making" (Papert & Harel, 1991, p. 6), and Design-Based Learning. At the four research sites, students followed the design thinking process to create a plan and design a prototype that will be tested and redesigned (Doppelt, 2009). Students also shared their product with an authentic audience. For example, at In-School 2, the students plan-design-make-test and redesign their drain in the lesson *The Little Boy who Lived Down the Drain*. About the finding that design-based model was more prevalent, this is in line with Liao (2016), who maintains that design thinking is an essential component to STEAM education. Further, Gess (2017) stated that an authentic STEAM program should be integrative, intentional and anchored in design. According to ADST curriculum "designs grow out of natural curiosity" (British Columbia Ministry of Education, 2016, p. 1) and "doing these types of [STEAM] learning activities . . . you are activating kids' natural curiosity" (Special education teacher, In-School 2). So, when students design a creative and innovative solution, it can develop from the student's natural curiosity and desire to figure out how things work.

### 6.1.3 Classroom Teachers' Views on Pedagogy, Instruction and Curriculum

How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals?

The main findings on pedagogy, instruction and curriculum from discussions with the focus group were about classroom teachers relating the STEAM programs' environment, curriculum and instruction at the four research sites to their own experiences in STEAM Education. The classroom teachers also shared the structuring, models and stages they preferred as well as what they saw as the valuable enablers in these structures, models and stages. The enablers included the opportunity for student voice, celebration, self-reflection and multiple pathways to success afforded by the STEAM models.

#### 6.1.3.1 Preferred Approaches and Stages: Full Integration, Collaboration, Celebration, Planning and Connections

Focus group participants identified their preference for a "fully integrated approach that is cross-curricular, not just about technology or a program or a specific device." Teacher

D said, “I did . . . like the collaborative piece in a lot of [the STEAM programs] … asking [students]… a lot of questions.” One participant related to her own work in which the teacher engaged students in creating short videos with the valuing of the celebration stage because: “it was important that you have that time with the kids to talk about what worked and the challenges and finding a real life connection.” Participants also spoke about the value of “the planning piece … sketching out a variety of models before … building” as seen in the four STEAM environments and curriculum models. There are several “metacognitive pieces … a lot of self-reflection … a lot of looking at different ways … [that it] could have been done” (Teacher D) in the curriculum models and during the “making process”. According to Madden et al. (2013) metacognitive thinking “requires a shift from thinking about teaching content within a [specific] domain to . . . asking how [that] knowledge can be used” (p. 543) in a real-world context.

#### 6.1.3.2 Preferred Curriculum Model

Design-Based Learning (DBL) is a key element in STEAM education because it engages students in the design process by creating a plan and designing a prototype that will be tested and redesigned (Doppelt, 2009). Overall, all four teachers identified that the design thinking process in DBL was the main pedagogy they used for STEAM lessons and activities and that they also see the applicability of other models: “I gravitate towards the design-inquiry process, but I also think that almost like indirectly … the partnering model … I kind of like blend it, in models and approaches ... it all comes back to needs of the students.” DBL was the main pedagogy used at each site and it was valued by the focus group participants because it is student-centered and it allowed students to create a design based on their interests and needs (Mehalik et al., 2008).

#### 6.1.3.3 Enablers of the Curriculum Models

Focus group participants commented on the importance of creating a social environment for students that involves collaboration and community. The classroom teachers noted that the enablers of such an environment, including student-centered, student voice, empowerment and feedback from their peers. Teacher C noted that this model created “multiple pathways to success” for the students and shared with the focus group that no matter the pedagogy “it all comes back to needs of the students . . . where the needs are.” The focus group teachers also noted the value of giving students a voice and empowering them to share their ideas and be involved in the creation of the unit and lesson. Another enabler noted the benefits of allowing students to have a voice the students “remember those projects because it had student voice and . . . they felt a part of the project . . . [they felt] like they had a say in creating the unit, so they retain[ed] it for a long time” (Teacher B). At In-School 2, the teacher librarian’s definition of student voice was different than the focus group participant. The teacher librarian said, “we make sure everybody’s ideas are heard,” whereas the focus group teacher described students having a voice when they are involved in the planning and creation of a unit. No matter the definition of student voice, both the instructors/teachers agreed about this enabler that it was “a lot of empathetic design, so how that makes the students feel” and actively listening to the students (Teacher C). This comment was in line with the response from the teachers at the sites: “to be self-directed learning, really listening to the students’ voice” (Teacher librarian, In-School 2).

The findings from the focus group when teachers reflected on their own teaching practices in STEAM, preferred as well as enablers of STEAM environments, models and stages of the lesson for the research sites echo the findings of Robinson (2013) and Katz-Buonincontro (2018). The integration of the STEAM programs provided students with multiple representations, multiple ways to approach a problem, multiple ways to express themselves, and multiple entry points of engagement (Robinson, 2013). Robinson further maintained that, through these multiple pathways, traditionally underrepresented students can have access and equality for academic success and a higher quality of education. STEAM can be described as a holistic approach to learning because it’s student-centered and meets the student’s social, emotional and academic needs (Katz-Buonincontro, 2018).

#### 6.1.3.4 Tensions of the Curriculum Models

The open-ended nature of the design-inquiry process allowed Grade 5 students multiple entry levels and multiple ways to approach a problem in their design, materials and the execution of their plan. When the Grade 5 teacher was asked "What are some of the challenges that you have observed or experienced when you are working in this STEAM program/Makerspace?" she responded by referring to the academically gifted student who while in the Makerspace he was "just wandering here and there because he has so many ideas popping up in his head and he wants to go and he wants to help other people rather than focusing on what he's doing."

This finding suggests that a possible tension of the design-inquiry process is that certain students might have difficulty staying focused and on task because of its open-ended nature. Similarly, Leszczynski et al. (2017) found that there were challenges with open-ended inquiry, and they noted that "the challenges of an open-ended lab [inquiry] were that any tool could be used" and students expressed "feelings of uncertainty and cluelessness" (p. 30). Despite the challenges of the design-inquiry process and its open-ended nature, students benefited from the multiple entry levels and multiple ways to approach a problem which could lead to "multiple pathways to success" (Teacher C, Focus Group).

## 6.2 Research Question 2

What do students learn through different models of STEAM education?

**Student Learning**

From the curriculum document and interview transcript analysis it was evident that students learned character-building and academic skills. The teacher librarian at In-School 1 summarized these skills as "skills to express their ideas, transferable skills so they can take with them to the next grade level and [use] . . . some of those skills together in unconventional ways." In the interviews and focus group, the participants referred to the tasks and activities as rich and authentic tasks. This authenticity was evident when I observed the lessons. During these observations, it was evident that students constructed their own knowledge, designed and built STEAM objects and shared their learning with an authentic audience. These character-building skills can empower students to solve real-world problems, develop “perseverance and grit,” provide students with the tools to have a “better life essentially and work life,” and students “can make a difference in the world.” By integrating the arts into STEM, students learn character-building skills that can help them engage in their community and develop a global perspective.

### 6.2.1 Theme 3: Student Learning and Transferable Skills

The main findings on student learning are developing persistence and adaptability and teaching transferable skills. The non-profit cases showed some similarities and differences to the in-school cases in their approach to student learning, specifically in the development of the character-building skills: curiosity and imagination, oral and written communication, perseverance and adaptability, collaboration, and critical thinking and problem solving.

One of the main character-building skills mentioned during the interviews was perseverance. The instructors/teachers encouraged students to make mistakes and take risks. The students’ learning experience and the “making process” were important in each STEAM program. Students documented the “making process” and shared their thinking through presentations, written documentation, photos and videos at Non-Profit 1 and both in-school cases. It appeared that the two in-school cases provided students with more opportunities to communicate in written form and share their thinking since with each lesson students were given a handout and student log to record their ideas and thoughts as seen in Figure 29 and 30. In contrast, Non-Profit 2 instructors did not explicitly mention in the curriculum documents or during the lessons observed that students should document or write, but allowed their students the freedom to make a plan or sketch their ideas using multiple mediums, such as writing, modeling (i.e., clay) and/or designing it digitally.

The director at Non-Profit 1 wanted his students to “look at the world around them as the place that can be changed by their ideas . . .  [and] make this city [world] a better place somehow.”  At Non-Profit 2, Instructor 2 explained that “giving them the tools to have a better life essentially and work life, that’s where adding technology and adding these new features, new STEAM learning comes from.” The director, instructors and teachers are empowering the students to make a difference in their community and the world. The director of the STEAM program said, “what we are trying to do is to empower people [kids] to feel like . . . they can make a difference in the world” (Non-Profit 1). The findings suggest that, by teaching these character-building skills, the instructor/teacher can empower these students to solve real-world problems, to have more opportunities in the future and to have an impact on the world. The findings also support Conley et al. (2014) claims that by integrating the arts into STEM promotes communication and critical-thinking skills and it helps students to develop a global perspective.

#### 6.2.1.1 Perseverance, Adaptability, Failure and Iteration

At the non-profit and in-school sites, students appeared to learn or practice persistence and adaptability when going through the design-inquiry process of plan-design-make-test-redesign and repeat**.** The director and instructor at Non-Profit 1, mentioned in the interviews that they created a learning environment in which students were not “afraid of making mistakes and trying new things,” and failure and iteration were built into the lesson or session. Similarly, the teacher librarian at In-School 2 said that one of greatest benefits of STEAM was “developing mindsets, developing perseverance and grit in an openness to try new things.” The teacher librarian explains “I think that’s one of the things that we’re trying to build is perseverance and risk taking and grit and … it’s more about the learning . . . [and] the learning is more about the process” (In-School 2). Encouraging students to persevere by taking risks, making mistakes, and by developing grit and resilience was evident in all the STEAM programs I studied. I observed that, at the non-profit and in-school sites, the instructors/teachers also seemed to create an environment in which students felt comfortable making mistakes and taking risks because students had a positive teacher-student relationship. This appeared to be unrestricted when the students were asking questions and interacting with the teacher.

#### 6.2.1.2 Transferable Skills

At all the research sites, students learned character-building skills (21st Century skills) which were "transferable skills so they can take [it] with them to the next grade level" and use those skills in another context (Teacher librarian, In-School 1). The findings on students learning skills that are transferrable is in line with the literature on the benefits of STEAM learning: In STEAM education students are able to transfer their knowledge across disciplines and solve creative problems in another context (Gess, 2017; Liao, 2016).

Industry, political, and educational leaders want students to develop workforce competencies by "'promoting deeper' learning through skills such as problem solving, critical thinking, and collaboration" (Allina, 2018, p.80). A Grade 5 teacher at In-School 1 echoed this by saying "I think the biggest thing is [STEM/STEAM] just speaks to kids, this is their language right now. This is their world if you think about like future job opportunities this is like 21st Century learning for kids." According to Hughes (2017), students need these character-building skills to "develop and apply for successful learning, living and working" (p. 102). The STEAM programs in this study teach character-building skills, such as "critical thinking and problem solving; collaboration and communication; and creativity and innovation" (Liao et al., 2016, p. 29) that can be transferred to another context, such as in the home, in high school, in post-secondary education and in the workforce.

### 6.2.2 Theme 4: STEAM Tasks and Learning Experiences

The main findings on STEAM tasks and learning experiences, curriculum and transcript analysis, and lesson observations showed that the STEAM tasks and learning experiences focused on: student engagement in the STEAM tasks, transdisciplinary approach to STEAM, and rich tasks and authentic experiences. The design thinking process engages the students in "constructing [an] authentic understandings through iterative [STEAM] cycles of learning in transdisciplinary classrooms" (Gess, 2017, p. 40). At each site, students experienced rich and authentic tasks in each STEAM program. During the interviews, half of the adult participants (7 out of 14) used the word authentic and real-world to describe these STEAM tasks. The other adult participants used words like meaningful and rich to describe the students' learning experience. The findings revealed that students were interested in how things worked and learning something new. In the interviews and observations, students showed excitement and engagement when they found the activities fun and created their own inventions.

#### 6.2.2.1 Tensions in Student Learning and STEAM Tasks

As indicated in the interviews, the curriculum documents the teacher and teacher librarian shared with me were all aligned with the Ontario curriculum and were more detailed including specific curriculum standards (sections 5.1.4 and 5.4.2). The in-school sites appeared to do well at conceptualizing the learning in science, technology, engineering, arts and mathematics by incorporating inquiry-type questions and success criteria that included specific curriculum standards (as seen in Figure 19 and 20). This was evident when the students at the in-school sites were able to articulate the specific academic skills learned in the STEAM programs (Section 5.4.2). The Non-Profit, on the other hand, appeared to explicitly focus on teaching transferable skills, such perseverance, collaboration, communication, critical thinking and problem solving. Similarly, the in-school sites valued these character-building skills as well as the academic skills. Although, the in-school and non-profit sites approached the curriculum and instruction differently, this was reflective of the site's objectives and constraints, such as the provincial curriculum/standards which are required at the in-school cases and incorporated into their lessons and unit plans.

#### 6.2.2.2 Student Engagement with STEAM Tasks

Students in all the STEAM programs had fun learning how things worked together, and they seemed excited and engaged in the activities because it interested them. For example, Student 3 said "it was neat how it went together, how light and energy work together" (Non-Profit 2). The Grade 1 students said the Minecraft station was his favourite STEAM activity "because they got to choose patterns and shapes" and "building is [was] fun" (Student 6, In-School 1). This echoed what a Grade 5 teacher expressed that STEAM is "a great way to engage people [kids] and learn new technologies" (In-School 1). Similarly, the special education teacher said "I find that they're naturally engaged [and] intrinsically motivated" in these STEAM activities (In-School 2). The findings support Upitis (2011) claims that "student engagement is central to learning … [and that] the arts play a vital role in ensuring that students remain engaged by encouraging them to learn" (p. 1) kinaesthetically, cognitively, collaboratively and connecting them emotionally with the concepts they are learning. All the STEAM tasks were hands-on, providing students with the opportunity to learn by making and constructing their own knowledge.

#### 6.2.2.3 Transdisciplinary Approach to STEAM

STEAM practices can be described as "thinking through the materials" (p. 17), which helps students have a deeper understanding of the material and make connections between the other disciplines (Guyotte et al., 2014). In the curriculum documents, examples of Science, Technology, Engineering, Arts and Mathematics tasks demonstrated that students were transferring their knowledge across multiple disciplines (Gess, 2017; Liao, 2016) at both the non-profit and in-school sites as seen in Tables 8 and 9. For example, *Robotic Playgrounds* is a hands-on program at Non-Profit 1 that explores themes at the intersection of architecture, design and making. Students learned about architecture and installation design to reimagine, remix and recreate green spaces and concrete landscapes.

Similarly, in the *STEAM Makers 3D Printing* course at Non-Profit 2 students design and print their own 3D creations. Students learned about 2D and 3D geometric shapes and artistic design simultaneously. In this course, students had to use mathematical, technological and artistic thinking to print their 3D prototype. At In-School 1, students designed an origami flip-flop made out of paper. Students had to think about aesthetics using artistic thinking, symmetry using mathematical thinking, and comfort and practicality using engineering design thinking. The findings support the idea that STEAM education provides students with an authentic learning experience, which can be described as transdisciplinary because it "goes beyond, transcends, the boundaries of a particular discipline" (Kreber, 2009 p. 25), and the knowledge gained can be applied to a real-world context (Costantino, 2018; Herro & Quigley, 2016). In the STEAM programs, students appeared to transcend the traditional boundaries of each individual discipline; as a result, they experienced these "rich and authentic" tasks that seemed to be a more meaningful learning experience.

#### 6.2.2.4 Rich Tasks

Most of the STEAM tasks were rich and authentic because they promoted "multiple cycles of design," incorporated "powerful interdisciplinary projects" in which students transfer knowledge between disciplines, "contextualized the learning in STEM [/STEAM]" to make abstract concepts more meaningful, and created an "environment that values multiple ways of working" to design and build (Blikstein, 2013, p. 18). A Grade 2 teacher at In-School 2 explained that "these rich tasks . . . connect to the overall experiences or draw on a theme to the lessons they naturally come with Science, Technology, Art, Engineering, Math, all those things naturally come out if you give them time." The findings reveal that these STEAM activities cannot be rushed, but students must take the time to fully develop their ideas and gain a "deeper understanding" of the material being taught (Clark & Button, 2011; Land, 2013; Robinson, 2013).

#### 6.2.2.5 Authentic Experiences

Students in each STEAM program constructed their own knowledge by making and sharing their final product with an authentic audience such as peers, parents and members of the community. These findings resonate with Papert's definition of constructionism in which students construct their own knowledge and learn through discovery, exploration, building, making and sharing their work with an authentic audience (Alesandrini & Larson, 2002).

At Non-Profit 2, Instructor 1 explained that with "STEAM . . . it has to include some form of authenticity." Teacher D echoed this by saying "I really like the authentic experiences and the rich tasks" (Focus Group) in the STEAM programs. The Grade 5 teacher further explained that these STEAM activities provide students with skills "that are valuable and realistic for them" (In-School 1) to build a prototype or solve a real-world problem, which makes this experience meaningful for both the teacher and the student. The instructor/teacher and the students appeared to be invested in the learning process because, in every lesson I observed, all students were engaged, on task and the instructor/teacher was excited to share their thoughts on these authentic experiences in their STEAM program. These findings are consistent with Reeves et al. (2004) claims that students should have authentic tasks that have a real-world context that integrate across the disciplines (Armory, 2014). These findings also support Shaffer and Resnick's (1999) claims that "authentic learning . . . [is] learning that is personally meaningful for the learner . . . [and] relates to the real-world outside of school" (p. 195).

#### 6.2.2.6 Enablers of an Integrated Curriculum and STEAM Program

According to the Integrated Curriculum Model (ICM) framework, many of these STEAM tasks encourage "(a) advanced content, (b) high-level process and product work, and (c) intra-[disciplinary] and [d] interdisciplinary concept development" (VanTassel-Baska & Brown, 2007, p. 350). The STEAM tasks described in Chapter 5 that appeared to be successful had inquiry-based models, design-based models, transdisciplinary and/or interdisciplinary approaches to learning, rich tasks and authentic experiences, "low floor, high ceiling, wide walls" activities, and had higher-order thinking skills (i.e., Blooms taxonomy and 21$^{st}$ century skills), such as critical thinking and problem solving, for students to develop a deeper understanding of the concepts. This is in line with VanTassel-Baska's (1986) ICM model which incorporates "inquiry-based instruction, integration of technology, authentic assessment, and constructivist models for learning"

(VanTassel-Baska & Brown, 2007, p. 350) and uses “higher-order thinking skills such as critical thinking, creativity, decision making, and problem solving” (Kahveci & Atalay, 2015, p. 95).

The ICM framework has been used to challenge both teachers and students to a higher level of teaching and learning. Students in Grades 6-8 used the Arduino microcontroller to build a robot using connecting wires, breadboard, wheels and a motor as shown in Figure 41. During the study, students entered a robotics competition as a team in their district and were able to share their prototype with an authentic audience composed of teachers, students, parents, community members and administration. This STEAM task appeared to be intra- and interdisciplinary as students learned scientific (i.e., circuits, electricity), technology (i.e. Arduino microcontroller), engineering (i.e. plan, design, build prototype), arts (i.e., aesthetics) and mathematical (i.e., perimeter, distance, time, speed, measurement, direction, angles, geometry, area, volume) concepts simultaneously. Students also used mathematics skills to 3D print the base of the robot and used x- and y-coordinates to program the robot. The mathematics and technology tasks appeared to be intricately woven into the other STEAM disciplines and seemed to encourage high order thinking in the learning process and the product produced. The “low floor, high ceiling, wide walls” activities in these STEAM tasks seemed to challenge the students and “move [them] toward learning that is more meaningful and contextualized” (Hughes, 2017, p. 104) in STEM/STEAM (Blikstein, 2013).

#### 6.2.2.7 Tensions of an Integrated Curriculum and STEAM Program

According to Blikstein (2013) in these STEM/STEAM programs “educators should shy away from quick demonstration projects and push students towards more complex endeavors” (p. 18). There were activities such as these in the STEAM programs that can be labelled as “quick demonstration projects” (Blikstein, 2013). In the observations at the non-profit and in-school sites, I noticed that these tasks were used in introductory level courses or team challenges at the non-profit sites and that they were used in the introductory lessons at the in-school sites when students were learning a new technology such as the Micro:bit. Although these tasks did not meet most of the criteria in the ICM framework, they appeared to still have merit because students experienced how to collaborate, communicate in the team challenges and learn a new technology or skill in the introductory courses and lessons. Instructor 2 echoed this by saying “they [the students] still need foundational tools to get started, so the basics of how Scratch works or how Python works and then you lead them to a point where they can then do whatever they want to do” (Non-Profit 2). It appeared that the instructors/teachers used these “quick demonstration projects” to lay the foundation and then build the rigor in the lesson or unit from these more complex endeavors.

### 6.2.3 Classroom Teachers’ Views on Student Learning and STEAM Tasks

How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals?

The main findings from the focus group on student learning were: rich tasks and authentic experiences in STEAM; student’s perseverance, adaptability and resilience; and curriculum planning of a STEAM program. The participants in the focus group agreed with the fact that these character-building skills were valuable because they were rich, authentic and transferable, and could be used to solve real-world problems. The focus group teachers related the development of perseverance, adaptability and resilience with students at the four sites to their own experiences in STEAM Education. The classroom teachers shared their personal challenges and suggestions of how to develop perseverance and resilience with students. The focus group also described how they approached planning a STEAM activity or unit, and how their beliefs and pedagogies in STEAM have influenced their teaching practices.

#### 6.2.3.1 Rich Tasks

The findings on rich tasks and authentic experiences in the focus group relates to Madden et al. (2013), Herro et al. (2017), Quigley and Herro (2016) who studied interdisciplinary (Madden et al., 2013) and transdisciplinary (Herro et al., 2017; Quigley & Herro, 2016) approaches to STEAM, as well as the students engaging in authentic learning experiences and developing solutions to real-world problems. The teachers in the focus group valued these transferable skills that were "preparing them [the students] for a better world . . . [with] authentic experiences and the rich tasks" (Teacher C, Focus Group).

#### 6.2.3.2 Authentic Experiences

Similarly, Teacher D also valued these skills "that [are] preparing our students to connect with their learning . . . that they can take with them in the future . . . creating things that are being used in our community and are being used to solve real-world problems, [such as] . . . sustainability [issues], . . . solving some of these food and hunger issues, [and] water resource issues" (Focus Group). These findings support the claims of Madden et al. (2013) that STEAM education provides students with the opportunity to engage in authentic experiences by developing solutions to real-world problems. Other studies have shown that the transdisciplinary approach to STEAM can create an authentic learning experience for students (Herro et al., 2017; Quigley & Herro, 2016).

#### 6.2.3.3 Perseverance, Adaptability and Resilience

Perseverance was an important character-building skill seen in the curriculum documents, taught during the observations, and mentioned by 14 out of 17 teachers interviewed during the post observation, instructors/teachers and the focus group interviews. At Non-Profit 1, the director stated that failure and iteration were built into the lesson or course to help students develop perseverance. These findings are consistent with claims by Reeves et al. (2004) that failure and iterations should be built into the assignment itself to provide students with an authentic learning experience (Armory, 2014).

The focus group teachers mentioned their challenges in developing perseverance "growth mindset . . . [is] one of the biggest challenges when we're doing STEAM activities . . . it's like an unwillingness to try again or change the design even if it's not working" (Teacher B, Focus Group). The teacher librarian supported the idea that perseverance can be a challenge, he said "growth mindset and persistence and keeping a positive frame of mind seems to be more difficult with some of the students" (In-School

1). These findings are consistent with Hughes (2017) study, “when the students struggled with something, they found difficult, they would give up and refuse to keep trying . . . we needed to constantly reassure the students that making mistakes was an opportunity to learn” (p. 110). Teacher D suggested “that’s why I think that it needs to start in the younger years and this idea of building, designing and trying again, [and] being resilient . . . that messy process of try, fail, start again” (Focus Group). The findings support the idea that “a number of . . .  issues arise including how integrated STEM [/STEAM] programs might encourage more student engagement, motivation, and perseverance” (English, 2016, p. 4; Honey et al., 2014). In some cases, failure and iteration were built into the lesson itself so that students were challenged to persevere, troubleshoot, problem solve and use critical-thinking skills to design a better solution, more efficient product or to solve a problem. From the findings, it appeared that perseverance was not a skill that all students naturally have but was a skill that can be developed and taught over time through the process of try, fail, start again. At all the research sites, the Design-Based Learning model naturally encouraged students to persevere and learn from their mistakes when they design-make-test-redesign their prototypes.

#### 6.2.3.4 Enablers in Planning a STEAM Program

The participants in the focus group talked about the individual standards in STEAM (Science, Technology, Engineering, Arts and Mathematics) as well as STEAM as an integrated curriculum. These finding are consistent with Gess’ viewpoint that “the goal of an integrative STEAM education, from an instructional standpoint, are to intentionally present the content and practices of math and science in the context of technology, engineering, and artistic design” (Gess, 2017, p. 40). At the in-school sites, it was important for teachers to consider the individual science, technology, engineering, arts and mathematics standards since they were accountable to both parents and administration. The teachers were expected to show the specific academic standards that the students met. The teacher librarians at the in-school sites developed detailed curriculum documents that included the specific standards that students learned in each STEAM lesson and unit.

The focus group teacher, Teacher D discussed the value of looking “at the whole picture [i.e., integrated or transdisciplinary approach to STEAM] . . . when planning a STEAM activity” or unit. Teacher D also valued the importance of the individual disciplines of STEAM “what’s the art aspect and what’s the mathematical piece because sometimes you can just jump into the technology piece” (Focus Group). In my experience, technology can sometimes distract or detract the learner from developing a deeper understanding or learning the content knowledge, so the details in the planning of a STEAM curriculum are important. A Grade 5 teacher valued an integrated curriculum and “how many different parts of the curriculum you can teach with one STEAM activity or a STEAM cycle” (In-School 1). The findings suggest that it is important to consider the individual disciplines and standards to ensure that the lesson and unit has specific goals and objectives, rigor and level of difficulty.

In contrast, Liao (2016) suggested that “integrated STEAM education . . . [should be] focused on transformative learning experiences whereby STEAM subjects are presented together” (p. 45) and “STEAM should create a transdisciplinary space that cannot be defined in reference to any traditional sense of discrete disciplines” (pp. 47-48). This finding on curriculum planning revealed that there are different ways to approach or look at STEAM education when planning a lesson or designing a STEAM curriculum. While considering individual STEAM components to identify specific standards or objectives is useful, it is also important to provide students with an integrative or transdisciplinary approach to STEAM education. This is important because “students [need to] view their work as created through engaging with all these subjects and beyond these subjects” (Liao, 2016, p. 48) to transcend their learning experience to a real-world context.

It was evident through interviews, observations and the focus group that the interdisciplinary approach to STEAM, curriculum and instructional models of STEAM have influenced the instructor’s/teacher’s pedagogies, instruction and teaching practices. Teacher A expressed “we are doing all the math at once and we are just trying to build their level in mathematics . . . so not in isolation and that’s where . . . when I finally get back to my own classroom where . . . having a STEAM classroom to allow your students to cover the curriculum in a jumbled [interconnected] way" (Focus Group). Teacher B "view[s] a big STEAM project . . . that they have hit language, math, science, all sorts of curriculum expectations" simultaneously (Focus Group). These findings reveal that the STEAM curriculum can be described as fluid, in which multiple concepts can be taught at one time versus teaching a single subject or a specific expectation in isolation. This approach to STEAM education appears to provide students with a more authentic learning experience in which students use multiple disciplines to solve a problem. These findings are consistent with Lee's (2007) view that interdisciplinary units such as STEAM provide a meaningful context, approach a topic from different perspectives, and apply prior knowledge in new situations effectively.

#### 6.2.3.5 Tensions in Planning a STEAM Program

Contrary to the value of an integrated curriculum, Bequette and Bequette (2012) caution educators that STEAM may "weaken each discipline and confuse the boundaries between different approaches" (p. 40). In Harris and de Bruin's (2018) international study teachers identified three main tensions on implementing and planning a STEAM program: crowded curriculum, standardized testing and school curriculum restrictions. The teachers they interviewed identified how a "crowded curriculum" limits their time to meet with colleagues and plan cross-curricular activities as well as the time to implement STEAM activities in the timetable (Harris & de Bruin, 2018). Other tensions identified were standardized testing and "school curriculum restrictions" (Harris & de Bruin, 2018, p. 168). This is echoed by Teacher B in this study who says, "time is always a challenge and meeting all of the curriculum needs" (Focus Group). There appears to be a tension between these rich tasks in STEAM that require more time and the *crowded curriculum* that has both restrictions and constraints. According to Harris and de Bruin's (2018), despite the *crowded curriculum* that the integration of the arts can support a learning environment "through which wider domain learning and creativity is promoted" (p. 167).

Gresnigt et al. (2014) stated other constraints with implementing an integrative curriculum such as difficulty connecting the activity with the curriculum, lack of confidence in teaching subjects that are less familiar, struggles with assessment and evaluation of the tasks, and lack of support from administration. It is evident from the literature and the findings that teachers may experience some barriers when implementing and planning a STEAM program. Despite the hindrances to teachers and school leaders, studies have found that interdisciplinary units provide a meaningful context for students, they approach a topic from different perspectives, and students apply prior knowledge in new situations effectively (Lee, 2007).

## 6.3 Research Question 3

What types of assessment of student learning is happening in STEAM education?

**Assessment, Documentation and Sharing the Learning Experience**

In this section, I discuss classroom teachers' views on assessment, pedagogical documentation and sharing the learning experience with a wider community. Assessment and documentation are important in STEAM education to observe, record, interpret and share the learning experience (Krechevsky et al., 2010). Educators in the study spoke about the kinds of assessment, documentation and sharing such as anecdotal notes, photos and video recording, the enablers of these methods such as better understanding and extending learner's thinking and the students' overall learning experience. The educators also discussed the constraints of assessment such as the provincial report card that is organized by individual subjects. The findings on assessment, pedagogical documentation and sharing are in line with research and assessment policy, which maintain that a variety of forms of assessment can be used as a reflection of the teacher's practices, student learning and instructional/curricular practices, reflect upon whether the activity was student-centered or biased based on gender, ethnicity or social status (Mulcaster, 2017; Ontario Ministry of Education, 2015).

### 6.3.1 Theme 5: Assessment, Documentation and Sharing their Learning with a Wider Community

In the STEAM programs I researched, “the primary purpose of assessment was to improve student learning” (Ontario Ministry of Education, 2010, p. 28). Assessment in the STEAM programs was described as informal in the non-profit sites consisting of observations, questions and conversations with the students. At the in-school sites the assessment was organized based on the specific curriculum standards which consisted of anecdotal notes based on observations, conversations, pictures, videos, presentations, prototypes and the final products. The assessment at the in-school sites appeared to be more rigorous as the teachers and teacher librarians attempted to align their instruction with specific standards in the curriculum such as the Ontario mathematics, science and technology, and arts elementary education standards.

#### 6.3.1.1 Enablers of Assessment in STEAM Programs

Two teachers mentioned they had less difficulty with assessment because they were “not stuck on procedures and rules” in the curriculum or checking off a box, but more focused on the “really rich experience[s]” that students were having (Grade 2 teacher, In-School 1). A special education teacher at In-School 2 described her ease with assessment and how she assesses her students during a STEAM activity. “I would be making notes and observations based on the photos that I took . . . [and] the videos I took . . . this would be an example of how I would assess . . . I embed the assessment into it so I see it as a product right, product and observation. . .  So, I don’t find it [assessment is] that hard at all actually.” This is in line with Shaffer and Resnick’s (1999) claims that “the means of assessment reflects the learning process” in an authentic learning environment, such as STEAM education.

#### 6.3.1.2 Tensions of Assessment in STEAM Programs

In the interviews, some teachers expressed that there were some challenges with assessment because of the disconnect between the STEAM activities and the evaluation apparatus. A teacher described her challenges with assessment as “having to take such a rich experience . . . and document it into such a dry, formal . . . restrictive report card" (Grade 2 teacher, In-School 2). The findings suggest that these STEAM activities were difficult to assess because the teachers considered these tasks to meet integrated learning goals and did not match the structure of the Elementary Provincial Report Card, on which learning is reported under individual subjects and strands.

Another struggle in assessment is the "challenge . . . of meeting all of the curriculum" expectations. Teacher B explained that the difficulty is "that they [teachers] don't always see that they are meeting curriculum expectations in all the strands . . . and all sorts of curriculum expectations for the report card" in one STEAM activity (Focus Group). It appears that there's a disconnect between these "really rich experience[s]," the assessment and the evaluation. It seems like this disconnection between the assessment and the evaluation tool could hinder the teacher's ability to assess and give a grade that reflects this rich experience. The demands placed on the teachers by the Ontario Ministry of Education to evaluate students based on specific standards within an individual discipline are not yet consistent with the overall philosophy of an integrated and transdisciplinary STEAM curriculum. Despite the disconnect, the Ontario Ministry of Education states that "the teacher will consider all evidence collected through observations, conversations, and student products (tests/exams, assignments for evaluation) . . . before making a decision about the grade to be entered on the report card" (p. 39), which is in line with the types of assessment and documentation in the STEAM programs (Ontario Ministry of Education, 2010).

#### 6.3.1.3 Pedagogical Documentation

At the four research sites, pedagogical documentation in STEAM served three purposes: to assess, self-reflect and document the student learning experience. Although instructors/teachers at the other research sites used pedagogical documentation in their teaching practices, one educator the teacher librarian at In-School 2 spoke about her understanding, use and valuing of pedagogical documentation. Her views on the process of pedagogical documentation to encompass several ways of observing, recording, analyzing, following up on and extending students' learning. This finding echoes the Ontario Ministry of Education's (2015) definition that "pedagogical documentation helps them [teachers] plan with students, and co-construct experiences that build on individual student strengths and abilities" (p. 3).

From the interviews and informal conversations, it appeared that pedagogical documentation was a reflective process, which allowed the teachers to reflect on their own teaching practices and the students' overall learning experience. At Non-Profit 1, the director and instructors reflected quarterly by having staff meetings where they discussed what worked well, what did not work and what could be done differently. Similarly, at the in-school sites, the teacher librarian and classroom teachers reflected upon the same questions of what worked well, what did not work and what could be done differently after each lesson with the goal of improving the students' learning experience. At In-School 1, the teacher librarian met monthly with the school Maker Education team, which comprised of the teacher librarian and maker education teachers assigned to a specific grade level, to reflect, plan and develop a scope and sequence for the curriculum. This supports Harste's (2001) claim that "learning does not end with [the] presentation [or product] but rather with reflection, reflexivity, and action" (p. 15) taken after documentation.

#### 6.3.1.4 Documentation at each Research Site

Krechevsky et al. (2010) maintained that educators must continually document the STEAM learning process through observing, recording, interpreting and sharing. With respect to documentation, the two in-school teacher librarians created a website where they archived their personal observations of student learning along with observations from other teachers as well as posted blogs, and shared social media stories, which included photographs and videos of the students learning. Similarly, the two non-profit organizations have a website that features the different programs that they offer, where the instructors shared, through photographs and videos, highlights of student learning and of the learning environment of the STEAM lab/center. Each site documented the students' learning experience differently. The director, teacher librarian and teachers had to get consent from the parent for the students to be photographed, video recorded and to post these documents on the web. At the in-school sites, all photos taken of the students showed no faces, names or other distinguishing features. The teacher librarian at In-School 1 put a smiley face sticker to cover the students' faces if the pictures and videos were taken from the front. In contrast, at the non-profit sites, the director got permission from the parents to post pictures that did show distinguishing features and were taken from the front. The documentation and sharing of student learning with other colleagues were done confidentially and for reflection purposes during the celebration stage of the lesson/session.

#### 6.3.1.5 Sharing the Learning Experience with a Wider Community

In my findings, the sharing of the student and teacher learning experience in STEAM varied from site to site. The variations appeared to depend on the STEAM program's goals and objectives. At Non-Profit 1, they shared the learning experience with others through several community partnerships, such as collaborations with the Science Museum and Maker Festival. At Non-Profit 2, the STEAM lab/centre has a continuing partnership with the local school board and the community in which it resides. At the in-school sites, both teacher librarians continue to share the learning process through their school websites and social network accounts they have created with their personal observations, pictures, videos, blog posts and social media stories. At the in-school research sites, teachers and teacher librarians said that building capacity was a key component in their STEAM program. At Non-Profit 1, the director valued the community partnerships and said that "incredible results from it [the collaboration] they're really looking to us to bring our culture and our pedagogy into the rest of their museum . . . to make their place more open-ended and experimental." The findings on the collaboration between the Non-Profit 2 and the school board as well as its local community suggest that the instructors and directors at the non-profit sites sought to develop and expand their STEAM program through these community partnerships, but also to build mutually beneficial relationships. The findings show that the teachers, instructors and teacher librarians in the study valued sharing the learning and instruction with other educators in their STEAM programs and with the wider community with a goal to extend the "learning experiences to wider audiences" and contribute "to the collective knowledge about how students learn" (Krechevsky et al., 2010; Mulcaster, 2017, p. 37).

#### 6.3.1.6 Collaboration and Capacity Building

When the educators in the study were asked "What is your vision for this STEAM program?" the director and teacher librarians mentioned growth and capacity building either within their school/organization or beyond their bounded system by reaching out to the community. At the non-profit organization, collaboration was seen as an avenue to build community partnerships around the STEAM program.

At the non-profit sites, capacity building happened within the STEAM program, but also went further with community partnerships with school boards, local museums and businesses. Students also participated in community events such as the Maker Festival. At the in-school research sites, teachers and teacher librarians said that building capacity was a key component in their STEAM program: teachers collaborate "bringing more expertise to the table", " build capacity" "build capacity on their [the teachers'] end" "you share an insight between each other as to best practice and hopefully change things for the better going forward" (Teacher Librarian, In-School 1); team teaching and "different perspective", "build partnerships between the teachers", modelling collaboration for students, "school-wide process or even sharing it outside in the community" (Teacher Librarian, In-School 2).

Both teacher librarians made connections between documentation with collaboration and capacity building. The teacher librarian at In-School 2 elaborated on this connection:

> If we are sharing the documentation we have with each other . . . it shouldn't just end there; we should be sharing it with the staff . . . How we can make this a school-wide process or even share it outside in the community?

The teacher librarians empowered the teachers to share their ideas and to critically reflect upon their own teaching practices by sharing best practices, opening their minds to new ways of teaching and learning, and through “an ongoing, reflective, collaborative, inclusive, learning-oriented, growth promoting way” (Ho & Lee, 2016; Stroll & Louis, 2007, p. 2). The teacher librarian explained that, with respect to collaboration and team-teaching, it is the “whole triangulation of data, you always want a different person or a different lens to help validate what you’re seeing” (In-School 2). As evidenced in the results chapter, team-teaching and collaborating with other teachers can help validate the documentation process and “triangulate” the evidence on students’ learning by either having more than one person documenting the learning experience or having more than one person review the anecdotal notes, photographs and video documentations. Further, at the in-school sites sharing these documents with other educators can provide opportunities for teachers to share insights, best practices, possible improvements to the curriculum, instruction and student learning to possibly enhance the students’ overall learning experience.

Teachers “build capacity on their end to embrace this kind of mindset of changing the way they approach subjects and learning” and “put perspective into your practice and it might enlighten their practice too” (Teacher librarian, In-School 1). This is consistent with Hartman’s (2017) study on “school collaborative partnership” that conceptualized that the whole process of capacity building is organic, constantly changing, continuously growing and based on these mutually beneficial relationships that are built through willingness to change, mutual respect and persistence when things don’t go as planned. These collaborations and this capacity building have the potential to identify additional productive ways of teaching and learning through STEAM education initiatives. The instructors/teachers introduce new technologies, promote a creative learning environment, provide rich and authentic experiences, promote a communal teaching environment (i.e., giving students choice and voice in their learning), and provide a platform for students to share their ideas without restraint. The overall goal is to improve the students’ learning experience “socially, emotionally and academically”, which is in line with Katz-Buonincontro’s (2018) observations on policy, curricular, and programmatic developments in arts-based science, technology, engineering, and mathematics education.

### 6.3.2 Classroom Teachers' Views on Sharing the Learning Experience with a Wider Community

> How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals?

The main findings on collaboration and sharing of student learning from the focus group were collaboration and capacity building, as well as sharing the learning experience with a wider community. The classroom teachers in the focus group said they valued collaboration and capacity building, and commented on their experiences feeling isolated at times because they were the only ones in their school involved in STEM/STEAM initiatives. All of the teachers in the focus group saw value in the idea of sharing their learning experience with a wider community, and argued that for them it was done for the purpose of learning new ways of teaching STEM/STEAM. This was distinct from the purpose and experiences of the teacher librarians at the in-school sites studied.

#### 6.3.2.1 Collaboration and Capacity Building

For the teachers in the focus group, sharing the learning from the STEAM activities could be challenging sometimes. This was different for the teacher librarians at the in-school sites who had more opportunities to collaborate and build capacity with other teachers. Teacher D explained why this might be the case "I think it's because it's an isolating world . . . Sometimes there are one or two people in a building, but sometimes . . . you have to go outside to meet like-minded people and sort of gather ideas and things like that" using technology (Focus Group). This made it difficult for them to collaborate with other teachers or get their colleagues to "view a big STEAM project . . . [as meeting] all sorts of curriculum expectations for the report card" (Teacher B, Focus Group). This was echoed by the teacher librarian who expressed his challenges "trying to build capacity is another big challenge, after [teachers] buying-in has been established" (In-School 1). The challenges in collaboration and capacity building, identified by both the focus group and in-school teacher participants, are associated with the difficulty of finding teachers who are like-minded, are willing to collaborate and see the value of STEM/STEAM education. Despite these challenges, the teacher librarian at In-School 1 met monthly with a group of like-minded teachers (i.e., Maker education team) that were willing to use their time to design lessons and units for each grade level. This finding is consistent with capacity building "growing out of common interests and commitment" to student learning (Ho & Lee, 2016, p. 501). At the non-profit sites, the value in collaboration was associated with capacity building within the community through partnerships with other non-profit organizations, museums and the local school board rather than the capacity building among the instructors themselves. This finding contrasted with the value of collaboration and capacity building for the teacher participants in the focus group and at the in-school sites.

#### 6.3.2.2 Sharing the Learning Experience with a Wider Community

Besides collaboration and capacity building, participants in the focus group reflected on the data about sharing the instruction and learning from the STEAM activities with a wider community. Teacher B suggested "getting out there to the community and talking to experts or talking to other people who are actually in industry" to "engage the kids more in our world." These findings reflect how the learning and instruction can be shared through "collaborative conversations" with the students, their parents, educators and the broader community "for the purpose of furthering learning and connecting learners to their world" (Ontario Ministry of Education, 2015, p. 6). Teacher D encouraged her students to sign up for "entry level projects and contests were students are really creating things that are being used in our community and are being used to solve real-world problems." For the teachers in the focus group, the purpose of sharing the learning with a wider community seemed to provide students with the opportunity to engage with the world and solve problems based on real-world contexts. This is "because often they [the students] feel like they're isolated in the school and they are not having an impact . . . on the world and these [world] issues" (Teacher B, Focus Group). From the findings, it appeared that the focus group teachers desired that their students develop "a global perspective" (Conley et al., 2014) and participate in a "shared learning experience"

(Clark & Button, 2011) by getting students out in their community and solving real-world problems through STEAM initiatives.

## 6.4 Summary

The main findings of this research study focused on the curriculum and instruction models of STEAM education, student learning experiences, assessment, documentation and sharing student learning, and how classroom teachers view the models as meeting their goals. In this study, the physical and the social environment were important in encouraging students' creativity, collaboration and communication in the STEAM programs. At the four research sites, the main pedagogy used was design-based and inquiry-based models, which focused on the students' interests and encouraged students to construct their own knowledge. I also discussed the commonalities among the different curriculum models, such as the four stages of a lesson/session and how Papert's Constructionism, Design-Based Learning and Low Floor, High Ceiling, Wide Walls theories are the foundation for these curriculum and instruction models of STEAM. Students learned character-building skills that appeared to be transferable and empower them to solve real-world problems, develop perseverance and grit, engage in their community and develop a global perspective. The STEAM tasks at each site were described as rich tasks and authentic experiences. The findings also suggest that sharing learning in the STEAM programs with the community extended the learning experiences to a wider community and contributed to the collective knowledge about how students learn. I used the discussion section to address the research questions and examine some of the important findings of this study. In the next section, I will mention the implications, limitations and future research opportunities.

# Chapter 7

## 7 Conclusion

The conclusion section is organized according to the implications and recommendations of the study for research, policy or practice; limitations of the study; final remarks and possible future research. In the first section of the conclusion, I highlight the significance and some of the implications from this research study and recommendations for instructors, teachers, students, parents, school board curriculum leaders and policy makers. In the second section, I discuss some possible limitations of the study and how I addressed this in the study methods and design, as well as in the data collection and analysis stage. In the final section, I include final thoughts on how the findings address the research problem and opportunities for future research.

### 7.1 Implication of the Study for Research, Practice or Policy

This study provided rich descriptive data (Gay et al., 2009) on four case studies about STEAM programs in Ontario, Canada at the elementary level, detailing the learning environment, instruction and pedagogy, curriculum models, teacher-student interactions, student learning experiences, and assessment, documentation and sharing learning with a wider community. I also collected thick data (Gertz, 2008) from multiple sources: interviews, observations, curriculum documents, photos and photocopies of student work. The findings suggest that the physical and the social environment of these STEAM programs promoted students to be creative, collaborate and communicate with their peers. In each STEAM program, the main pedagogy used in the curriculum and instruction was design-based and inquiry-based models. The curriculum models in the STEAM programs resonated with Papert's Constructionism and with Design-Based Learning. The programs focused on student interests, were student-centered, and encouraged students to design a prototype and construct their own knowledge. Students learned character-building skills that seemed transferable and which could be used to solve real-world problems, develop perseverance and grit, engage them in their community and help them develop a global perspective. The STEAM tasks at each site were described as rich tasks and authentic experiences. The findings also showed different approaches to assessment, documentation and sharing student learning in each STEAM program.

The findings from this data have implications for designing, implementing and researching STEAM programs. For instance, this study's findings can be helpful to an educator or policy maker who is designing the curriculum and instruction for a STEAM program. It can also be useful to determine which model of STEAM education would be the most appropriate for a given context. Educators and policy makers can use the four stages of lesson/session to design a STEAM program that builds curiosity, allows students to collect data and facts, make and refine their design, and connect to the real world by sharing, reflecting and thinking forward. The enablers and tensions discussed in Chapter 6 have the implication to help policy, decision makers, teachers and teacher librarians in the design of the curriculum and instruction, and to optimize learning in STEAM education.

This study will deepen the field's understanding of STEAM education in Canada and provide new insights into the phenomenon, such as the importance of cultivating a creative learning environment that promotes creativity, collaboration and communication among students. Positive teacher-student interactions and a creative learning environment are essential for students to take risks, make mistakes and persevere. The curriculum and instructional models of STEAM education have a rich and authentic experience that "goes beyond, transcends, the boundaries of a particular discipline" (Kreber, 2009 p. 25) and teach students transferable skills that can be used to solve new problems and make a difference in the world.

This study's findings also included an iteration on how a group of classroom teachers viewed the models of STEAM education at the four research sites. This iteration had implications on the practicality and feasibility of these STEAM models in meeting classroom teacher's goals. This study sheds light on the importance of pedagogical documentation for both the student and the teacher to reflect, move the thinking forward and determine the next steps. The finding on the value of pedagogical documentation has implications for practice, especially at the in-school sites for the teacher librarians and teachers. To further the learning experience, teachers need to document and share the learning and instruction through collaboration and community partnerships with students, teachers, parents and the community.

Furthermore, there is a lack of research in determining and measuring essential 21st century skills (e.g., creativity, innovation, communication, collaboration) that are important for success in STEAM (Herro & Quigley, 2016). This study provides insight for educators and policy makers into how an "integrated STEM [/STEAM] programs might encourage more student engagement, motivation, and perseverance" (English, 2016, p. 4; Honey et al., 2014).

This study focused on K-8 education in the non-profit and in-school context. My recommendations for instructors/teachers are that the physical and social environment in a STEAM program are just as important as the pedagogies, curriculum and instruction implemented (as demonstrated in sections 5.1 and 6.1). It is important to cultivate a learning environment that promotes creativity and innovation (as noted by Harris & de Bruin, 2018 in sections 2.3 and 6.1.1). Students are more engaged when the lessons or activities are more open-ended, student-centered, and when students are involved in the process (as said by Teacher B in sections 5.1.6 and 6.1.3). My recommendations for the school board curriculum leaders and policy makers are to integrate the arts into STEM through the design and engineering process so that the STEAM program provides students with rich tasks and authentic experiences (as noted by Gess, 2017 in section 6.1.2). Involving the parents and the community in the learning process so that students have a "shared learning experience" and extend the learning beyond the constructs of the STEAM program (as noted by Clark & Button, 2011 in section 6.3.2). For teachers, teacher librarians and school principals who are already providing STEAM programs to learners, I recommend that educators incorporate pedagogical documentation into their professional practice to reflect upon the student learning for what worked well, what did not work and what could be done differently in order to enhance the students' overall learning experience (as said by Teacher Librarian, In-School 2 in sections 5.5.2 and 6.3.1). I would also suggest that students are given the time necessary to develop a deeper understanding and see the interconnections in a STEAM activity, to avoid rushing the process (as said by Grade 2 Teacher, In-School 2 in section 6.2.2). The focus of STEAM should be the student and their individual needs and interests, which may provide students with equal access to a quality education (as noted by Robinson, 2013 in section 2.6 and said by Focus Group participants in section 6.1.3).

## 7.2 Limitations of the Study

I conducted a collective case study, and this approach can allow the researcher to make more theoretical generalizations and explore the concept in further depth (Cousin, 2005; Yin, 2003). One limitation of a case study is that it is difficult to generalize the results to other cases and only limited generalizations (Gall et al., 2007) can be made when comparing how the case is similar or different to other cases. In my research study, I ensured that I referenced each case study specifically and I avoided suggestions that the results can be generalized to STEAM programs in Canada.

Other possible limitations are the length of the study and the number of research sites due to the restrictions of the Master of Arts program. Although the data I collected were extremely rich and thick (Fusch & Ness, 2015), it would have been beneficial to have a longitudinal study over a one to three-year period to develop a deeper understanding of the participants over time for more in-depth study and in-case analyses. At most of the research sites, I observed students at the primary (i.e., K-3), junior (i.e., grades 4-6) and intermediate (i.e., grades 7-8) level, but at the in-school sites I only got to observe students at the intermediate level during the clubs or competitions rather than a lesson.

The focus group consisted of only classroom teachers who were already involved in STEM/STEAM education. This was not done purposely but based on the teachers that responded to my invitations and decided to participate in the focus group. The focus group invitations were sent out with the letter of information about the research in the

Fall term and using an email list through acquaintances at the Faculty of Education and the local school board. A broader sample would have been informative to have the views from classroom teachers who were involved in STEAM education and those who had very little or no knowledge about STEAM. The response rates to the email invitation was low for teachers wanting to participate in the focus group, possibly because the time of the focus group was in the evening and the location was at the Faculty of Education. It might have also been the timing of the focus group date at the end of October around the time when teachers had grades due for student progress reports. Although this can be perceived as a limitation, the lack of diversity among the classroom teachers provided purposeful sampled data from the group of teachers already interested in STEAM which could be used to triangulate with the other data sources.

## 7.3 Conclusion and Future Research

The integration of the arts into the STEM subjects needs to be both purposeful and seamless to effectively engage students (Bequette & Bequette, 2012; Upitis, 2011). Teachers in this study considered the individual components of STEAM (Science, Technology, Engineering, Arts and Mathematics), as well as the interconnectedness of STEAM and how the individual disciplines work together to provide students with rich experiences and integrated learning opportunities. Liao (2016) suggests that "integrated STEAM education . . . [should be] focused on transformative learning experiences whereby STEAM subjects are presented together" (p. 45) and "STEAM should create a transdisciplinary space that cannot be defined in reference to any traditional sense of discrete disciplines" (pp. 47-48). For students to transfer their knowledge from one context to another, the learning must go beyond the individual disciplines and seamlessly integrate STEAM (Liao, 2016).

The STEAM instructional programs in this study offered by non-profit organizations and publicly funded schools showed many similarities and differences among the pedagogy, instruction, curriculum models and the student learning experience depending upon the learning environment, instructors/teachers, students and the available resources. The results of this study could inform the practices of teachers who seek to engage and motivate students to learn STEM subjects by integrating the arts. Specifically, students are “naturally engaged and intrinsically motivated” in the STEAM programs through learning a new technology and engaging with materials in an innovative way. These STEAM activities naturally lend themselves to student engagement because they focus on the students’ interests and needs. It is important to have teacher collaboration to design and implement these STEAM activities and share their findings with a wider community (Krechevsky et al., 2010; Mulcaster, 2017).

To gain a better understanding of STEAM education, I conducted a collective case study at the elementary level with four STEAM programs in Ontario, Canada. In order to fully understand the implication of this research, a focus group was conducted to see how classroom teachers view such models of STEAM education meeting their curriculum and instruction goals in the classroom. I specifically looked at curriculum and instruction models to provide educators, researchers and policy makers with models of STEAM education in a Canadian context.

Although the findings provided deeper insight into STEAM education there are several possibilities for future research. Educators, researchers and policy makers have an invested interest in assessment and documentation. It would be beneficial to research pedagogical documentation in further depth in the context of STEAM education to gain more insight on how educators assess and document the STEAM learning process. Many of the research studies on STEAM education focused on the academic skills that the students attained. It would be interesting to further investigate the character-building skills, such as communication, perseverance, adaptability, collaboration, critical-thinking and problem-solving skills. Specifically, how these character-building skills transfer to other contexts and different subject areas over time.

This study provides a snap shot of the STEAM programs, in which the data were collected over four months. I highlight the findings from the interviews, observations, curriculum documents and the focus group and the cross-case findings among the different data sources. In order to provide even more insight into this phenomenon of

STEAM education there needs to be more research sites and data that are collected over a longer period of time. A longitudinal study with a larger sample would provide more data to theorize and understand STEAM education in greater depth, and also see the growth and modifications in the STEAM programs.

It also would be beneficial to conduct an international study on STEAM education in different countries and how they approach the curriculum and instructional models of STEAM similarly and differently in order to broaden the researcher's perspective on the curriculum and instruction models of STEAM education in different countries. There are so many possibilities in the field of STEAM education since this is a growing area of interest over the last decade such as conducting the study in different geographical regions of Ontario and Canada, researching specifically unpaid non-for-profit programs or schools in rural areas, or investigating provinces such as British Columbia which has a STEAM related curriculum (i.e., ADST). The value to the researcher is to broaden the scope and explore different geographical and physical environments in which STEAM education is being implemented.

Some of the proponents for the STEAM movement have been politically driven: to train students to be world leaders in science, mathematics and technology by fostering an interest and deeper understanding in STEM through the arts (So et al., 2018). Countries, such as Canada and Australia, see the benefits in STEAM education, recognizing that the design and creativity are essential for the development of successful scientists, engineers and mathematicians (Hogan & Down, 2016). Nations would like their students to be able to compete globally and be able to create innovative solutions to current global issues (Madden et. al., 2013). The STEAM initiatives have been more politically driven to encourage students to study mathematics, science and engineering at the post-secondary level and, subsequently, to become world experts in this field of study.

Politicians and industry leaders tend to focus on the academic skills and career paths of students whereas in the STEAM programs in this study the instructors/teachers valued the process and the character-building skills that students developed. For example, students were encouraged to persevere by taking risks, making mistakes, and by developing grit and resilience. The instructors/teachers created a physical and social environment that promoted creativity and innovation through the digital and craft materials, the computer and cutting tools and sample artefacts as well as the spaces on the floor or on the table to work collaboratively, and positive teacher-student interactions that encouraged students to create different artefacts. All of the lessons and units were student-centered with these "low floor, high ceiling, wide walls" activities because they allowed students multiple entry points, multiple ways to approach a problem and encouraged both creativity and curiosity (Gadanidis et al., 2011; Gadanidis, 2015). The instructors/teachers were more focused on students learning these character-building skills in which students were able to transfer their knowledge across disciplines and solve creative problems in another context (Gess, 2017; Liao, 2016). The focus was not only on the academic skills, but on these rich tasks and authentic experiences that enhanced the students' overall learning experience and made the experience more meaningful. As educators, researchers and policy makers the goal should be the same to teach students skills that are useful to them and get students to transcend their knowledge across a discipline so that it can be applied to another context, rather than focussing on a specific standard, concept or discipline.

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# Appendices

## Appendix A. Ethics Approval Form

Western Research

**Western University Non-Medical Research Ethics Board**
**NMREB Delegated Initial Approval Notice**

**Principal Investigator**: Dr. Immaculate Namukasa
**Department & Institution**: Education\Faculty of Education,Western University

**NMREB File Number**: [redacted]
**Study Title**: STEAM Education: Investigating the Integration of the Arts

**NMREB Initial Approval Date**: March 17, 2017
**NMREB Expiry Date**: March 17, 2018

**Documents Approved and/or Received for Information**:

| Document Name | Comments | Version Date |
|---|---|---|
| Instruments | Focus Group Interview. Received January 5, 2017. | |
| Instruments | Instructor/Teacher Interview. Received January 5, 2017. | |
| Instruments | Student Interview. Received January 5, 2017. | |
| Instruments | Post-Interview Director. Received January 5, 2017. | |
| Instruments | Pre-Interview Director. Received January 5, 2017. | |
| Instruments | Introductory Interview Director. Received January 5, 2017. | |
| Instruments | Classroom Observation Protocol. Received January 5, 2017. | |
| Recruitment Items | Email Script for Recruitment | 2017/02/16 |
| Western University Protocol | Received March 7, 2017. | |
| Letter of Information & Consent | Parents | 2017/03/07 |
| Letter of Information & Consent | Instructor | 2017/03/07 |
| Letter of Information & Consent | Director | 2017/03/07 |
| Letter of Information & Consent | Classroom Teacher | 2017/03/07 |
| Revised Assent | Student | 2017/03/07 |

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the above named study, as of the NMREB Initial Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Ethics Officer, on b[redacted]MREB Chair or delegated board member

EO: Erika Basile ___ Nicole Kaniki ___ Grace Kelly ✓ Katelyn Harris___ Nicola Morphet ___ Karen Gopaul ___

**Western University, Research,** Support Services Bldg., Ste. 5150
London, ON, Canada N6G 1G9 t. 519.661.2161 f. 519.661.3907 www.westernu.ca/research

**Appendix B. Email for Recruitment**

Western

## Email Script for Recruitment

**Subject Line: Invitation to participate in research**

Hello director/principal/teacher/parents,

We have received your email address from the teachers/instructors/parents involved in the STEAM program. You are being invited to participate in a study that we, Immaculate Namukas and Marja Miller are conducting.

The purpose of the research study is to explore different curriculum and instruction models of STEAM education. The study involves interviews, observations, photographs of students working and student work products, and photocopies of student work.

The time commitment will be minimal and the observations will occur during the regularly scheduled lesson. The interviews with adult participants will be 40-60 minutes long, while the student interviews will be a maximum of 15 minutes. All the observations, interviews and other items listed above will be done at the location of the STEAM lab/center/program.

If you would like more information on this study or would like to receive a letter of information about this study please contact the researcher at the contact information given below.

Thank you,

Immaculate Namukasa
Western University
[redacted]
(519) 661-2111 X [redacted]

Marja Miller
Western University
[redacted]

Version Date: 16/02/2017

## Appendix C. Sample Letter of Information and Consent

Western

# Letter of Information and Consent

**Project Title: Steam Education:** Investigating the Integration of the Arts

**Document Title:** Letter of Information and Consent – Instructor/Teacher

**Principal Investigator + Contact:** Immaculate Namukasa, PhD, Faculty of Education, Western University; [redacted], 519 661 2111 [redacted]

### 1. Invitation to Participate

My name is Marja Miller and I am a master's student at Western University, Faculty of Education in curriculum studies. I am currently conducting research on STEAM education and would like to invite you to participate in this study.

### 2. Why is this study being done?

The purpose of the research study is to explore different curriculum and instruction models of STEAM education in a non-profit and in school environment (e.g. students in schools, STEAM lab/center, STEAM club, STEAM teachers in schools, school principals, and school leaders in charge of steam programs in schools, school board research officers, if applicable).

### 3. How long will you be in this study?

The study will take place in the Spring term 2016-2017.

### 4. What are the study procedures?

If you agree to participate in this study you will be asked to participate in one interview. The interview will be done after the observation and will take 20-30 minutes. The interview will occur at a place that is convenient for you and will be audio recorded.

As the researcher I will be conducting interviews and observations of your students. The class observation and individual student interviews will occur during the lesson. The students who consent to participate in the study will be asked to participate in one in class interview and one group interview. The in class interviews with the students will be informal, asking them about their project(s) and experience in the STEAM program. The students will also participate in one group interview 15 minutes before or after the observation. Their written work will be photocopied for the study. I hope to capture how the students plan and communicate through their drawing/writing. Photos of the students working on their projects and the final product will also be taken. I want to understand better what the students are learning and making in the STEAM program.

If the names of the teachers or students who are not part of the study are inadvertently heard in the audio or video recording the researcher will edit the interview transcript to ensure that they are not included. I will be using personal quotes from the interview transcripts as an illustration, to deepen the readers understanding and to give participants a voice.

You will be provided with a copy of the transcript of your interview responses to review and make any changes to it as you wish. This might take 20 minutes. The information collected will be used for research purposes only, and neither your name nor information which could identify you will be used in any publication or presentation of the study results.

### 5. What are the risks and harms of participating in this study?

There are no known risks to participating in this study.

### 6. What are the benefits of participating in this study?

Benefits of participating in this study have the potential to positively affect the implementation of STEAM education in schools and in outside school programs.

### 7. Can participants choose to leave the study?

Participation in this study is voluntary. You may refuse to participate, to answer any questions, or you may choose to withdraw from the study.

### 8. How will participants' information be kept confidential?

Representatives of The University of Western Ontario Non-Medical Research Ethics Board may require access to your study-related records to monitor the conduct of the research. All information collected for the study will be kept confidential. All study information will be stored in a locked cabinet. Data will be destroyed confidentially five years after publishing the study results. While we do our best to protect your information there is no guarantee that we will be able to do so. If data is collected during the project which may be required to report by law we have a duty to report. If the results of the study are published, your name will not be used.

**9. Are participants compensated to be in this study?**

You will not be compensated for your participation in this research.

**10. What are the rights of participants?**

Your participation in this study is voluntary. You may decide not to be in this study. Even if you consent to participate you have the right to not answer individual questions or to withdraw from the study at any time. If you choose not to participate or to leave the study at any time it will have no effect on your employment status.

**11. Whom do participants contact for questions?**

If you have any questions about the conduct of this study or your rights as a research participant you may contact the Office of Research Ethics, The University of Western Ontario at [redacted] or [redacted] If you have any questions about this study, if you require any further information regarding this research project or your participation in the study you may contact Immaculate Namukasa (519) 661-2111 [redacted] email: [redacted] or Marja Miller [redacted] email: [redacted].

**This letter is yours to keep for future reference.**

CONSENT FORM (Teachers- Audio or video recording)

**Project Title: Steam Education:** Investigating the Integration of the Arts

**Document Title:** Letter of Information and Consent – Instructor/Teacher

**Principal Investigator + Contact:** Immaculate Namukasa, PhD, Faculty of Education, Western University; [redacted], 519 661 2111 [redacted]

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction. I consent to:

Check all the items that apply

☐ Interview Audio Recorded

I consent to the use of:

Unidentified verbal quotes obtained from my interview transcripts used in the results and publication of this research study ☐Yes ☐ No

Name of teacher:

Signature of teacher: Date:

Name of Person Obtaining Informed Consent:

Signature of Person Obtaining Informed Consent:

Date:

## Appendix D. Pre-Interview for the Director/Program Founder

Pre-Interview: Director/Program Founder/leader

Adapted (Ghanbari, 2014; Misher, 2014)

<u>Introduction script:</u>

You have been implementing a STEAM curriculum in this STEAM program. In an effort to better understand the impact and successes/challenges of STEAM education the researcher would like to ask you to respond to a series of questions. This interview should take about 60 minutes.

All responses will be held confidential. No individual participant will be identified in the analysis of this interview. The researcher will be transcribing your responses as well as audio recording this session to guarantee accuracy. You will be given a transcript of your responses and if there are statements that were inaccurately recorded or information you feel uncomfortable sharing, it will be removed from the research study.

<u>Script:</u>

During this interview you will respond to 5 questions. Please provide as much detail in your responses as possible.

**Demographics Information:**

1. I am wondering about the initial motivations for opening up this STEAM program. What was your personal motivation for pioneering this program?

2. Who were the key individuals in establishing this program, and how did they assist in developing this program?

3. What is your vision for this STEAM program for the next five years?

**Curriculum Models:**

4. What makes this program different?

    **Probe, if needed:** than, for example, a traditional science, math, or technology learning labs/centers/programs

5. What are the student/program learning objectives of this program?

# Appendix E. Director/ Teacher-Librarian Interview

Director/Teacher-Librarian Interview

Adapted (Ghanbari, 2014; Misher, 2014)

Introduction script:

You have been implementing a STEAM curriculum in this STEAM program. In an effort to better understand the impact and successes/challenges of STEAM education the researcher would like to ask you to respond to a series of questions. This interview should take about 60 minutes.

All responses will be held confidential. No individual participant will be identified in the analysis of this interview. The researcher will be transcribing your responses as well as audio recording this session to guarantee accuracy. You will be given a transcript of your responses and if there are statements that were inaccurately recorded or information you feel uncomfortable sharing, it will be removed from the research study.

Script:

During this interview you will respond to 6 questions. Please provide as much detail in your responses as possible.

**Demographics Information:**

1. I am wondering about the initial motivations for opening up this STEAM program/Makerspace. What was your personal motivation for pioneering this program?

2. Who were the key individuals in establishing this program, and how did they assist in developing this program?

3. What is your vision for this STEAM program for the next five years?

**Curriculum and Instructional Models:**

4. What makes this program different?

    a. **Probe, if needed:** than, for example, a traditional science, math, or technology classroom

5. What are the student/program learning objectives of this program?

6. What type of curriculum or instructional model do you commonly use at this STEAM program/Makerspace?

7. Is there anything else you would like to share with me or ask me about?

# Appendix F. Teacher Interview

Teacher Interview

**Demographics/Accessibility**

1. What attracted you to work in the STEAM program/Makerspace as an instructor?

2. What prior experience do you have in STEAM education/Makerspaces?

3. How do you facilitate the individual needs of every student?

   **Probe, if needed:** Gender, age, socioeconomic status, special needs or giftedness

**Curricular and Instructional Models**

4. What style of teaching do you commonly use in this STEAM program/Makerspace?

**Benefits/Challenges**

5. What are some of the greatest benefits of this STEAM program/Makerspace that you have observed?

6. What are some of the challenges that you have observed or experienced working in this STEAM program/Makerspace?

7. What are some of the greatest benefits of collaborating with teacher-librarian or another teacher to create these design inquiry activities?

8. What are some of the greatest challenges of collaborating with teacher-librarian or another teacher to create these design inquiry activities?

**Post-Observation (STEM school learning):**

9. What do you think the students learned in the activity or lesson from your perspective?

10. How do you see the STEAM program/Makerspace as being similar or different from a typical classroom or school learning?

11. Is there anything else you would like to share with me or ask me about?

# Appendix G. Instructor Interview

Instructor Interview

**Demographics/Accessibility**

1. What attracted you to work in the STEAM program as an instructor?

2. What prior experience do you regularly draw from when working in this STEAM program?

3. What type of training, professional development, or resources did you receive to prepare you to work with children in this STEAM program?

4. How would you describe the types of students demographically that come to the STEAM lab?

5. How do you facilitate the individual needs of every student?

   **Probe, if needed:** Gender, age, socioeconomic status, special needs or giftedness

**Curricular and Instructional Models**

6. What are the different types of activities that are offered at this STEAM lab/center/program?

   **Probe, if needed:** I am wondering if you follow some set program or model?

7. What style of teaching do you commonly use in this STEAM program?

**Benefits/Challenges**

8. What are some of the greatest benefits of this STEAM lab/center/program that you have observed?

9. What are some of the challenges that you have observed or experienced working in this STEAM program?

10. What are some of the greatest benefits of collaborating with teacher-librarian or another teacher to create these design inquiry activities?

11. What are some of the greatest challenges of collaborating with teacher-librarian or another teacher to create these design inquiry activities?

**Post-Observation (STEM school learning):**

12. What do you think the students learned in the activity or lesson from your perspective?

13. How do you see the STEAM lab/center/program as being similar or different from a typical classroom or school learning?

14. Is there anything else you would like to share with me or ask me about?

# Appendix H. Student Interview

Student Interview

Adapted from ROM in My Backyard Pilot Project – Club STEAM (Johnston & Tolkunow, 2016)

1. What has been your favourite activity at the STEAM program/Makerspace so far?

2. Why is your favourite STEAM activity?

3. What is one cool thing you've learned so far in the STEAM program/ Makerspace?

4. What have you learned about Science, Technology, Engineering, Arts and Mathematics so far at the STEAM program/Makerspace?

# Appendix I. Focus Group Interview

Focus Group Interview

Written verbatim

Adapted from Cooperman (n.d.); Krueger & Casey 2000, 2002; Krueger et al. 2001

**Script:** Welcome my name is Marja Miller and I am a master's student at Western University, Faculty of Education in curriculum studies.

Our topic of the focus group discussion today is STEAM education. The results will be used to better understand how classroom teachers view STEAM education models, both in a non-profit context and in-school contexts.

You were selected because of your experience and expertise teaching STEM (Science, Technology, Engineering and Mathematics) subjects at the elementary level in the public school system.

**Guidelines:** There is no right or wrong answers, only differing points of view

- We are tape recording, one person speaking at a time
- We are on a first name basis
- You don't need to agree with others, but you must listen respectfully as others share their views
- My role as moderator will be to guide the discussion

Let each of us introduce ourselves the grade(s) we teach, school we teach at and what we know about or our involvement in STEAM education.

I am going to begin by sharing with you, through a 20 minute presentation, what I have learned about the STEAM models used through conducting four case studies of STEAM programs in an out-of-school and in-school contexts in Ontario.

**Open-Ended Questions**

1. What interests or experiences do you have with STEAM in the classroom?

   Probe: What areas of STEAM education interest you? What types of STEAM activities have you seen or implemented in the classroom?

2. What do you like about the STEAM models presented?

   Models: Maker Education, the Launch Cycle, Hands-on Learning, Guided Inquiry, Design-Inquiry, Partnering and uTEC Maker Model.

3. What don't you like about the STEAM models presented?

   Probe: Who has a different perspective on that? How do others feel about that point? Can someone build on that?

4. In what ways could some of the models/stages presented be used to meet curriculum and teaching goals in a school classroom?

   Probe: How could it be useful (or not useful) in your teaching?
   Probe: Could you give me an example of how you might use some of the STEAM models in your classroom?

   - Stage 1: Building Curiosity
   - Stage 2: Data and Facts
   - Stage 3: Making and Refining
   - Stage 4: Real World and Thinking Forward

5. Overall what did you think of the STEAM programs I have shared?

   Probe: Can you tell me more about how you felt about the STEAM program? What would you change to make the program better?

6. Did any of the themes I mentioned stand out to you and why?

   Themes: Student-driven, Hands-on Learning, Student empowerment, Student engagement, Authentic experiences/Rich tasks, and Teacher collaboration

   Probe: Can you explain what you mean by . . . ?

7. Is there anything else you would like to comment on?

**Closing Thoughts (10 min)**

Before we end, are aspects of STEAM we didn't talk about that you want to bring up?

One last question.... We have time for each one of us to share one final thought. Anyone want to share?

**Closing (5 min total)**

Thanks so much for participating and sharing your opinions today.

**Thank you so much for your time!**

# Appendix J. Classroom Observation Protocol

## Classroom Observation Protocol

Adapted from Luna, 2015

Instructor ___________________________ Date _______________________

School ___________________________ Class_______________________

Observer___________________________ Time _____________________________

| **Research Question** |
|---|
| What curriculum and instruction models of STEAM education are implemented in non-profit and in school contexts? |

| **STEAM Classroom/Workshop Environment** | |
|---|---|
| **Organization of the STEAM lab**<br>➢ Take picture/video of STEAM lab | |
| **Number of Students:** | |
| **Use of Technology:**<br>*What types of tools and technology are used in this STEAM lab/center/program? Organization and access to tools and materials.* | |
| **Environment Checklist** | |
| **Check all that apply:** | |
| □ STEAM lab/center | □ Traditional Classroom setting |
| □ Visual Displays of STEAM projects | □ No examples of STEAM projects |
| □ Instructor Facilitator | □ Instructor lecturer/presenter |
| □ Instructor-student interaction positive | □ Instructor-student interaction negative |
| □ Student-student interaction positive | □ Student-student interaction negative |
| □ Grouped seating | □ Individual seating |
| **Notes:** | |

## Classroom/Workshop Activities

**Type of Instruction/pedagogy. Check all that apply:**

- ☐ Lecture/Presenter
- ☐ Class discussion
- ☐ Small group discussions
- ☐ Learning Centers/Stations
- ☐ Teaching/Student Interaction
- ☐ Other
- ☐ Problem-based learning
- ☐ Reading, seatwork
- ☐ Hands-on activity
- ☐ Cooperative learning
- ☐ Assessment

**Notes:**

| | |
|---|---|
| **The tasks and Activities** | |
| **Student Engagement:**<br>High: 80% or more engaged<br>Medium: 50-60% engaged<br>Low: 80% or more off task | ☐ Low ☐ Medium ☐ High |
| **Students' Attitude towards STEAM or STEM activities:** | ☐ Positive ☐ Negative ☐ Indifferent |
| **Differentiation:** | **Check all that apply:**<br>☐ Multiple ways to approach a problem<br>☐ Low floor and high ceiling approach to learning<br>☐ Open-ended problem with multiple outcomes<br>☐ Flexible and adaptable lesson plans<br>☐ Adaptation for learning disabilities and giftedness |
| **Arts integrated into the lesson:** | ☐ Seamlessly ☐ Added component ☐ N/a |

## Other Observations

**Check all that apply:**

- ☐ Collaboration
- ☐ Self-motivation
- ☐ Self-regulation
- ☐ Curiosity
- ☐ Problem-solving
- ☐ Other
- ☐ Communication
- ☐ Self-confidence
- ☐ Perseverance
- ☐ Innovation
- ☐ Critical Thinking skills

| Additional Notes |
| --- |
| |

# Appendix K. Curriculum Models in the STEAM Programs

STEAM Education Models in the STEAM Programs

## Non-Profit 1

**Maker Education Model**

(Inspired by Connected Learning, experiential learning and inquiry-based learning models)

Play

- Explore new tech
- Tinker/Experiment
- Take things apart

Design

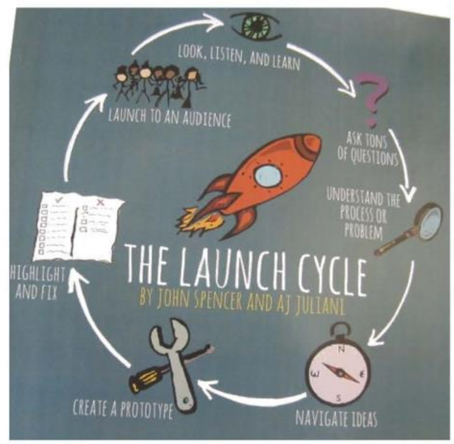
- Purpose behind what they're doing
- How it connects to their interests

Make

- Build
- Fail
- Iterate

Celebrate

- First time it works
- Describing it to someone
- Fail and learn




## Non-Profit 2

**The Launch Cycle**

1. **L**ook, Listen and Learn – Have a sense of wonder.
2. **A**sk a ton of Questions – Spark the students' interest and curiosity.
3. **U**nderstand the problem or the process – Through research.
4. **N**avigate ideas –Apply knowledge to solve a problem or create something new.
5. **C**reate a Prototype – Digital or tangible product.
6. **H**ighlight and fix – Note what works well and what needs modifications. Students need to know that each mistake takes them closer to success.
7. Now it's ready to launch it to an audience. They share their work with an authentic audience and might even share it with the world.

## Non-Profit 2

**Hands-on Learning Model**

**"Hands-on"** as "relating to, being, or providing direct practical experience in the operation or function of something; involving or allowing use of or touching with the hands; characterized by active personal involvement; gained by actually doing something rather than learning about it from books, lectures, etc." **Basically, hands-on learning is learning by doing**. We have the STEAM kids' classes, so hands-on versus digital literacy. Source: https://www.merriamwebster.com/dictionary/hands-on)

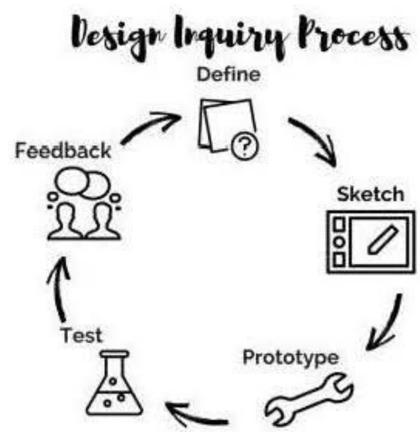
## In- School 1

**Guided Inquiry Model**

**ASK** when it comes to exploring, **Collecting ideas** so that's the big idea when it comes to investigating, Processing information that's the **PLAN**, and then the creating portion I have just put the word **MAKE** so it coincides with the Makerspace and it's a cyclical, cyclical still so they know that it doesn't necessarily end after you make that first thing. We call them STEAM cycles or inquiry cycles for each unit/lesson.

## In- School 2

**Design-Inquiry Model** (Curriculum and Instructional Model)




**Define:** What interests you? What might you like to build? Who will the product be designed for? What purpose or function will your product serve?

**Sketch:** What might the product look like? What materials will you need? Where can you find resources that help you build it? (Place YouTube or website links here)

**Prototype:** How might you break down the big project into smaller steps?

**Test:** Which components are most important/need to be done first? What works well and what needs to be modified?

**Feedback from your peers:** Moving forward and reflecting on the process.

## In-School 2

**Partnering Model**

The teacher is learning alongside the student. In the Partnering model the teacher is not the expert, but a facilitator/collaborator with the student.

**uTEC Maker Model**
https://sites.google.com/site/utecmakermodel/

**U for Using:** Enjoying; Sampling; Engaging; Playing; Participate in or experience what others have created

**T for Tinker:** Playing; messing around; Questioning; Researching: Making personal changes to others' creation

**E for Experimenting:** Building; Trying/Failing; Repurposing: Modifying and testing theories; Learning from failure / success

**C for Creating:** Inventing; Producing; Entrepreneurship: Novel product; Ideas; Inventions

# Appendix L. Sample Curriculum Document Non-Profit 1

Non-Profit 1: Imagineering

**Description**
Imagineering is a class that introduces kids to the fundamental skills of making and programming. Students will take part in activities that teach 21st century skills, such as collaboration and critical thinking, through games and storytelling. At the end of the class, they will be given the opportunity to apply these skills to a hands-on project using hand tools, craft materials, and digital fabrication tools (3D printers and the laser cutter). By focusing on these dispositions, students can develop a more permanent understanding of concepts in engineering and computer programming which translate to making and beyond.

**Lesson Plan**
Activities are meant to have a low-threshold and high ceiling, to differentiate instruction among age groups and abilities in the class

**Routine**
Come up with activities that encourage critical thinking
Encourage students to make connections between the dispositions developed in the class with real-world examples

Introduce show the beginning of the story or problem and the end
"*explain-experimenter*'s reasoning group were given corrective feedback by an experimenter, then asked to explain the experimenter's reasoning (e.g., "Actually the two rows are the same. How do you think I knew that?")...encouraging children to think about and explain someone else's reasoning provides a valuable teaching method for advancing students' thinking and learning. Requesting explanation of someone else's thinking is also an especially feasible teaching method, based as it is on children's interest in and capacity for *psychological explanation*." (Wellman & Lagattuta, 2004, p.493)

**Introductory Routine**
Introduce a concept in the beginning of class to create a mental set related to the day's activities
Choose activities that challenge the student's causal reasoning
Encourage them to create hypothesis to draw out preconceptions and misconception

**Closing Routine**
Reintroduce the concept from the beginning of the class

Resources
https://studio.code.org/s/course2

**Week 1 - Introduction to Logical Thinking**
Happy maps

Theme and Mental Set
Community

Assessment
Behavior

Resources
https://studio.code.org/s/course1/stage/1/puzzle/1

**Week 2 - Logical and Collaborative Thinking**
Continue with happy maps

Theme and Mental Set
Picture book: *The Boy and The Airplane*
Wordless picture book
Open discussion on logic -- use to review *Happy Maps*
Community
Introduction to Theory of Mind

Assessment
Interaction Behavior

Resources
https://www.youtube.com/watch?v=VGi2bnRFqzM

**Week 3 - Introduction to Programming**
Look at Graph Paper Programming

Theme and Mental Set
Picture book: *The Boy and The Airplane*
Logical Thinking

Assessment
- Theory of Mind
  Logical

Resources
https://youtu.be/Yy1zbkfRtIg

**Week 4 - Building a Foundation**

Mental Set
Picture Book: *Rosie Revere, Engineer*
Introduction of Growth vs. Fixed Mindset

Resources
https://www.youtube.com/watch?v=eZqKqI8AvnA
http://community.mindsetworks.com/blog-page/home-blogs/entry/mistakes-are-not-all-cr eated-equal

**Week 5 — Real-Life Algorithms**
NEED AN ACTIVITY (CONSTRUCTION)
Instructions using pictures

Mental Set
Introduce mistakes as a review of the previous week's activity
Picture Book: *The Girl Who Never Made Mistakes*
Mistakes

Identify mindset mistakes
Stretch mistakes
Aha-moment mistakes
High-stakes mistakes
Sloppy mistakes

**Week 6 - Building a Foundation with Algorithms (small group)**

Mental Set
Picture Book: *The Most Magnificent Thing*
Making connections between mistakes and the growth mindset

**Week 7 – Building a Foundation with Algorithms (large group)**

Mental Set
Picture Book: *Iggy Peck, Architect*
Collaboration
Theory of Mind

**Week 8 - Applications in Design**

Mental Set
Picture Book: *The Dot*
Generating ideas

**Week 9 - Applications in Design**

Mental Set
Picture Book: *What Do You Do With an Idea?*
- Committing to ideas

**Week 10 - Applications in Design**

**Works Cited**

Wellman, H. M., & Lagattuta, K. H. (2004). *Theory of mind for learning and teaching: The nature and role of explanation. Cognitive Development, 19*, 479-497.

http://www.ascd.org/publications/books/103027/chapters/Mental-Set.aspx

http://community.mindsetworks.com/blog-page/home-blogs/entry/mistakes-are-not-all-created-e qual

http://www.visiblethinkingpz.org/VisibleThinking_html_files/06_AdditionalResources/makingthink ingvisibleEL.pdf

# Appendix M. Sample Curriculum Document Non-Profit 2

Non-Profit 2: Program Summary, Technology and Materials

**STEAM Kids 101**
Discover the exciting world of Science Technology Engineering Art and Math. Get a taste of 3D printing, Digital Design, Coding, new technologies, and other fun ways of learning 21st century skills. Ages 6-8. 4 sessions.
Technology used: Scratch coding software, laptops, FDM 3D printer, LASER cutter, Shrinky Dink Plastic and toaster oven, recycled pop bottles as part of Cartesian diver project, potentially Little Bits Ozobots and Spheros depending on the session.

**Creative Coding: Ozobots**
Ozobot-a tiny robot, big on fun! Learn to code the Ozobot using colours, lines, games and drag and drop block coding. A great introduction to coding and robotics. Ages 6-8. 4 sessions. Technology used: Ozobots, Ozobot Evo, Laptops, Ozoblockly Coding Ozoblockly Games, Marker coding using paper and markers, iPad Ozobot games.

**STEAM Artist: Craft Makers (Kids 6-8)**
Learn the crafty side of STEAM. Have fun learning valuable skills while creating with your own two hands. Maker Spaces are for makers of all ages! Ages 6-8. 4 sessions.
Materials used: Paper, Pens, Markers, Pencils, Card stock, Acrylic Paints, Hardboard.
Technology used: The LASER Cutter and Gravit.io are used to help structure th making of a Jigsaw Puzzle. iPad is used to scan hand drawn images.

**STEAM Makers: Laser Cutting (Kids 6-8)**
Learning the joy of creating with the laser cutter! Begin your Maker journey and discover the joys of design and engineering. Create, design, prototype, test, redesign, and repeat! Ages 6-8. 4 sessions.
Materials used: Plywood, cardboard, paper, pens, glue, craft supplies.
Technology used: LASER Cutter

**Creative Coding: Intro To Coding With Scratch (Kids 6-8)**
See how easy learning computer coding can be! Scratch is all about fun games and playful learning with the amusing Scratch Cat. Enjoy digital literacy by learning to code with friendly drop and drag colour coded blocks. Ages 6-8. 4 sessions.
Technology used: Laptops and scratch.

**STEAM Artists: Ultimate SLIME Makers (Kids 6-8)**
Slime, slime, slime and yes, even more SLIME!!! Lots of goopy, gloppy, gushy new creative ways to learn experimental science. Ultimate Slime recipes that you will be sure to love. Ages 6-8. 4 Sessions.
Materials used: PVA glue, glitter, contact lens solution, milk, water, plastic cups, ziplock bags.

**STEAM Makers: Little Engineer (Kids 6-8)**
Ask questions, explore your curiosity and become a problem solver! Little Engineers will discover the fundamental concepts of energy, materials, and movement.
Ages 6-8. 4 Sessions.
Materials used: Balloons, string, popsicle sticks
Technology used: Little Bits, LASER Cutter, Circuit Blocks, Ozobots, Spheros

**Creative Coding: Celebrate Coding (Kids 6-8)**
Celebrate coding! It's "Hour of Code". Go above and beyond the Hour of Code while playing with a

range of coding activities on and off the computer
during the month of hour of code. This is your chance to shine as a courageous coding champion and show your friends the joy of coding. Ages 6-8. 4 Sessions.
Technology used: Code.org projects, Scratch coding, Micro:Bit

**STEAM Artist: Jewellery (Kids 6-8)**
Every piece of jewellery has a story, discover yours! Create your very own jewellery using 21st century STEAM tools. Create cool buttons, wristbands and hair accessories that you customize. Ages 6-8. 4 Sessions.
Materials used: Plywood, acrylic plastic, acrylic paint, Craft supplies, embroidery thread, beads, magnets, pins. PLA plastic
Technology used: LASER Cutter, 3D Printer

**Kids Coding - Video Game Coding from Scratch**
A fun, informal class for beginners to learn to create your own video games using M.I.T. Media Lab's programming language, "Scratch". Students will start to develop 21st century digital literacy, creative problem solving and teamwork while making a series of interactive animations and games. Build a world of ideas! Creative technology, 3D design and Science projects for kids. Not only will these courses build kid's creative confidence, it will also introduce them to some amazing digital tools to gain 21st century Grades 3 to 7. 5 weeks.
Technology used: Laptops, Scratch

**STEAM Makers: 3D Printing (Kids 9-12)**
Design and print your own 3D creations! 3D printing is one of the fastest growing fields of design. Have fun expanding your design skills while learning the secrets of creating in 3D. 4 sessions.
Technology used: Tinkercad, Magica Voxel, Cura, Preform, Form Labs 3D printer, Lulzbot 6 3D Printer, Lego

**Creative Coders: Get in the Game (Kids 9-12)**
Love playing video games, then put yourself right in the game! Using drag and drop block coding and green screen technology, become the hero of your very own game that you code and design. Digital literacy has never been so fun!
Technology used: Green screen, scratch, laptop, iPad, Piskel App, Magica Voxel

**STEAM Artist: Drawing and Painting (Kids 9-12)**
Learn to look at the world in a creative and exciting way. Get to know the basics to start on your journey to becoming a master designer.
Draw and paint using STEAM technologies that bring art to a new level.
Materials used: Craft Paper, sketchbooks, watercolour paper, art pencils, acrylic paint, sharpies, plastic ribbon.
Technology used: Graphics Tablets, iPads, Belkin stages, online avatar design software.

**STEAM Makers: Laser Cutting (Kids 9-12)**
Discover why the Maker Movement loves Laser Cutting! Learn essential design and engineering skills to build your digital vocabulary and technology skills. Create, design, prototype, test, redesign, and repeat!
Materials used: Plywood, cardboard, paper, pens, glue, craft supplies.
Technology used: Laptops, iPads, Gravit.io, box making software

**Creative Coders: micro:bit Games (Kids 9-12)**
The Amazing BBC Micro:bit is a serious gateway to FUN!! The Micro:bit uses block based coding, lights, buttons and sensors to inspire a new generation of play. Connect it, program it, download it, play it and then master it!
Technology used: BBC Micro:bit, Lego EV3s, laptops, Scratch coding, Makecode coding

**STEAM Artists: Printmaking (Kids 9-12)**
Let your creativity, love of design and technology soar! Printmaking is a fantastic way to combine craftsmanship with 21st century technology and learn spatial reasoning, the fundamentals of drawing and elements of design.
Materials used:
Mylar sheet, cloth, screen printing frame, screen print ink, screen print squeegee, Lino print materials, laser engraving rubber.
Technology used: Laptops, LASER Cutter, Gravit.io, Inkscape, Corel Draw, scanning

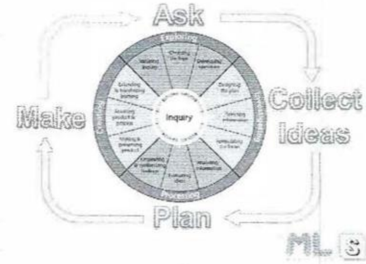
**STEAM Makers: Stop Motion Animation (Kids 9-12)**
Produce and direct your very own stop motion animation! Enjoy watching ordinary objects move, run and come alive through the magic of stop motion animation. Your child will create the storyline, backgrounds and characters in their original creation.
Materials used: Modeling clay, miniature green screens, cardboard, Legos, paper, craft supplies.
Technology used: iPads, LASER Cutter, Stop Motion Studio

**Creative Coders: Intro to Coding –Hour of Code– (Kids 9-12)**
Go above and beyond the Hour of Code while playing with a range of coding challenges and games on the computer during the month of hour of code. This is your chance to shine as a courageous coding champion and show your friends the joy of coding.
Technology used: Scratch 3.0 Beta, Micro:bits, Python online coding

**STEAM Artist: Jewellery (Kids 9-12)**
Start a new fashion trend! Learn to make unique jewellery that you design! Use the laser cutter to make pendants, earrings and more!
Materials used: Jewellery fasteners, wire, enamel paint, acrylic plastic, hardboard, plywood
Technology used: Laser Cutter, Hand tools, Toaster oven

# Appendix N. Sample Curriculum Document In-School 1

## MakerEd/Inquiry Skills Continuum

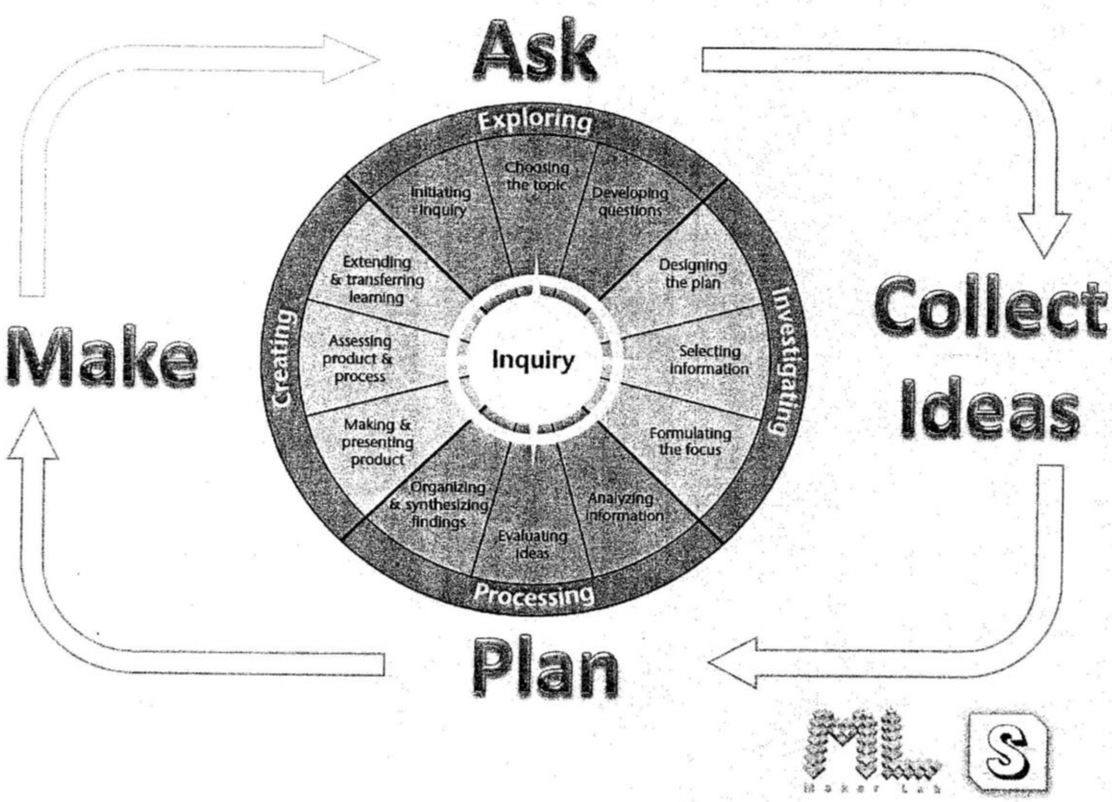



**Scaffolding traditional and modern skills development**
[while prompting/initiating inquiry tasks to meet grade level expectations/curriculum/social justice considreations]

The **MakerEd Teacher** will develop and strengthen makerspace skills while supporting curriculum.

The **Classroom Teacher** will develop and strengthen understanding of the curriculum while allowing students to express or explore ideas using makerspace skills whenever possible.

| SOFT SKILLS | Primary | Junior | Intermediate |
|---|---|---|---|
| Guided Inquiry Model | Beginning | Explicit | Strengthen |
| Curiosity & Imagination | Explicit | Strengthen | Strengthen |
| Oral Communication | Explicit | Strengthen | Strengthen |
| Written Communication | Beginning | Explicit | Strengthen |
| Initiative | Explicit | Strengthen | Strengthen |
| Growth Mindset / Adaptability / Persistence | Explicit | Strengthen | Strengthen |
| Collaboration | Beginning | Explicit | Strengthen |
| Critical Thinking / Problem Solving | Beginning | Explicit | Strengthen |
| Accessing Information / Analyzing Information | Beginning | Explicit | Strengthen |



# Appendix O. Sample Curriculum Document In-School 2

In-School 2 Curriculum Document

**Constructing Knowledge: Reading, Playing, Thinking, Making, Sharing, Reflecting Math is mPower-ful!**

As a teacher librarian in our school, one my most important roles is to facilitate and spark meaningful learning experiences for our learners (staff included!). I often like to refer to myself as a "maker-librarian". Indeed, it is my goal in all learning to enable and engage our students; to foster making experiences that: 1) directly link to the curriculum and 2) use a variety of tools tailored to our students', interests and skill sets.

One of our favourite ways to encourage a maker culture in our school is by providing opportunities for teachers and students to collaborate in the LLC utilizing great literacy. Books serve as a wonderful provocation and meaningful way to provide context for making and connecting to a text, while utilizing technology to share, empower and inspire.

As a long time advocate of TVO and an active member in the TeachOntario community, we have been promoting the use of mPower in our school as a tool to help engage and support the varied needs of our learners. While most classes are using this tool indirectly to scaffold learning in centers or at home, this week our grade three class is going to actively utilize it to scaffold our explorations regarding perimeter.


In our learning commons, we like to broach making using a four part lesson framework (an adaptation of Dr. Marian Small's Three Part Lesson).

With the addition of mPower to support and scaffold learning, the four part lesson plan is slightly modified to reflect a design inquiry approach.

Our learning goals for this lesson will include, but are not limited to the following:

- I am learning how to express personal thoughts and feelings about what has been read
- I am learning how to sort ideas and information to express my thinking
- I am learning how to problem solve and work as part of a team
- I am learning how to estimate, measure, and record the distance, using standard units
- I am learning how to draw items using a ruler, given specific lengths in centimetres
- I am learning how to estimate, measure, and record the perimeter of two-dimensional shapes, through investigation using standard units

- I am learning how to create simple and/or complex scripts and understand algorithms; debugging programs when I run into challenges
- I am learning how to create multimedia artifacts to communicate and share my thinking

**Minds On:**

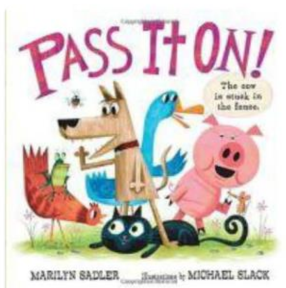
We are going to begin our learning with an image of a fence.

**What do you see? What do you notice?**

**What do you think is happening?**

**What might need to happen next?**

**Let's Read, Practise and Plan!**




*Read* - The mentor text for learning is *Pass It On*!

**How might we recreate a big enough fence for Cow to graze? And build it so that she won't get stuck?**

**How might we create a fence with a perimeter of __________?**

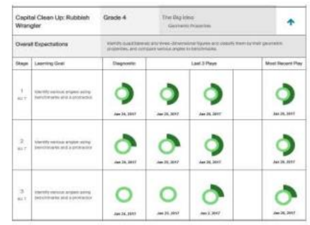
**What math might we need to practice and use?**

*Practise*


mPower's Fencing Frenzy is a great game that we will use help students gather the mathematical knowledge and practise the computational skills they will need in order to construct a fence for Cow. This game, like all mPower games, is designed to work in response to the student's learning process in order to meet their individual learning needs. If a student is experiencing difficulty, the game will trigger scaffolding. If the student becomes frustrated, he/she will be given incentives to keep engaging and think more rigorously about the math. Students who acquire the concepts more readily will play the game less, and will act as leaders to help mentor their peers.

As students play, they will be encouraged to document their learning by taking screenshots of their work for later curation and reflection. What are they finding difficult? Where did they succeed? What strategies did they use?

Once a sufficient time has been allocated for exploration and discovery, we will use the the mPower assessment reports as a diagnostic tool to gather information about student strengths and next steps in learning. These reports will serve as an invaluable resource in the formation of our future guided groups for making in math - we can look for the students with similar results and pull them together to receive a mini-lesson - and/or create mixed ability groups to facilitate peer mentorship and instruction.




*Plan*

Based on the mPower reports we will create groups based on the current needs of our students.

After students are placed into groups, we will co-construct our success criteria for documentation and reflection. It is hoped that together we can come up with a list of success criteria similar to the following:

- I can document and explain some of my successes, strategies and difficulties calculating perimeter using mPower
- I can document my plan and how it may have changed
- I can document the measurements of the fence
- I can document our calculations of the perimeter
- I can document our most important learning skill

In groups, students will draft up a plan for a fence that will allow Cow (a cow plush toy) enough room to graze. The fence should also be constructed so that Cow will not get stuck inside. Fence designs must have a perimeter of (perimeter to be determined) _______________cm. Students will be provided with an iPad in order to document their learning.

**Let's Make, Tinker and Modify!**

Once plans have been constructed, students will be presented with a variety of loose parts in order to construct their fence. Students are encouraged to continue to document their learning process with their iPads. They are also encouraged to make notes on their plans of any changes to their designs.

Once fences are completed, and depending on the interest of the group, we may choose to test out our fences and program a path for a Beebot (disguised as a cow) to meander through.

Students will do a gallery walk to view all the constructed fences.
Peers will give feedback to each other's designs using the two stars and a wish format.

**Let's Connect and Reflect!**

Students will refer back to the success criteria to curate evidence of their learning using the documentation they've collected on their iPads. They will use the photos they've taken to create an artifact that illustrates their learning journey on a curation app of their choice that best suits their needs (ie iMovie, Pic Collage, Book Creator, Educreations, Google Docs with the Read&Write extension).

Possible questions for reflection:

- What did you learn?
- What did you struggle with? Where did you find help? What strategies did you use?
- How did your learning unfold? What did you do first? Second?
- What was your most important learning skill you used in order to succeed? Collaboration? Creativity? Critical Thinking? Communication?

Students are encouraged to create notes to help explain their thinking and creations when their artifacts are shared at home and with the school through student portfolios and classroom/library learning commons documentation panels.

Making learning visible in this manner allows for dialogue to occur about learning not only amongst students, but amongst learning communities in order to drive learning forward. We are all learners and researchers with our students; we need to model our own maker mindsets in the pursuit to uncover rather than cover the curriculum. It is when we honour our students' interests, questions, and discoveries that *mPowerment* occurs.

# Curriculum Vitae

| | |
|---|---|
| **Name:** | Marja Gabrielle Bertrand |
| **Post-secondary Education and Degrees:** | Western University<br>London, Ontario, Canada<br>1999-2004 B.Sc. |
| | Western University<br>London, Ontario, Canada<br>2004-2005 B.Ed. |
| | Western University<br>London, Ontario, Canada<br>2016-2019 M.A. |
| **Honours and Awards:** | Province of Ontario Graduate Scholarship<br>Honors Roll for academic performance 1994-1999<br>Deans Honor List 2001-2003 (also during B.Ed. and M.A.) |
| | Joan Pedersen Memorial Graduate Award.<br>2018-2019 |
| **Related Work Experience** | Instructor Preservice Teachers<br>Education Research Assistant (RA)<br>The University of Western Ontario<br>2016-2019 |

**Publications:**

**Miller, M.**, & Namukasa, I. (November 2018). STEAM movement in Ontario, Canada: A case study on the curriculum and instructional models of four STEAM programs. Paper presented at the 5th *International STEM in Education Conference,* Queensland University of Technology (QUT), Brisbane, Queensland, Australia. Available at https://stem-in-ed2018.com.au/proceedings-2/

Namukasa, I., & **Miller, M.** (November 2018). Integrated computational thinking and mathematics thinking: An analysis of two geometry activities. Paper presented at the *5th International STEM in Education Conference*, Queensland University of Technology (QUT), Brisbane, Queensland, Australia. Available at https://stem-in-ed2018.com.au/proceedings-2/

Namukasa, I. K., Patel, M., & **Miller, M.** (2017). Introductory CT and math in the middle grades: Tools and resources. *Math + Code 'Zine, 2(2).* Available at *http://researchideas.ca/mc/ct-and-math-in-middle-grades/*

**Miller, M.**, & Wojnarski, S. (2017). Fusion of art and computational thinking (extended version). *Vector, 58(1), 28-32.* Available at *http://www.bcamt.ca/wp-content/uploads/2017/05/581-Spring-2017.pdf*

**Miller, M.**, & Wojnarski, S. (2016). Fusion of art and computational thinking. *Math + Code 'Zine, 2(1).* Available at *http://researchideas.ca/mc/art-ct/*

**Presentations & Workshops:**

Namukasa, I., & **Miller, M.** (September 2018). Computational making and "Mathematics Art" activities in the context of STEAM in schools. Microtalk presented at the *Digitally Engaged Learning (DEL)* Conference, York University, Toronto, ON.

Namukasa, I.K., Banks, A., Macintosh, S., **Miller, M.**, Roy, B., Tangredi, D., & Computational Thinking Team at Western (May 2018). Coding, computational thinking, and maker space tools and activities in schools: A maker workshop. Workshop presented at the *Ontario Association of Physics Teachers (OAPT)* Conference, Western University, London, ON.

**Miller, M.** (April 2016). STEAM education: The benefits of integrating the arts. Paper presented at the *Robert McMillan Symposium,* Western University, London, ON.

**Miller, M.** (February 2016). From STEM to STEAM: Success for all students in mathematics. Workshop presented at Brock University for Teacher Candidates, Hamilton, Ontario.