Examining Informal Makerspace Learning Environments:
Using Inquiry-based Learning to Facilitate Critical Thinking Skill Development

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Abstract

Makerspaces have emerged into the educational environment as a place to enable learners to develop needed 21st century learning skills (Bowler & Champange, 2016; Bevan, 2017). Learners need to develop critical thinking skills to enable success in an ever changing, more technologically fluent world. With the student-directed nature of a makerspace, pedagogies such as inquiry-based learning may allow for the promotion of critical thinking using questioning, reflection, analyzing data and expressing information to others (Lemley, Schumacher, & Vesey, 2014; Vossoughi & Bevan, 2014). Inquiry-based learning aligns with the 21st century skill of critical thinking as it is the ability to reflect, analyze and evaluate (Loes & Pascarella, 2017; Ventura et al., 2017); creating more emphasis on the potential value of a makerspace, the student-directed nature, and the fact that inquiry-based learning requires critical thinking about a topic. This qualitative case study research aims to investigate informal makerspaces that use inquiry-based learning pedagogies to determine if they, in fact, facilitate the goal of critical thinking development. Through semi-structured interviews with facilitators and instructors in informal makerspaces meaningful and informative insights were gained regarding this unique, informal learning environment; analysis of the data will deepen our understanding of makerspaces, particularly where inquiry-based learning pedagogy is utilized to achieve the goal of developing critical thinking skills.

Keywords: Makerspace, 21st century skills, critical thinking, Inquiry-based learning, informal learning

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Introduction

Continually evolving information and communication technologies (ICTs) are embedded in the lives of youth, which may increase the need to use higher order thinking skills to meet the demands of society now and into the future (Bowler & Champagne, 2016; Cross, 2017; C21 Canada, 2012; Beichnern, 2014). Furthermore, the access to ICT has become increasingly more available for youth. This ease of access both inside and outside the classroom leads to more information being relayed causing an increased need to develop skills in analyzing large amounts of information (Steeves, 2014; Rideout & Robb, 2019). The way information is gained has become more instantaneous and available, in multiple formats, causing an r/evolution in how knowledge can be acquired (Beichnern, 2014). Cultivating an optimal environment to promote learning that harnesses the power of these new technology and can, if implemented well, increase development of higher order thinking skills, such as problem solving, critical thinking, creativity and collaboration, the skills needed in the 21st century is key (Lemley et al., 2014; Canada C21, 2012). Ideally, for this to occur, learning environments should include multiple mediums for student-directed exploration (Chu et al., 2018). Makerspaces are media-rich learning environments that encourage hands-on building with the use of ICT tools and traditional building tools (such as scissors, power tools and glue guns) for learner-driver exploration allowing a broad range of learning methods creating an opportunity to address the development of higher-order skills such as critical thinking. The pedagogies used in makerspaces focus on student-directed and active approaches and fit within a constructivist learning framework where learners construct their own knowledge, encouraging learners to innovate, be creative, and develop critical thinking and questioning skills (Kurti et al., 2014; MacKenzie, 2016). Further, the aspect of sharing information, which occurs in a makerspace relates to social constructivism or, more precisely, constructionism, a term associated with the creation of an artifact in a constructivist environment which commonly occurs in a makerspace (Papert & Harel, 1991). Specifically, pedagogical approaches such as inquiry-based learning can be useful to encourage such outcomes as higher-order thinking skills (Kurti et al., 2014; Chu et al., 2018). For example, learners in an inquiry-based learning environment, such as makerspaces, are encouraged to articulate their own questions leading to an increase in motivation and learner engagement. By analyzing makerspaces as a learning environment that activates student-directed learning pedagogies, it was possible to examine and understand how these dynamic, self-directed learning environments can be used to develop 21st century learning skills, in particular, critical thinking, in a renewed processive and forward-looking manner. This investigation focused on the development of critical thinking, as demonstrated, and facilitated in informal makerspaces.

Research Problem

With the ever-evolving development of new ICTs (e.g., wireless networks, internet, and online platforms), the demand for well-designed educational environments that harness the 'pedagogical power' of these new ICTS; learners will also need to reconcile their learning skills in order to prepare for current societal needs (Canada C21, 2012; Ventura et al., 2017). One strategy to enable the development of learning skills is to foster and facilitate the development and maintenance of *curiosity* in youth; this state-orientation is important to create opportunities for learners to use critical thinking to solve problems of any variety and novelty. However, the complexity of developing these skills in a traditional educational setting is not easily achieved (Canada C21, 2012; Sasson et al., 2018; Lemley et al., 2014). The emergence of makerspaces has provided new options for creating engaging "multiple media" education, which includes a variety of technologies and tools for hands-on exploration. In a makerspace there is "an interplay of high and low technologies, producing a sense of playfulness or the unexpected" (Bevan, 2017, p. 78); learners are encouraged to explore and move beyond their own experiences and thinking to test their ideas and understanding, using new (or even familiar) technologies and materials. In other words, exploration in a makerspace can mean interacting with high tech, such as 3D printers or building Arduino powered robots, but also combine with the use of basic craft supplies, and tools (glue guns, soldering irons, and power tools). However, since makerspaces use active learning pedagogies, including project-based learning, problem-based learning, inquiry-based learning, and design thinking, all having constructivist epistemologies, more variations in the learning outcomes may be evident (Bowler & Champange, 2016; Cattaneo, 2017). Historically, research has been conducted on makerspaces with much of the research on the design and purpose of makerspaces, participants use of materials and space, lessons carried out and assessments used in formal settings (DeRosa, 2016; Litts, 2015; Cross, 2017; Martinez & Stager, 2013; Bowler, 2014). There is a need, however, to expand the understanding of how these diverse learning outcomes interact with the material and pedagogically rich environment of a makerspace to develop higher order thinking skills, specifically critical thinking skills, in an informal makerspace setting. It is important to note that learners who are fluent in higher order thinking can easily adapt these skills to novel situations (Canada C21, 2012). Critical thinking, for example, is an important skill in decision-making, establishing a pathway for young learners to solve “real-world” problems. By focusing on critical thinking, as a specific and important 21st century learning skill, parameters can be clearly defined to understand how and if this skill can be developed in an informal makerspace learning environment.

Informal makerspace education can provide an opportunity to embed 21st century skills such as critical thinking, as it is an “open-ended, nonlinear, and often messy way to generate innovation and creative solutions” (Bowler, 2014, p.60). However, this non-traditional view of formal learning can create a misalignment of goals. A formal educational environment is traditionally teacher-directed. Most often learning occurs through traditional lecture style classroom and focused curriculum-based explorations. In contrast, informal education is often open-ended and has less ties to a formalized curriculum, where a teacher acts as a facilitator coaching the learner (Bevan, 2017). Informal learning is most often driven by intrinsic motivation, in which the drive to learn comes from the learner’s own motivation to explore and investigate topics of interest (Gutwill & Allen, 2009). Most makerspaces adopt this informal learning orientation to allow learners the freedom to explore, investigate and use inquiry-based skills to learn about phenomena. For makerspaces to facilitate the development of critical thinking skills. There is a need to move beyond a traditional context of education (i.e., teacher-directed) and examine non-traditional learning environments, such as informal makerspaces, that activate student-directed pedagogies. The paucity of research literature specifically investigating such learning environments points to a need to methodically investigate makerspaces as an informal learning environment that also implement inquiry-based pedagogies, to discover if they can be leveraged to promote the development of critical thinking skills. Therefore, this research seeks to investigate the following central question:

> *How are critical thinking skills activated, demonstrated, and developed in an informal makerspace where inquiry-based learning pedagogies are used?*

Secondary, but related research questions will also be examined, namely, to access the perspective of the facilitators:

According to the facilitators, in an informal makerspace where inquiry-based learning pedagogies are use:

1. *What instructional strategies used appear to help develop critical thinking skills?*
2. *How are critical thinking skills activated, demonstrated, and developed?*

Through this investigation in an informal makerspace which uses inquiry-based methods, a deeper and more thorough understanding of how facilitators of makerspaces encourage the development of critical thinking skills in youth was discovered and analyzed.

The research focus was to investigate and understand critical thinking skill development in informal makerspaces, skills that utilizes the student-directed and active learning pedagogy of inquiry-based learning. This understanding has been realized through a close examination of how facilitators and educators utilize inquiry-based learning instruction in an informal makerspace to develop critical thinking for school-aged youth. The methodology that was chosen to best support this investigation was a *qualitative instrumental case study* (Creswell & Poth, 2018). Primary qualitative data from semi-structured interviews with facilitators of informal makerspaces, selected from across Canada, provided the research data by which to examine the inquiry-based methods facilitators use in a makerspace, but will also investigates the potential of such contexts, technologies, and teaching methodologies to enhance realization of the goal of developing critical thinking in youth.

Significance of the Study

Chu et al., 2018, claim that "education systems have not evolved in parallel, in infrastructure, pedagogical methods, or actual curricular material that will maximally prepare students for the current and future world" (p. 8). In other words, educational environments need to reflect the 21st century learner as much as they need to develop the skills needed to be successful in society (Lemley et al., 2014). This view of educational environments, results in a shift to include an alternative view to education where "collaboration, creativity, innovation, entrepreneurial know-how, and ethical citizenship infuse teaching and learning. Students and teachers co-design their work" (Canada C21, 2012, p.9). These diverse teaching and learning methods possible in such "open" learning environments such as makerspaces can provide an enriching and engaging learning experience. However, it can be challenging to align new approaches with formal education contexts. In most classroom settings, educators *transmit* information (via lectures) *to* the learner and there is a strong corporate impetus to adhere to standardized curriculum and teaching methods (Martinez & Stager, 2013). Through an alternative approach, such as inquiry-based learning, whereby the educator and learner co-create the curricular path, learning becomes "a social process, with students and teachers working in partnership with each other and with experts beyond school, supported by digital technologies" (Canada C21, 2012, p.9*)*. Pedagogical approaches, therefore, that are *student-focused and student-directed* place the teacher in the role of "mentor," aiding students' self-directed learning. Also, with inquiry-based learning there is an emphasis placed on the process of *thinking* and the formulation of *questions*, whereby learning is led by the student, which in turn can increase learner motivation (Edelson et al., 1999). Makerspaces are such a learning environment, whereby student-centred pedagogy is apparent and where inquiry-based learning is used to explore topics under study, using a variety of technologies and tools, all of which may promote the development of critical thinking skills (to name but one competency). In addition, makerspaces, by their very structure, promote social interaction and sharing of information with peers, reinforcing the connection between collaboration and the development of critical thinking skills (Loes & Pascarella, 2017; Ventura et al., 2017). Therefore, makerspaces with student-directed pedagogies, are the ideal location to further study the use of inquiry-based learning in these contexts, specifically examining the development of critical thinking skills.

As makerspaces move into the formal education system (i.e., K-12), a better understanding of the successful pedagogies used and the type of learning that occurs in informal makerspaces is needed. Informal environments may provide much-needed pedagogical insight into how similar approaches could transfer into formal teaching and learning environments (e.g., K-12, higher education, training). Learning environments that include flexible learning, cross curricular experience, and offer the freedom to pursue creative pursuits, are essential to grow the capacity of young learners to develop critical thinking skills (among others) and better enable them to effectively learn and work in the new world of "connectivity" (Canada C21, 2012; Lemley et al., 2014; Martinez & Stager, 2013; Cross, 2017). Therefore, it is essential to examine and "map" thoroughly and methodically, the novel learning environment of a makerspace through a careful analysis of current research student-directed pedagogies, to be better able to review the importance of developing 21st century skills. Chapter Two provides a thorough review of the background, relevant literature, with a framework established to examine the development of critical thinking skills in an informal makerspace where inquiry-based learning pedagogies are used, and to extend the understanding of the instructional strategies that may facilitate the development of critical thinking.

Key Terms

Makerspaces are physical environments that are technology-rich and utilize constructivist pedagogies. They have been called fab labs, hackerspaces, tech shops, all having similarities with a formal laboratory that outputs creativity and produces innovation. This environment provides a collaborative, hands-on and community-based workspace for people to develop new skills and create innovative content (Martinez & Stager, 2013; DeRosa, 2016; Litts, 2015).

Critical Thinking relates to the ability to use higher order cognitive skills (infer, analyze, and conceptualize) to develop solutions to problems. Further, it is the ability to reflect, analyze and evaluate, all of which are skills needed to inquiry into problems, attempt to solve problems and produce conclusions (Loes & Pascarella, 2017; Ventura & DiCerbo, 2017; Lemley et al., 2014).

Informal Learning are open ended exploration, having less ties to a formalized curriculum occurring in places where learners are free to expand their discovery into a topic of their choice using manipulatives, tools, and materials freely. Informal environments can be places such as museums, interpretive centres, libraries, even online environments (Hein, 1998; Gutwill & Allen, 2009).

21st century skills: With new technology and an ever changing, more globalized world, new skills are required for future generations of learners to stay competitive in the future workforce. This results in a change in pedagogy to allow educators to create learning experiences that will reach 21st century competencies. (Battelle for Kids, 2019; Canada C21, 2012).

Inquiry-based Learning: Is the construction of knowledge, skills, and understandings of the world through questioning and experience-based discovery. Inquiry-based learning can appear differently in various educational settings moving from structured inquiry to more of a student driven approach in open ended inquiry (MacKenzie, 2016).

Chapter Two
Literature Review

There is significant research reviewing the pedagogical merits of makerspaces (DeRosa, 2016; Litts, 2015; Cross, 2017; Martinez & Stager, 2014; Bowler & Champange, 2016). However, understanding how makerspaces can be utilized to develop specific skills, like critical thinking, in an education setting requires additional investigation. Bowler and Champange (2016) reviewed makerspaces exploring if these dynamic environments can develop 21st century skills such as creativity, collaborations, critical thinking, and problem solving. Through their investigation, inquiry-based learning methods were used as a tool to develop a reflective practice by the participants. The result was a discrepancy between the physical product the youth wanted to create in the makerspace and the reflective thought processes, which is the goal of inquiry-based learning (Bowler & Champange, 2016). A caveat is that the creative excitement in makerspaces can be overwhelming, perhaps causing learners to want to develop a product without attending to the cognitive process important in inquiry-based learning. This making process can result in less attention being paid to the thinking process and development of higher order skills. Therefore, Bowler and Champange (2016) surmised that in a makerspace, inquiry process changes as learners start by creating and then ends with understanding the question, "What do I know? should be asked within the context of creating and not as a precursor to the process?" (p. 122). Makerspaces can encourage thoughtful creation, discovery with tools and objects to learn about what they do and understanding of how they are designed. The learning in a makerspace can be still furthered if the exploration is supported with student-directed learning adding the process for making within the inquiry cycle to include more attention to thought processes and utilizing critical thinking skills (DeRosa, 2016; Bowler & Champange, 2016; Bevan, 2017).

Twenty-first Century Skills

With new technology (e.g., ICTs) and an ever-changing, more globalized world, a new skill set is required for current young learners to develop skills that will connect them to future global needs (Chu et al., 2018; Canada C21, 2012; Lemley et al., 2014). Access to information in digital formats is increasing, creating the need to analyze information presented using higher order thinking skills such as metacognition and critical thinking. The learning environment in which learners develop these complex thinking skills is key. Understanding the dynamic, student-directed environment of a makerspace may contribute to our collective realization of concrete strategies and processes that promote 21st century learning skills. However, to implement such new approaches to pedagogy, it will require multiple stakeholders such as school divisions, governments, and special interest groups to be fully engaged. By including multiple partners in the development of a more "optimized" educational environment, new models of learning such as makerspaces, can be promoted and researched for effectiveness regarding teaching 21st century learning skills.

C21 Canada is a non-profit organization that promotes the inclusion of models for 21st century learning Canada's educational system. Working together, education professionals across Canada have developed a set of guidelines which are aimed to influence how education might be conducted in the future. C21 Canada indicates the need to change pedagogy to allow educators to create learning experiences that will reach 21st century competencies. C21 Canada proposed actionable items for the development of learning in Canada, with the goal to integrate 21st century skills into schools through teaching practice and learning technologies (Canada C21, 2012). By relating a set of competencies that builds the conceptual framework, shared across Canada, their goal of integration, connecting these skills within the educational environment may be achieved (Canada C21, 2012). The 21st century skills indicated by C21 Canada include:

- Creativity, innovation, and entrepreneurship
- Critical thinking
- Collaboration
- Communication
- Character, culture, and ethical citizenship
- Computer and digital technology

Each of the skills relates to a current and future necessary competency in a knowledge-driven global economy. For example, it identifies the need for learners to become adaptable, using skills such as critical thinking to investigate, evaluate and execute decisions in novel contexts and/or have yet to be determined. The C21 Canada related its model to the needs of the Canadian population. However, while meeting the needs of the Canadian population, the skills presented by C21 Canada are limited as the skills may not address the needs of a greater global population.

Battelle for Kids presented an additional set of skills comparable to the competencies presented by C21 Canada. The P21 Framework for 21st Century Learning, advocate for skills development in learners to create workplace readiness skills and generate conversations with those invested in the education system to help implement this skill development. The P21 Framework served as a catalyst for 21st century learning by building collaborative partnerships among education, business, community, and government leaders so that all learners acquire the knowledge and skills they need to thrive (Battelle for Kids, 2019). Through advancing evidence-based education policy making, the P21 Framework describes 21st century skills that learners need to have to be successful in a society that is globally connected through digital tools (Battelle for Kids, 2019). According to this organization the skill set, and expertise development highlight the importance in the current and future global context are collaboration, communication, critical thinking, and creativity. These are collectively called the "4 C's." The P21 Framework includes methods that guide learning, as well as the key skills, that have elements that are interconnected reflecting the collaborative nature of education and how they are transferable to future careers (Battelle for Kids, 2019).

While Canada's C21 and the P21 Framework are similar models of 21st century skills, additional frameworks have been explored suggesting alternative models (Binkley et al., 2012; Chu et al., 2018). Still, similarities and issues exist between the various models. For example, Binkley et al. (2012) cautioned that current models do not offer a clear idea of how these can be implemented into the curriculum, suggesting that if these skills cannot align within a set curriculum, they are less likely to be implemented. To address this problem, Binkley et al. (2012) created a model looking at measurable outcomes, relating them to knowledge, skills, attitudes, values, and ethics (KSAVE). The KSAVE model moves toward a pathway of assessment in the development of a skills framework listing 10 skills in four categories, including:

- ways of thinking: creativity and innovation;
- ways of working: communication and collaboration;
- tools for working information literacy and ICT literacy;

- living in the world: citizenship and social responsibility (Binkley et al., 2012).

This framework was designed so it can more easily be applied to an educational environment and have a clear process to develop an assessment tool. Binkely, et al. (2012) recommends "assessments must systematically ask students to apply content knowledge to critical thinking, problem solving, and analytical tasks throughout their education, so that we can help them hone this ability and come to understand that successful learning is as much about the process as it is about facts and figures" (p.25). Following these recommendations would not only change what is learned but *how* it is learned, moving the importance to the process of learning rather than the content of the material. This re-focus on learning processes aligns with student-directed learning seen in inquiry-based environments (such as makerspaces) because much attention is spent on the process of *thinking* (MacKenzie, 2016; Jansen, 2011; Zion & Mendelovici, 2012).

Examining 21st Century Skills

Although 21st century skills appear to be a valid foundation necessary for the growth of learning needed to fulfill an ever-changing society, it is important to view their place not only in the current educational realm but their place historically. With each century, there has been an importance on developing new skills to reflect the needs of society into the future (Lucas, 2019; Rotherham & Willingham, 2010). Early in the 20th century skills were promoted that were to encourage growth, moving into a new decade of learning beyond what was achieved in the industrial revolution (Lucas, 2019). Similarly, today, the focus of skills reflect the needs of society building on technologies not yet developed, as described by Canada C21 and Battelle for Kids (Chu et al., 2018: Canada C21, 2012). Historically, another layer emerges Tan (2016) compared 21st century skills, specifically the P21 Framework, with Confucian theories which date back to the 6th Century finding that skills can still resonate even centuries later. In particular Tan (2016) suggested for, "both Confucius and the P21 framework, critical thinking cannot take place in a vacuum without the acquisition of a knowledge core" (p.1236) establishing the idea that thinking it is integral to societal growth and key to a fully developed learner throughout history (Tan 2016; Lucas, 2019; Rotherham & Willingham, 2010; Chu et al., 2018). The fact that certain competencies repeat in importance throughout history, draws certain criticism as the skills are not new, with each decade a seemingly new set of skills are viewed as being most essential for the further development of society which can make these important skills lose meaning or at least motivation to carry them forward (Lucas, 2019). With this lack of meaning comes uncertainty among educators to combine the development of these skills with already established curricular requirements and epistemological practices (Rotherham & Willingham, 2010). This confusion and uncertainty can be compounded with influences from sources outside of the educational realm. Criticism has been directed at for P21, for example, as it could be an attempt by technology companies to get more influence over the classroom since the major sponsors are large multinational corporations such as Crayola, Disney, and Destination Imagination (Sawchuk, 2009). This criticism leads to the importance of reviewing these skills, regardless of the platform to maintain the importance of developing key competencies in youth, such as critical thinking, while still being cognizant of the challenges these might face (Rotherham & Willingham, 2010; Sawchuk, 2009).

21st Century Skills Conceptual Framework

Each of the discussed frameworks for the development of 21st century skills have specific merits. Distinguishing the most effective depends on their use in the educational environment. For the analysis related to the current research, it is important to look more closely at Canada C21, as it aligns with current educational practices within the region of this research. Canada C21 emphasizes the development of new skills, such as critical thinking, through the increased use of technology and the development of competencies to use technology for growth within global environments fostering a future of innovation and critical thinking (Canada C21, 2012). Furthermore, Canada C21 reflects the current population of learners and the future educational goals of the Canadian population.

To further examine 21st century learning skills, it is necessary to examine them in the context of a makerspace environment which is the context of this current research, specifically those which use an inquiry-based approach to teaching and learning. While a global examination of the collective set of 21st century learning skills is beyond the scope of this research, it is key to refine and target skills to explore them in depth. One of these skills, repeated in all models reviewed and within the historical context, is critical thinking. In the researcher's opinion, critical thinking is the most relevant to inquiry-based learning due to the need for in-depth thinking into a topic and the metacognitive element of inquiry thinking (Wheeler, 2000; Sandoval, 2005; Chu et al., 2018; Rotherham & Willingham, 2010). An important component of the "making" process is the development of meaningful designs which requires utilization of the process of thinking and critical thinking. Furthermore, critical thinking is essential for designing tools needed to process future technology that is novel and not yet developed (Paul, 1993). In the following sections details, and definitions of critical thinking, as it relates to 21st century skills, will be described.

Critical Thinking

Critical thinking relates to the ability to use higher order cognitive skills to develop solutions to problems (Canada C21, 2012). Although finding a definition of critical thinking that is similar, identifying the same abilities in learners, may be problematic as various research differs in its definition of the term, the use of higher order cognitive abilities to reason, make assumptions and deduce is seen in most models and descriptions (Loes & Pascarella, 2017). Ventura et al. (2017) describe critical thinking as "the ability to acquire, process, interpret, rationalize and critically analyze large volumes of often conflicting information to the point of making an informed decision and taking action in a timely fashion" (p.10). Researchers associate critical thinking with abilities such as reflection, analysis, and evaluation, all of which are skills needed to inquire into problems, and produce solutions (Loes & Pascarella, 2017; Ventura et al., 2017). Facione (1990) described the ideal critical thinker as one that is "inquisitive, well-informed, trustful of reason, open-minded… focused in inquiry and persistent in seeking results" (p.3). Facione (1990) theorized a set of six critical thinking skills, which include: interpretation, analysis, evaluation, inference, explanation, and self-regulation. The claim here is that when these skills are developed in learners, they are more equipped to use critical thinking in decision-making and designing solutions to problems encountered. In the development of these specific skills, Facione (1990) was seeking a clear way to evaluate and define critical thinking and thereby provides us with a clear *set* of skills that, in turn, furnishes a model (or "template") for the development and implementation of critical thinking in makerspace education.

The most familiar template for critical thinking in an education setting may be the Watson Glaser Critical thinking appraisal, an instrument used to assess critical thinking skills in learners. According to the Watson Glaser critical thinking appraisal, critical thinking is a combination of attitudes, knowledge and skills that includes the ability to inquire into a problem, find evidence to the support the argument, develop generalizations and ability to apply it to existing knowledge (Magnussen et al., 2000; Aiyub et al., 2021). The critical thinking skills related to this appraisal include assumption, deduction, argument analysis, drawing conclusion as well as subskills such as deduction, and inference (Aiyub et al., 2021). The skills identity in this appraisal echo those of Facione and other assessment tools used in the analysis of critical thinking in educational setting such as Blooms Taxonomy (Aiyub et al., 2021). Determining the definition of critical thinking further enables educators to apply skills and develop an awareness of how to nurture the skills in learners. Through the creation of various frameworks, the related skills and abilities needed for learners to demonstrate critical thinking in a learning environment can be explored.

According to Venturea et al. (2017), critical thinking involves problem solving when there is no obvious solution. The *Pearson-Critical Thinking Framework* (Ventura et al., 2017) was developed to further define critical thinking based on skills that can be used broadly, but also in specific subjects or contexts (such as makerspaces). The Pearson-Critical Thinking Framework, as seen in figure 2, includes four dimensions to define critical thinking: systems analysis, argument analysis, creation, and evaluation (Ventura et al., 2017). These skills are similar to the framework set forth by Faicone (1990) and the used in the Watson Glaser critical thinking appraisal, but better reflect the complexity of an education system that has embedded rapidly changing technology. For example, creation includes the skill of "computational thinking" which guides computer programming and problem solving and is often seen in makerspaces using computer technologies to analyze and efficiently debug coding problems. This framework, then, provides adaptability to the complexity of how to include critical thinking into an educational environment.

Figure 1

Pearson Critical Thinking Framework

SKILL	DESCRIPTION	EXAMPLE BEHAVIORS	RELATED SKILLS
Systems analysis	Identifying and determining the relationships between variables to understand a system	Identify variables Test hypotheses Control for third variables	Troubleshooting Systems thinking Problem-solving Scientific reasoning Analysis Hypothesis-testing
Argument analysis	Drawing logical conclusions based on data or claims.	Identify claims to support a position Avoid cognitive biases (e.g., confirmation bias) Draw valid conclusions from a data analysis	Deduction Induction Problem-solving Reasoning Decision-making Data and information literacy Inference Data analysis
Creation	Creation of a strategy, theory, method, or argument based on a synthesis of evidence The artifact that is created goes beyond the information at hand	Provide arguments from multiple perspectives in a synthesis Develop a new tool to test compounds in a solution	Synthesis Computational thinking Dialectic debating Designing Planning
Evaluation	Judgment of the quality of procedures or solutions. Involves criticism or a work product using a set of standards or specific framework	Use an ethical framework to judge if a business is violating ethical principles in their accounting records Determine if an electrical installation in a home meets a standard of safety	Criticism Auditing Appraisal Authentication

Note: Pearson Critical Thinking Framework. Reprinted from Ventura, et al., (2017). Skills for Today: What We Know about Teaching and Assessing Critical Thinking. London: Pearson. (CC BY-NC-ND 3.0)

In addition to defining critical thinking skills, the Pearson-Critical Thinking Framework described methods for teaching critical thinking in a learning environment (Ventura et al., 2017). Suggested are four ways that critical thinking can be included in education, namely: general, infusion, immersion and mixed (Ventura et al., 2017). These methods are on a “spectrum,” from critical thinking being taught as a separate course, to critical thinking being infused and part of all curriculum subjects (Ventura et al., 2017). In student-led pedagogies, such as within a makerspace environment, the task of solving real-life scenarios and learner-developed questions allows for critical thinking to be “infused” as an integral part of the learning process; in other words, critical thinking skills can be used in every part of the learning process. This embedding of critical thinking skills in all parts of the learning environment was also investigated by Sasson et al. (2018). They found that innovative learning environments, such as inquiry-based learning context (e.g., makerspaces) allow for growth and development in critical thinking skills. Through an observation of a constructivist-based environment, learners’ critical thinking and question-posing skills were analyzed (Sasson et al., 2018). Innovative techniques were applied to create a constructivist-based environment, such as mobile seating arrangements, team problem-solving areas, case-based instruction to reflect real-world situations and both formal and informal settings (Sasson et al., 2018). The development of higher-order thinking was observed in this learning environment, including critical thinking. The authors claim that for learners to use critical thinking, it requires “thorough, purposeful and deliberate, to focus on the issues at hand, fully evaluate all parts of its complex, challenging claims and arguments” (p. 205). Here, it can be suggested that the design of a learning environment is critically important to develop higher order thinking, allowing learners to grow relevant critical thinking skills. Within a makerspace, for example, providing learners with the opportunity to develop critical thinking through reflection and questioning *throughout* the process of inquiry learning is a central tenet of good design. The student-directed pedagogy of inquiry-based learning needs further examination to fully illustrate its connection to critical thinking in a makerspace.

Inquiry-Based Learning

Inquiry is the topic of an extensive amount of research and when doing an online search, *inquiry-based learning* can yield significant number of links, books, and scholarly articles all describing inquiry in education (Jansen, 2011). Through an investigation of peer reviewed articles, Pedaste et al. (2015) discovered over 2000 matches for inquiry-based learning. It is the researcher’s view that the number of investigations focusing on inquiry relates to its importance in an educational setting, as well as pointing to the complexity of the concept.

It is thought that student-directed pedagogies such as inquiry-based learning might further the development of higher-order thinking in learners (Jansen, 2016). However, there is some difficulty defining the meaning of inquiry-based learning due to the complexity in how it is used as an action, a delivery method, and an act of learning; with each iteration the application of inquiry-based learning can change (Wheeler, 2000). Wheeler (2000) described the variability of the word *inquiry* as "an elastic word, stretched and twisted to fit people's differing worldview" (p.14). This ambiguity may cause many educators to define inquiry on their own terms. At a *basic* level, the act of inquiry is to ask questions (Sandoval 2005; Demir & Abell 2010; Kluger-Bell, 1996). When learners seek information through asking questions, they create their own personal pathways to knowledge and actively exploring workable solutions to concrete problems. Curricular outcomes related to inquiry focus on seeking a deeper understanding of phenomena, requiring metacognitive abilities regarding ways solutions and ideas are formed and processed. The act of inquiry, then, is described as building "knowledge, abilities, and inquiring habits of mind that lead to deeper understanding of their world and human experience" (Saskatchewan Science Curriculum, 2011, p.7). As learners acquire a deeper understanding, they also develop the methods and processes to create inquiry-based learning. When this develops it is a way of seeing inquiry as a *method* to learning being "both a methodology and a vehicle for learning content" (Ash & Klein, 2000, p.217). In summary, the literature indicates that inquiry-based learning is the construction of knowledge, skills, and understanding of the world through questioning and experience-based discovery.

Types of Inquiry. Due to the complex nature of inquiry-based learning, it can appear differently in various educational settings moving from an instructor-directed experience to a more open-ended student driven approach (Ash & Klein, 2000). Inquiry-based learning aligns with a constructivist learning framework, "which emphasizes the idea that knowledge is not transmitted directly from the teacher to the student but is actively developed by the student" (Zion & Mendelovici, 2012, p.383). Inquiry-based learning, then, can be placed on a *continuum* consisting of structured inquiry at one end, modeled inquiry at the midpoint and open-ended inquiry at the opposite end (MacKenzie, 2016; Zion & Medelovici, 2012).

Structured inquiry puts increased authority on the role of the educator. In this type of inquiry-based learning environment, the educator provides the question and guides the learners through each step of the process (Zion & Medelovici, 2012). The role of the learner, therefore, is to follow the instructional guidelines of the educator. Structured inquiry causes the learners to make decisions that are dependent on the educator, who sets the goals they will attempt to achieve (Coiro et al., 2016). Within the makerspace context, learners in structured inquiry are engaged in hands-on investigations, observations, and work collaboratively with an educator and other learners to find solutions (Zion & Medelovici, 2012). The educator plays an important role in structured inquiry as they instruct learners through each phase of the inquiry process and promote dialogue which is needed to develop thinking skills (Litts, 2015; Kurti et al., 2014). This more traditional, linear approach to inquiry-based learning allows learners to gain skills in how to conduct an inquiry and think using methods described in a teacher-led environment.

Guided inquiry is still educator-led in that it provides instructions that learners will use to gain understanding about a topic (Kuhlthau et al., 2007). These instructions are central and create a concrete learning path for the learner. In guided inquiry, learners investigate a question, issue or topic that is provided to them by the educator but, importantly, the learners are responsible for discovering more about the topic, analyzing data, and communicating a solution (Zion & Medelovici, 2012). In guided inquiry, then, attempts are made to empower learners to seek their own solutions, only having a reliance on a teacher to provide the main point of the investigation and initiate the process.

Modeled inquiry is based on the learners' observations of the educator or experts (Coiro et al., 2016). In modeled inquiry, the educator displays behaviors that they want the learners to observe and to later replicate. Learners will observe the educators' thinking processes through inquiry phases such as questioning, testing, and communicating, while expressing what is expected of the learner at each stage (Coiro et al., 2016). This inquiry method creates an opportunity for learners to understand how inquiry can be used as a thinking process, as the educator can verbalize internal questioning dialogue and inquisitive actions. By observing the educator's talk through their thought process, the learner can replicate the action and develop an awareness of and aptitude for higher order thinking (e.g., critical thinking).

Open inquiry fits best in autonomous, learner-directed activity, as it highly promotes learner-centered investigations. In this model, learners make decisions and create learning pathways based on their intrinsic motivations to examine and investigate authentic questions (i.e., developed by the learner) (Coiro et al., 2016; MacKenzie, 2016). Open inquiry or "free inquiry" as it is also referred to, moves the learner to the centre and the educator as someone who is there to support their investigations (Wheeler, 2000). The learning environment is, therefore, student-centered with a complex inquiry level requiring the learners to exercise specific skills needed for deep thinking, with the educator working in a "mentoring" role (Zion & Medelovici, 2012). For learners to achieve this level of inquiry, they need to organize their own work and understand the process of inquiry (Edelson et al., 1999).

Open inquiry-based learning can be used as a pedagogical method to optimize the learning experience. MacKenzie (2016) developed a model that can be used to drive learners to open or free inquiry using an "essential question". The author claims that learners discover their essential questions, an open-ended investigation, from a topic that is of interest to them where they can find personal meaning. Carried out in a formal classroom setting, a free inquiry unit instructs learners to move through a process in which they explore a passion, develop goals, find what is interesting, and take on a new challenge. However, the open method to inquiry-based learning creates a new learning environment unfamiliar to some youth who have mostly experience more traditional didactic classroom learning, although MacKenzie (2016) states that if learners had "the opportunity to ask questions they were encouraged to explore, it would guide them to a more meaningful and enriched educational experience" (p.46). Importantly, the level of thinking and active participation by learners may only be achieved through the development by the educator and/or instructional designer to create a learning environment that promotes learner-directed investigations.

The phases of inquiry range in complexity from structure to open, extending for both the learner and the educator. The learner will "grow and move through these levels at different speeds" (Coiro et al., 2016, p.7). For example, in some inquiry-based learning environments, not all phases will be reached due to the design of the lessons, goals of the environment and experience with prior inquiry instruction (MacKenzie, 2016; Coiro et al., 2016). However, the goal of a learner reaching a metacognitive level might be key to encouraging the development critical thinking, through the active, guided participation in an inquiry-based learning environment. If the development of critical thinking was the highest level achieved, a learner can then engage with higher-order thinking skills (e.g., metacognition) and the ability to understand the processes needed to achieve this level of inquiry thought.

Generally, *open* makerspaces support learners as thinkers and producers of knowledge, which is created through the development of understandings, active engagement, and rousing intrinsic motivation (Vossoughi & Bevan, 2014). Depending on the makerspace, different levels of inquiry can occur due to the structure and pedagogical design of the space. The design of a makerspace can either encourage or discourage higher levels of inquiry from occurring (Vossoughi & Bevan, 2014). The space must be attractive to learners (e.g., setting, tools available) as well as help promote inquiry skills. Kurti et al., (2014) suggest that for open, inquiry-based learning to occur in a makerspace, learners need to be attracted to the space claiming that by inviting curiosity, wonder, and encouraging playfulness, inquiry learning will occur. It is further argued that the active and creative inquiry-based environment of a makerspace is an effective context that allows for learners to engage in activities freely, exploring learning through creation, and allows for learners to take ownership of their learning (Vossoughi & Bevan, 2014).

In summary, using an inquiry-based learning environment, the educators' role is to coach student-directed learning. When inquiry-based learning is used as a method to gain knowledge, the educator's role moves to "that of stewardship over the development of knowledgeable thinkers about inquiry" (Wheller, 2000, p.18). This orientation and associated processes facilitate learning by encouraging critical thinking, as well as direction about the task or lesson. This coaching-teacher role can take various forms (as described above). The learners, in turn, may use various methods to determine their path and process of discovery. This learning pathway can be seen in the method of asking learners "essential questions" (MacKenzie, 2016) which guides thinking and orientates the learner to ask thoughtful questions, promoting in-depth investigations and allows for learners to explore diverse mediums. As educators shift into a mentoring role where they co-learn or learn alongside students, their skills are essential to activate and facilitate the makerspace environment (DeRosa, 2016; MacKenzie, 2016; Zion & Mendelovici, 2012). Having the educator become fluent in student-directed pedagogies, then, as well as the design and implementation of a makerspace environment will advance learning and the development of essential thinking skills (i.e., critical thinking) in learners.

Active Learning Pedagogy

Active learning pedagogies encompass many areas of learner-centered constructivist epistemology including problem-based, discovery based, inquiry-based (IBL) and project-based learning (PBL) all of which are seen in a makerspace (Cattaneo, 2017). The reflective practice occurring in an IBL environment and the hands-on approach to learning in a makerspace sit within active learning pedagogy. In addition, active learning describes the role of an educator within the constructivist approach and similarly to how it is described in IBL with the educator taking on the role of mentor (MacKenzie, 2016). Active learning spaces are designed to facilitate interactions between learners in contrast to traditional fixed classroom designs which can prevent the development of active learning; therefore, a makerspace may create an increased opportunity of active learning and hands on interaction (Beichnen, 2014; Apkarian, et al., 2021). The collaborative environment supported in active learning may be seen in a makerspace and key to the development of 21st century skills (Beichnen, 2014). Moving away from lecture-style learning associated with formal education environments, active learning should include constructivist pedagogies creating a learner driven approach.

Constructivism and Constructionism in Learning Environments

In inquiry-based learning, the learner *actively* constructs knowledge connecting it to active learning theory and constructivism pedagogy. The active engagement of the learner in inquiry-based learning contexts facilitates the development of their own, unique knowledge structures and understanding is enhanced through connections made within and between various content foci (Gijselares, 1996; Savery & Duffy, 1995). In other words, core principles of constructivism are put into practice via inquiry-based learning environments. A focus is placed on the importance of the learning *environment* because it describes learning as not only occurring inside the head of the learner but within an activity-based and engaging learning environment (Litts 2015; Martinez & Stager 2013). Driscoll (2005) suggest that in a constructivist pedagogy, learners actively participate by doing and exploring the world around them. Fundamentally, constructivism describes the learner as active, seeking meaning and constructing knowledge through socially mediated learning experiences (Martinez & Stager, 2013).

However, in constructivist pedagogy, being learning-centred does not *necessarily* include the active ability to share meaning through the production of a shareable object which is relevant in modern learning (Martinez & Stager, 2013). This aspect of learning was expanded by Papert & Harel (1991) who extended the role of the learner in constructivist learning environments to include the production or building of a *concept*, either verbally, physically, or mentally, calling this concept constructionism. This cognitive process may, for example, produce a *shareable construct* that can take on the varied physical forms such as construction of a robot, story, computer code or song (Martinez & Stager, 2013). Alternatively, constructionism can include using an object to develop cognitive skills. Papert and Harel's (1991) original idea was those objects such as computers are materials that can be used in learning and creation (Martinez & Stager, 2014). The focus, then, becomes learning through making or constructing; constructionism is "about the making of both knowledge and personally meaningful external artifacts. Making is a constant conversation between interpretation and representation" (Litts, 2015, p.22).

Whether the learner is making meaning through inquiring about a problem or developing a solution using physical manipulatives, the learning environment in which they interact is, critical. When constructivist pedagogy is extended to include the development of a tangible or shareable object, constructionism is put into practice (Martinez & Stager, 2014). The learner can develop their cognitive understanding through social interaction, contact with tools and manipulatives, and the option to construct their path to learning. Makerspaces, then, can be seen as ideal environments for the application of constructionism, as they allow for the development of a tangible object to be created, as well as use the student-directed pedagogies associated with activity learning and constructivist pedagogies. In addition, makerspaces that specifically use inquiry-based learning may produce evidence of higher order thinking taking place, as learners are developing these (such as critical thinking skills) in an immersive, constructivist learning environment.

Informal Learning Spaces

Both formal and informal educational environments have similar qualities depending on how the content is presented and the learning is facilitated (Hein, 1998). In formal education, the curriculum is pre-determined by someone other than the learner (i.e., national curricular standards and assessment-based guidelines); as Hein (1998) suggests, formal education environments are places in which "they teach a specific, hierarchical curriculum" (p.7). The pedagogies used in structured, hierarchical curriculum generally match the learning environment design of a traditional classroom, with rows of desks facing the instructor, usually positioned at the front of the room. In contrast to a traditional classroom, informal learning sites are more suited to an open space with multiple media tools such as manipulatives, equipment, and materials freely available to learners to expand their discovery into a topic (Bevan, 2017). Informal learning sites do not generally have a defined curriculum, as they allow the learner to control their learning journey through self-directed discovery (Gutwill & Allen, 2009). Also, within informal learning contexts, there is freedom to discover new and “uncharted” topics that are of interest to the learner propelled by intrinsic motivation to learn more about the topics (Hein, 1998; Gutwill & Allen, 2009; Bowler & Champagne, 2016). Museums, interpretive centres, libraries, even online informal learning environments (i.e., courses, forums) may “constitute an ideal environment for teaching and learning inquiry skills, offering a number of features often unavailable in schools” (p. 711, Gutwill & Allen). Many informal spaces like libraries and museums have embraced makerspaces because they are hands-on, collaborative, and interactive, having a blend of technology and art (Bowler & Champagne, 2016). Informal learning environments often have interdisciplinary subjects allowing for cross-curricular connections to be made thus “engaging students in design-build activities that allow them to explore ideas, develop skills and understanding within particular (and often interdisciplinary) disciplines” (p. 6, Bevan, 2017), having the ability to move through disciplines, promoting active learning pedagogies. Makerspaces can be in formal spaces, such as schools, to informal locations such as libraries and public venues like a storefront. Bieraugel and Neill (2017) reviewed on-campus learning spaces such as libraries, greenspaces, student unions, common areas and makerspaces to determine which location would foster the development of creative thinking and innovation. While they found that makerspaces allowed for a high level of creative development, academic makerspaces still need fixed locations that allow for collaborative discussion and reflective thought (Bieraugel & Neill, 2017).

Koole et al. (2017), suggested that makerspace can exist within many levels of formality and learner engagement by suggesting they can be mapped on a continuum of environments where makerspace can fit with in a formal instruction quadrant to the amount of control the learner has within a makerspace. On the continuum, in which formal environments are located activities that are highly regulated including lessons with steps most often seen in a traditional classrooms exercise or even less formal in a space in which a learner might have the guidance of an instructor as in an apprentice relationship (Koole et al., 2017). When more control is given to the learner, the environment moves in the continuum to more informal settings such as clubs or studios, a location that is closely related to the formal environment but allows for more learner autonomy (Koole et al., 2017). As the level of control increases, the setting moves into a learner-controlled informal environment in which the learner can participate in individual pursuits, for example, researching a concept or learning a new skill that have been motivated by the learner (Koole et al., 2017). When looking at the relationship between the formality of the setting and level of learner control in a makerspace, it is possible to see connections to the stages of inquiry-based learning. When the makerspace allows for more learner autonomy, higher levels of inquiry might be achieved (Vossoughi & Bevan, 2014) with a possible space for this to occur being an informal setting, if the learner can exercise their ability to use higher order thinking skills in open inquiry (Coiro et al., 2016; Vossoughi & Beavan, 2014; MacKenzie, 2016).

According to Bowler and Champagne (2016), by including a reflective practice into the making process, an increase in higher order thinking can be obtained. By having educators or mentors in the makerspace providing questions or prompts, learners can develop thinking skills and increase the learner’s cognitive development (Bowler & Champagne, 2016). This action of using questions, aligns with guided inquiry in which learners rely on an educator to set the parameters of inquiry, allowing for the learner to explore solutions and investigate through using physical manipulatives as available in a makerspace. Once a learner becomes confident in the reflective thinking process, the use of open inquiry can be used in a makerspace to encourage more reasoning and a purposeful making practice (Bowler & Champagne, 2016; MacKenzie, 2016). Cross (2017) suggests that if makerspaces move into a formal education environment, it will assist in the development of skills such as computational thinking, among others, in which learners will understand the *process* of creation and not just how to make the product. Current educational environments that include makerspaces may allow for new skills to be developed drawing on a constructivist approach, makerspaces move beyond the tools and into a place and process for learning that can develop skills newly important to society.

What are Makerspaces?

Makerspaces are physical environments that are technology-rich and utilize constructivist pedagogies (Bevan, 2017; Martinez & Stager, 2013). Having roots in what is sometimes referred to as "hacker culture," the ability of Makerspaces to change or adapt to meet new needs (Niaros et al., 2017). While these spaces can also be called fab labs, tech shops, or the more popular *makerspaces*, they all have similarities with a formal education laboratory that outputs creativity and produces innovation using inquiry and processes that inspire higher order thinking. To reiterate, makerspaces can provide an informal, collaborative, and hands-on workspace that combines technology and art to produce innovative products and teach new cognitive skills (e.g., critical thinking) (Bowler & Champange, 2016; Webb, 2018; Bolwer, 2014; Sheridan et al., 2014). Makerspaces can be simply described as a "place where people come to create things" (Webb, 2018, p. 37). These highly interactive spaces blend materials and technology, allowing learners to have freedom to create unique pathways to learning and ownership over what is created (Martinez & Stager, 2013).

Makerspaces grew out of the larger maker movement in which technology was the driving force for open information and a variety of accessible tools providing an environment for creation and a vehicle to share a specific interest or hobbies around the world (Dougherty, 2012). The "Maker Movement" has developed from the desire and activities of an increasing number of people who actively pursue the creation of objects and materials, as well as seeking out forums to discuss their creation and processes (Halverson & Sheridan, 2014). Halverson and Sheridan (2014) refer to the maker movement as "the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" (p.496). Dale Dougherty, founder of Make Magazine, furthers the idea that the Maker Movement came "about in part because of peoples' need to engage passionately with objects in ways that make them more than just consumers" (Dougherty, 2012, p.12). Attributable to the ubiquity and ease-of-use of information and communication technologies (ICTs in particular) makers from around the world have access to online discussion forums, thus allowing for a broad range of communication and sharing of ideas instead of only within smaller makerspace communities (Dougherty, 2012); in addition, this ability to connect with others using makerspaces reinforces the role social relationships have on the development of new cognitive understanding and skill development.

Importantly, in a makerspace there is “an interplay of high and low technologies, producing a sense of playfulness or the unexpected” (Bevan, 2017, p.78). Learners are encouraged to explore and move beyond their own experiences to test new technologies and tools. While advanced tools such as robotics, computers and 3D printers are common, basic supplies such as cardboard, glue and tape also have high importance in a makerspace (Cross, 2017; Bevan, 2017; Austin, 2017). The aspect of using both common and new materials to the learner tools available is important when developing 21st century skills such as creativity, collaboration, innovation, and computational thinking, all of which can be developed in makerspaces through using technology and innovative tools (Austin, 2017; Bieraugel & Neill, 2017). Spending time in a makerspace can have positive impacts on creative development, communication, and collaboration, all skills needed in the future. Jarrett (2016) claims that time in a makerspace can be summarized as the development of “a mindset defined by the qualities of caring, thinking, designing, and acting” (p.51).

Located in schools, museums, libraries and community centres, makerspaces are diverse in their programming and teaching/learning methods employed. For example, *Steamlabs*, a non-profit organization, located in Toronto, Ontario, is a hands-on learning environment operating since 2010. Their stated mission is to empower communities to use technology and physical tools to discover the world around them by inventing, exploring, and playing. *Steamlabs* runs educational programming with partnering groups in the Toronto area, including the Ontario Science Centre and a coffee shop, The Maker Bean Cafe (Steamlabs, 2020). Ontario Science Centre and the Maker Bean Cafe are diverse environments having varied audiences. However, all three organizations have the same goal for audience engagement: to allow for inquiry into the world of making. Without permanent locations or buildings, Steamlabs utilizes its partners to create makerspace programs that bridge many age groups including content such as day camps and ongoing projects lasting multiple sessions. Another example, namely, the *Makeshop* at the Children’s Museum of Pittsburgh, provides participants open access to tools, physical materials, and digital resources. This makerspace offers similar programming content and a comparable target audience to *Steamlabs*, however, with a fixed location, it acts more as a traditional makerspace (more traditional makerspaces are geared toward adult audiences, having an emphasis on sharing tools, resources and knowledge, and can be found in many cities). The Saskatoon Makerspace, as well as *TechWorks,* both in Saskatoon, are a community of makers able to engage with tools and equipment at a main hub; access to the makerspace is through a membership, which is a similar practice to many makerspaces. While lessons are provided for the use of tools and equipment, there is limited additional programming or lessons for members. However, regardless of the format, all makerspaces appear to have similar goals, namely, to inspire creativity and cultivate 21st century skills, innovation, and the exploration of hands-on manipulation of materials to create.

Makerspaces as 21st Century Learning Environments

When learning environments implement student-directed pedagogies such as inquiry-based learning, higher order thinking skills, such as critical thinking can flourish (Sasson et al., 2018; Lemley et al., 2014). Also, makerspaces can offer a chance for learners to thrive in a stimulus-rich environment that uses their motivation to propel inquiry into a topic. These highly interactive spaces include materials, resources and create a new culture of learning that could help foster 21st century competencies, specifically, critical thinking skills. In such environments, learners are no longer passive receivers of knowledge but desire to be autonomous and connected to the process of learning (Lemley et al., 2014). The extent to which makerspaces use inquiry-based learning pedagogies to foster the development of higher order thinking skills needs to be further investigated, specifically at the development of critical thinking skills in a makerspace environment.

The connection between 21st century skills and the pedagogies used in a makerspace learning environment makes it possible to develop an idea of how critical thinking skills can be realized. However, there are limitations to the maker movement that may affect their presence, and presence in the formal school system therefore strengthen their placement in an informal setting. Changing educational goals, the popularity of some technologies over others and new trends sways the interests of decision makers in formal environments who might place less emphasis on developing these makerspace environments. In addition, economic challenges to establishing a makerspace, including the high cost in tools, equipment, and technology, may cause some formal educational institutions to examine makerspaces closely as it could have a high financial impact in an era of uncertain times. Therefore, by evaluating the effectiveness of makerspaces in building 21st century skills in school aged youth, highlighting the richness of informal learning places outside the constrictions of the formal educational context is essential in furthering the possibilities of this learning environment.

Makerspaces are dynamic environments that are rich in technology utilizing active learning pedagogies. Pedagogies that included inquiry-based learning which build the development of higher-order thinking skills to question, investigate, and examine propelling learners through various stages of inquiry. Informal makerspaces provide a collaborative, hands-on and community-based workspace where learners can develop new skills including critical thinking. The use of Pearson critical thinking framework provides this analysis with guiding principals allowing for clarity in the definition of critical thinking and how it can be identified in the informal educational makerspace setting. In the following chapter, the methodology used in this investigation is described providing careful details in the collection and analysis of information and data.

Chapter Three
Methodology

As previously discussed, now more than ever, there is a need to develop critical thinking skills in youth as there is an increased use of information and communication technologies creating more access to information with a higher rate of change. Learners need to develop essential thinking skills such as critical thinking to be properly equipped to transform their knowledge, attitude, and skill. Makerspaces may provide the ideal environment in which the development of these skills can be facilitated and realized. This investigation aimed to review the extent to which inquiry-based learning pedagogies are used within an informal makerspace to promote the development of critical thinking, as observed by facilitators working with the environment. The research question was therefore, *how are critical thinking skills activated, demonstrated, and developed in an informal makerspace where inquiry-based learning pedagogies are used?* In addition to this main question, the secondary questions that were asked to further access the perspective of the facilitators included *according to the facilitators, in an informal makerspace where inquiry-based learning pedagogies are used;*

1. *What instructional strategies used appear to help develop critical thinking skills?*

2. How are critical thinking skills activated, demonstrated, and developed?

The participating makerspace facilitators provided feedback on the activation and demonstration of critical thinking skills when inquiry-based pedagogies were present and reviewed the instructional strategies that are commonly implored. With both inquiry-based learning and critical thinking, the emphasis was to explore how higher-order thinking could increase the pathways to knowledge in a meaningful way.

Rationale for a case study

The research design used in this study was a qualitative instrumental case study focusing on informal makerspaces that use inquiry-based learning pedagogies and the ability for these environments to facilitate critical thinking in youth. An instrumental case study can be defined as a “qualitative approach in which the investigator explores a real-life, contemporary bounded system” (Creswell & Poth, 2018, p. 96). Stake suggests that cases can be “simple or complex” (p. 135), adding that in an instrumental case study “proliferates rather than narrows” (Stake, 1978; Stake 2008, p.7). An instrumental case study creates an opportunity to investigate diverse cases that can have expansive details. Using this current study as an example, makerspaces and the specific location of informal environments in combination with the deeper investigation into the development of skills may have been an expansive topic. However, narrowing the study to a particular pedagogy, namely, inquiry-based learning with a clear focus on the evidence for and development of critical thinking as witnessed by facilitators, provides a “focal point” for this topic. The specific use in this research methodology of an *instrumental* case study advanced the understanding, creating uniqueness and providing further insight into the case before the entire role of learning in makerspaces (Stake, 1978; Stake, 2008). Using an instrumental case study, this research focused on one issue, namely, the development of critical thinking in informal makerspaces, that utilized inquiry-based teaching and learning methods to gain insight into this specific learning environment and how it further develops critical thinking skills (Creswell & Poth, 2018; Stake, 2008). In addition, since the methodology used was that of an instrumental case study, this focused the research to a specific pedagogy of inquiry-based learning, within makerspaces, to investigate the development of critical thinking as observed by site specific educators.

Trustworthiness

The pursuit of "trustworthiness" in qualitative research provides the researcher with confidence in findings and is used to confirm validity and reliability of such (Creswell, 2009). For example, trustworthiness was employed in this research to provide clarification on the meaning and verify the interpretation of the researcher (Stake, 2008). In this case after interviews were transcribed, participants were further engaged to review what was said in the interview and were able to provide clarification on their responses. Further trustworthiness was validated through interviewing three participants from different locations in Canada to provide a detailed examination of the case and multiple viewpoints. Trustworthiness was further established through the determination of codes which were reviewed through multiple coding cycles. The condensing of codes into themes provided a closer analysis of the data and enhanced the trustworthiness (Saldaña, 2013). The researcher reviewed the transcripts along with the associated codes to ensure that there was constant comparison within the data which was consistent with the set code definitions. This process further clarified the codes and strengthened their relationship with the data.

Ethical Considerations

Approval for this study was granted by the Behavioural and Biomedical Research Ethics Boards at the University of Saskatchewan prior to the initiation of the research. All participants were asked to complete a Participant Consent Form before interviews were conducted. After the interviews, participants were asked to review the transcription and provide any updates or notations to what was described in the interview. Participants submitted a Transcript Release Form (see Appendix B) to confirm the use of this data gained through the interview. Participating locations are identified however to ensure anonymity, the utmost care was given to protect individuals in the interviews by coding names in the data analysis. Further to ensure additional anonymity, participant consent forms were kept in a separate location to that of the data, all being kept electronically on a secure server.

Participants

Recruitment of participants focused on informal makerspaces from locations in the Canadian provinces of Alberta, Saskatchewan, Manitoba, and Ontario. Initial recruitment occurred through email and selections of participants were made that focused on makerspaces which support youth through their educational programming, deliverable content, and membership programs (see Appendix C for copy of the Invitation to participate, Recruitment Email). Also, each participating site was chosen based on their ability to provide detailed and experience-based information about the critical thinking skills observed in youth participating in makerspaces. Sites were chosen based on potential connections between the site and the objectives of the research. The participating locations were all informal makerspaces that offer learner-centered content and saw the importance of development of 21st century skills, such as critical thinking in their operations and programs. The three participating facilitators were each from a different makerspace all having slightly different pedagogical and structural configuration, which is not uncommon as makerspaces in general can differ due to their main audiences, physical structure, and other factors. With this sampling, the makerspace was that of a general population, community-driven and site-based location.

Participant Identity. The three participating facilitators were from separate informal makerspace all having numerous years of experience working as educators within the makerspace community. Educational backgrounds, position within the organizations and experience levels of the participants varied. To maintain confidentiality the participants will not be identified and will not be associated with their makerspace. As part of the analysis participants were given codes which were modified to be presented as pseudonyms within this analysis. The pseudonyms preserve confidentiality among the participants by preventing connections with the makerspace in which they work to be identified. However, to provide a further exploration into the characteristics important in describing the experiences, abilities and attitudes of the facilitators, the following description of the participating facilitators, along with their pseudonyms, will aid in the analysis.

Facilitator Celine provides engaging opportunities for audiences sharing knowledge and promoting the positive impact of informal environments. Celine has ten years of experience working within informal education providing support to those working within the makerspace and engaging with various audiences providing educational programming and content. Celine develops and implements makerspace activities, creates problem-based learning events and tinkering challenges for youth as well as adult audiences.

Facilitator Amir has a senior leadership role in the makerspace organization with numerous years of experience in the makerspace learning environment. Amir develops, implements, and facilitates technology educational programming to youth and adults promoting the importance of innovative thinking and thoughtful creation. In addition to experience in facilitation, Amir provides assistance and training for educators working within both formal and informal locations with makerspaces in an effort to grow the makerspace environment.

Facilitator Jaytee is an exemplar of a maker, working withing a professional technical field and within an informal makerspace. Jaytee takes on a leadership role in the makerspace providing guidance to fellow makers, promoting the development of new skills needed in that makerspace including critical thinking skills. In addition, Jaytee assists with the implementation of programs and learning events for audiences of various age and experience levels include youth.

The three participating facilitators were from makerspaces located in different cities, being Saskatoon, SK, Ottawa, ON, and Toronto ON. The following section provides a brief description of the three makerspace locations which the participating facilitators are from.

Steamlabs (Toronto, ON) - Steamlabs is a non-for-profit organization located in Toronto that provides all ages programming, training education for organizations and schools, as well as providing design, development, and consultation for educational institutions such as schools, science centres and community centres who are seeking to develop new makerspaces. Steamlabs was established in 2010 to promote the understanding of science and technology, allowing for equitable access for all to improve their community. Steamlabs has assisted in the creation and development of various makerspace in the Toronto area including locations such as the Ontario Science Centre, The Maker Bean Cafe and a community makerspace in the Centre for Social Innovation (now managed by the Toronto Tool Library). The consultation practice sustains the organization providing an opportunity to develop multiple spaces in addition to the facilitation of training for educators working within makerspaces. The additional component for Steamlabs is leading community-based programing and outreach. While Steamlabs maintained the makerspace in the Centre for Social Innovation, in a downtown Toronto location, their aim was to engage the community to provide an opportunity for exploration in science and technology. Various programs were offered for the general public for different age groups being both one -time events and extended workshops spanning numerous sessions. Steamlabs works with youth in various programs to grow their overall skills, such as collaboration and communication by allowing youth to work together and determine their own strengths, highlighting their individual talents and abilities. Steamlabs continues to work within the community, supporting innovation through dynamic programming with public audiences as well as offering consultation to develop new and innovative future makerspaces.

Saskatoon TechWorks Inc. (Saskatoon, SK) - Saskatoon TechWorks is a membership driven makerspace or hackerspace located in Saskatoon, Saskatchewan, providing its members with a space to work collaboratively, share resources and knowledge to create an atmosphere of learning that focuses on science, technology, mechanics, and digital arts. The 1500 square foot makerspace is equipped with hand tools such as saws, drills, screwdrivers, wire cutters, hammers, and an electronic bench with soldering equipment, as well as 3D printers, laser cutters and computers. Saskatoon TechWorks is primarily self-directed as there are no paid staff and only volunteer members facilitating the needs of the organization. The community of makers at Saskatoon TechWorks, perpetuates the ideals of social learning through a strong collaborative outlook, members assisting each other in the development of new projects using the informal learning opportunities to work through projects and share insight from one another. In addition to the physical location, Saskatoon TechWorks facilitates an online chat forum and social media site to connect members while not at the physical location furthering the community collaboration and sharing of resources in particular knowledge. Past programs at Saskatoon TechWorks included youth directed programming that included building sessions which explored robotics allowing for participants to assemble small robots. Information sessions and non-member events are hosted to continually grow the community of makers and provide members with new skills-sets and shared learning opportunities.

Exploratek - Ingenium Canada (Ottawa, ON) - Exploratek is an interactive permanent exhibition space within Ingenium Canada. Ingenium Canada comprises three museums including the Canada Agriculture and Food Museum, Canada Aviation and Space Museum and the Canada Science and Technology Museum. Exploratek creates an interactive hands-on makerspace for visitors to the Canada Science and Technology Museum. Within Exploratek, visitors to the space can experience self-directed active learning pedagogy including scheduled programming and activities, in addition to longer in-depth workshop engagements with the aim of engaging visitors with science, technology, engineering, arts and mathematics (STEAM). To achieve this goal of engagement in STEAM, Exploratek established certain characteristics for the makerspace including *flexibility*, the changing of the experience both physically through the layout and through differing activities, *functionally* being thoughtful about the experience and materials within, *welcoming* initiating a universally designed space that is *enticing* for all visitors no matter ability level or age. In addition to the audience comprising the general public to the museums, such as family groups, visiting school groups can book and participate in specialized content directed at inquiry-based learning. Museum staff in Exploratek take on the role of facilitator guiding visiting participants through challenge activities encouraging self-directed interaction leaving the visitor to create and explore as they desire. Programming within the space includes many active learning lessons such as exploring circuits, in which visitors build electrical circuits from pre-assembled parts, building bridges out of plastic rods and creating vertical three-dimensional pathways for moving a ball.

Methods

The data collection method for this research included semi-structured interviews, conducted with participating facilitators who were working within the selected informal makerspaces. The interviews were conducted with open-ended questions to allow the participants to provide in-depth responses and insight into the research question. The use of in-depth interviews with facilitators' open-ended questions allowed for a richness in meaning and individualist understanding from the facilitators' perspective (McMillan & Schumacher, 2010). The questions were knowledge-based seeking information about the perception of the facilitator based on the knowledge they have from observations within a makerspace. To establish clear interview protocols consistent across all participants, prior to the interview questions the researcher reviewed key terms associated with the study which included *makerspaces, inquiry based learning* and *critical thinking*. The definition of key terms was provided using online slides presented to the participant during the interview. Participants were shown the Pearson critical thinking framework model, as seen at figure 2 (in chapter 2) to describe critical thinking and explored the types or phases of inquiry to thoroughly explain the researcher's intended definitions of these terms. Each of the three interviews were approximately 1.5 hours in length focusing on the facilitator's observations of the instructional strategies used within an informal makerspace to activate, develop, and demonstrate critical thinking. The interview protocol included remote eweb-conference service (no in-person interviews occurred for data collection) with questions and answers facilitated using the programs WebEx and Zoom (Morrison et al., 2019) (as seen in Appendix A). All interviews were digitally captured (i.e., recorded), with data saved as an MP4 file; transcribed verbatim, using the featured transcriptions tools available on the web conferencing service, for further analysis. Transcriptions were saved and shared with the participant for their review, allowing the participant the ability to modify or clarify their responses. A Transcript Release Form, which can be seen at Appendix D, was sent to participants, signed and returned to the researcher prior to data analysis.

Data Collection Method

The recorded MP4 interview transcriptions were analyzed using NVivo, a qualitative research analysis software for qualitative coding (Creswell & Poth, 2018). The transcribed interview data was analyzed to reflect on its overall significance, then emergent codes identified were synthesized in a within-case analysis (Creswell & Poth, 2018). These codes (or "nodes") are useful in determining relevant words, phrases, or paragraphs in the research data (Saldaña, 2012). In the early stage of the research, a priori codes reflecting the initial research question were reviewed for relevance and utility in the initial data analysis process. The a priori codes included inquiry-based learning, higher order thinking skills, critical thinking, problem-solving process, hands-on interaction, and future of makerspaces learning.

The coding method included a first and second cycle using a structured code list established from the a priori codes or deductive codes, the use of the Pearson critical thinking framework and the developed emergent codes (Miles et al., 2014). The first coding cycling established deductive codes, included inquiry-based learning, higher order thinking skills, hands-on learning, future of makerspaces, instruction, makerspace, and critical thinking as defined by the use of the Pearson critical thinking framework. The first coding cycle allowed for similarities to be developed from the interview questions and the content presented by the participant in the interview included frequent words and phrases that were used that related to inquiry-based learning in a makerspace. The first coding cycle is essential to "initially summarize segment of data" (Miles et al., 2014, p.86) and from there to further relate to topics to help establish further themes. The use of the Pearson critical thinking framework (see figure 2 in chapter 2) created a thorough analysis on critical thinking creating a clear definition of associated terms, breaking down the complexity of the term into suitable items such as analysis, problem solving, troubleshooting, reasoning and decision making (Ventura et al., 2017). The Pearson critical thinking framework is made up of four main dimensions including systems analysis, argument analysis, creation, and evaluation. This framework does not include individualistic traits or rely on the notion that some learners are predisposed to critical thinking; rather, this conceptual framework allows for practical applications of critical thinking to be made, creating a clear pathway for the investigation into the status of critical thinking in a makerspace learning environment (Ventura et al., 2017). To explain further, the use of the Pearson critical thinking framework focuses on activity generation to promote critical thinking, which is useful in a learning environment such as a makerspace and important in verifying the use of the term within the analysis. (Ventura, et al., 2017). Using the Pearson critical thinking framework helped to produce a clear path forward, distilling the concept of critical thinking further in the coding process.

From this first stage, the second coding cycle was used to determine patterns as “a way of grouping those summaries into a smaller number of categories, themes or constructs.” (Miles et al., 2014, p.86). During the second coding cycle, inductive codes immerged, through similarities in the data, formulating terms that included collaboration, scaffolding, communication, questioning, creativity and going beyond the tools. Further, as a final analysis, NVivo was used to explore the data in additional iterations to review the language of the participants to carefully and thoroughly review the overall context. After the multiple coding cycles, unanticipated or emergent codes were formulated through a continued and repeated analysis of the transcript data.

Limitations

Several limitations in this study could have impacted the results. Acquiring data from the facilitators who work within the makerspaces only provide a certain level of analysis, somewhat anecdotal, risking the clarity of the analysis. The data collected was not quantitative, assessing for certain that critical thinking was gained, increased, or developed by the individual learner who participated in activities within the makerspace. There were no in-depth assessments given to analyze the specific skills developed and how these skills would be achieved. Amendments could be made to address the exclusion of formalized testing by including the Watson Glaser critical thinking appraisal or other similar assessment. The challenging being the nature of an informal environment does not always that include an aptitude style assessment. Using alternative feedback methods such as rubrics, self-assessments or evidence provided by the facilitator would help to understand how the skills of critical thinking are expanding, promoting, and furthering through instruction and facilitation of active pedagogies. This study did not aim to assess the level of critical thinking that occurs in a makerspace rather if the makerspace environment could cultivate the development of 21st century skills.

One possible solution to the lack of tangible evidence that would support the growth of critical thinking could have been to make naturalistic observations within the makerspace locations. This could have been then reinforced with established lessons developed using inquiry-based learning and a formalized assessment method such as a grading rubric, developed to determine if the learners used critical thinking during a particular lesson. This methodology would not have been without challenges as determining how best to assess critical thinking in an informal environment makerspace is unclear. Further, data collection began during the COVID-19 pandemic which would have made any in-person observation nearly impossible. Many, if not all, informal makerspaces experienced closures in the past year and from the participants analyzed in this study all experienced closures. The recruitment of additional participants would have resulted in lower interest in participating in the intended research.

The variations in sampling were yet another limitation, while there was great benefit in the differences in the formats of the participating makerspaces (within a museum, membership based, and nonprofit), these variations could be considered a limitation as making in depth comparisons can be difficult. It is important to reflect to the purpose of this study as it was not the intent to compare the trustworthiness of the makerspaces to use inquiry-based learning to develop 21st century skills; however, it was to further gain insight into how the skills of critical thinking are activated, developed, and demonstrated within a makerspace according to a facilitator. The variation in samples could be thought of as a beneficial factor as it helped to produce evidence of similarities in how critical thinking skills are promoted regardless of the variations in makerspaces.

The makerspaces explored in this instrumental case study, sought the perspectives, insights, and feedback of participating facilitators as to the development of critical thinking skills in youth within an informal makerspace where inquiry-based learning is used. This data was yielded in semi-structured interviews from three participating facilitators all having varied and distinctive experiences from their individual makerspace locations. The analysis included inviting the three participants to review the transcribed data, the researcher reviewing the data through multiply coding cycles, and concluding with formulation of themes. In the following section, an analysis is provided reviewing the themes, providing insights into the key findings describing how critical thinking skills are activated, demonstrated, and developed in an informal makerspace.

Chapter Four
Findings

The findings of this qualitative case study were developed from in-depth interviews with three facilitators from informal makerspaces in Canada. The research questions that guided the collection of data were*, how are critical thinking skills activated, demonstrated, and developed in an informal makerspace where inquiry-based learning pedagogies are used?* In addition, to further explore the depth of experience of the facilitators from an informal makerspace exploration of the questions:

- *What are the instructional strategies used?*
- *Which instructional strategies appear to help develop critical thinking skills?*

In the report that follows, the conversation from the in-depth interviews with facilitators who actively work in a makerspace are explored through quotations allowing for the reader to develop personal insights into the research. The names of the participating facilitators are pseudonyms to maintain the privacy participant identity. The conversations explored a wealth of experience and insights of interactions with young learners, peers, and colleagues. The results are divided into sections, breaking down the research questions exploring how critical thinking skills are activated, demonstrated, and developed within the participating informal makerspaces.

Activated: Questioning

The instructional strategies used within a makerspace are of key importance in the development of skills best associated with critical thinking. During facilitated lessons or activities, the prompting of questions within a makerspace fuels skills necessary to expand and promote higher order thinking including critical thinking (Bowler & Champagne, 2016).

According to the Pearson critical thinking framework, the skill of creation, includes the ability to generate strategies, synthesis information and develop a plan all of which are features of using higher order thinking skills (Ventura et al., 2017). In this current investigation, facilitators noted that the activation of critical thinking skills is most visible when using active learning pedagogies that include inquiry-based learning, using questioning behaviors, which are prompted by the facilitator and initiated through the instructions for the activity being presented. For example, in the case where learners are presented with problem-based activity in which a challenge is set, or an activity is provided based on solving a dilemma. Questions proposed to students deepen their understanding and fuels their exploration into a topic (MacKenzie, 2016) allowing for further investigations and through exploration of a topic. In this study, one participating facilitator referred to as Celine, noted the way in which facilitators use question prompts allowing for the learner to deepen their thinking without the facilitator providing a solution to the learner:

> By asking those questions like, what is it you're trying to do, it's often it's the first thing we're going to ask, you know. So, what's your project and instead of [the learner] saying it's not working. Okay, well, what is it you're trying to do, how did you go about this. Even before the end of that amount of questioning because they finally understood throughout. What went wrong, or how to troubleshoot it.

With inquiry-based learning, the use of questions propels learners into the inquiry cycle; this thought process within a makerspace creates mindful makers, placing the importance of thought, creative design, and critical thinking into making (Bowler & Champagne, 2016; Pedaste et al.; Jansen, 2016). Facilitators expressed that by using questions as part of a lesson or activity, there is a possibility of developing critical thinking skills as witnessed through observations of activities within the makerspace as learners ponder questions throughout the process of completing their project. This use of questioning was expressed by the facilitator referred to here as Jaytee, who citing that the process learners use in making is evident and that critical thinking may be developing:

> Why did that happen and what can I do to change it? That I think involves a lot of critical thinking. It's the single thing that you do constantly throughout the entire process of making something unique in a maker space.

Learners within a makerspace are discovering ways to solve the issue at hand and while doing so are using thinking skills which can related back to the Pearson critical thinking framework, system analysis phase. The participating facilitators within the makerspaces explored in this investigation, described how using active based learning pedagogies, promoting the use of questions and problem solving, activating critical thinking. By employing inquiry-based learning and problem-based learning, learners can propel their thinking and move through stages of inquiry, creating increase in opportunities to question, investigation and explore.

Developed: Scaffolding

Inquiry based learning occurs on a spectrum moving from guided to open inquiry (MacKenzie, 2016; Zion & Medelovici, 2012; Coiro et al,, 2016). Learners must develop the skills of inquiry over time as novice learners need to be first guided into a level of inquiry requiring the most independence, open inquiry. The ability of learners to demonstrate deep questioning and related thinking skills can be created through scaffolding of learning within an inquiry-based learning framework, starting with a structured inquiry moving to open inquiry when skills and more confidence are available in the learners. This scaffolding suggests that inquiry-based thinking is best developed and most successful when scaffolding is used in a sequence relating to the types of student inquiry increasing from structured inquiry to open inquiry (MacKenzie 2016). In the conversations held with the participating facilitators it was expressed that the development of skills in a makerspace are also scaffolded, both thinking skills and those associated with the use of tools. The facilitator described that the instructed activities first start with a clear set of rules, instructions, and guidelines to allow for the learner to develop an understanding of the required steps and to encourage the learner to develop their own thought process. This thought process was expressed by the facilitator, referred to here as Amir, who includes developing a plan as an essential early step for the learners to do on their own:

> With structuring inquiry, we have a different topic each session so that they're not being overwhelmed with too many topics at once. The kids must come up with a plan then make sure that the teachers weren't the ones coming up with the plan.

Facilitators in a makerspace will also use stages or steps especially when learners are developing skills to use tools and equipment found in a makerspace. Some tools are complex, requiring guidelines on how to use them safely and many of the youth had not used them prior to their exposure in the makerspace. Tools and equipment included 3D printers, laser cutters or even hand tools like saws and drills. The complexity of this equipment requires clear and effective instruction prior to learners engaging with the equipment. The scaffolding used in a makerspace is described by Amir who explained that skills are built upon each other:

> First, 3D printing and 3D design and then we get into electronics. And then we get into HTML and CSS then they put it together. Putting all 3 of those things together into a little project. And those are all step by step, follow the instructions, there we try to get it into controlled inquiry by the end of each session.

Once skills in working with tools are developed, the learner can engage in the activity in a different way, even returning to the makerspace to participate in the same activity. As Celine noted, many learners are engaged in the activity even if they are familiar with it:

> People return to do the same thing…So they'll come into a challenge. And then they might come and do the same challenge again and then tell us, 'Oh, I did that last time'. And so they'll build on the skills they had the first time around, and build something more complicated the second time. Because often they will still want to do it. So that was a little bit of like okay well I just need to learn how the basic works.

This instructional strategy supports the pedagogy of inquiry-based learning, first starting with guiding learners to think critically, ask questions and freely explore, then move to a point when inquiry-based learning is a way to think and the dominant way to interact within the makerspace. Facilitators emphasized that the steps are essential, adding to the confidence of the learner. Facilitator Celine described a conversation with a learner discussing when something does not work the way they wanted to, they learn from their failures or mistakes, which further supports guiding though a thought process, encouraging a way to think beyond just carrying out a task or building of an artifact. Facilitator Celine retold this conversation with the learner expressing the learning process:

> Look at all the things you've managed, even though it's not doing what you wanted, or it's not working as intended, you've managed to do all of these specific things and it's like, oh yeah, I did manage to do that, you know. So it's not a binary system. Have you passed the exam? You didn't pass the exam. It's like, you know, you went through the process.

Whether the scaffolding strategies are used to introduce learners to the use of complex equipment or used to develop thinking skills in an inquiry-based learning activity within a makerspace it is key to developing the confidence for the learner to use skills associated with critical thinking. The goal is on the process of developing an idea and moving through the design process, furthering thinking skills along the way. Facilitators use many strategies in developing modes for delivering the skills needed to move learners through this process. The gradual development of tasks including developing thinking skills is built into each lesson. The process of scaffolding used to engage participation in activities can be carried out in a short interactive session or over an extended period of time. In one makerspace engaged in this research, the idea of a multi-week lesson was explored in detail to further describe the development of both thinking skills and the use of tools and equipment available in the space. Facilitator Amir described the time spent with learners in a multi-week program conducted within the makerspace, *"In our program that's for ages basically 13 to 18. That's 13 weeks, long, two and a half hours per sessions, so they have almost 40 hours with us."* Within this program there are a number of lessons that connect both the application of tools and encourage the use of thinking skills such as question prompts. Facilitator Amir describes this process:

> When they're learning about electronics, we have them build a little power measurement device. So, they do that step by step and then we say, okay, you build a power measurement device now, wander around the shop and measure some different objects and figure out what uses the most power? What is the least power? How could you make it more efficient?

During the first few week's learners gain knowledge in how to use tools and equipment as well as how to proceed through a thinking process related to inquiry-based learning. This program was then taken further, creating an opportunity for the learners to roleplay working in groups to take on a guided inquiry-based challenge, taking on the role of personnel working for a company hired to develop an innovation for a city. Facilitator Amir expanded by saying:

> Week 5 we have a challenge week, where we say, okay, we're going to now pretend that you are all a company and you've been hired by the city, and they want to encourage community gardens and so they've hired you to create what they want, what they're calling a gorilla garden gnome where it's a little object, they can plant into a bare patch of earth, stick it in there. And then it starts organizing the community to turn that bare patch of earth into a garden and it needs to connect to the needs of the environment.

This quotation describes guided inquiry-based lesson in which a problem-based activity is used to build upon skills. The conclusion to the programming allows the learners to engage what they learned putting their skills into practice to come up with their own problem to solve, which moves the lesson into a free inquiry-based learning stage. Amir describes the next changes of this multi-week program:

> Week 6 now is the bridge between 5 and 6, we say, okay, now go home. Think of the challenges your city faces and come up with an idea and you're going to pitch those ideas next week and form teams around that and just start building it.

Each group member takes on a role, discussed as a group on who will develop elements based on the learners' skills and interests. In this final stage of the program, the learners are in a free inquiry phase. Facilitator Amir, described the conclusion to the program as a presentation in which the group of learners pitch their idea to a panel of professionals:

> We set up something like Dragon's Den where there's 4 judges they have to pitch to and we tried to get them prizes. And they would pitch the idea, and we would also have it so that they were only competing against themselves. They're not competing against each other. It wasn't the judges choosing, which one to award it was them evaluating each other. Is this one good enough to award the prize too? So we always make sure to have enough prizes that they could be awarded to every group if necessary.

Throughout the program description it is possible to see the progression through different levels of inquiry-based learning, scaffolding the lessons based on the learner's own development. According to the participating facilitators, the use of scaffolding allows for gradual progression to deeper thinking levels and more autonomous learning within a makerspace. Skills are gained, not only in the use of equipment essential in a makerspace but also the skills related to thinking are increased when learners spend time in a makerspace and experience an environment that encourages independence and curiosity. Skills developed in the described lesson can be related back to the Pearson critical thinking framework, including drawing conclusions, decision making and using reasoning and deduction. The development of critical thinking occurs over time, with progressive stages, development of skills and guiding learners to increase their use of critical thinking.

Demonstrated: Informal Makerspace Environment

When learners are empowered to freely explore within an informal environment such as a makerspace, they increase their desire to learn about the topic, develop a new skill or master a technology tool (MacKenzie, 2016; Sheridan et al., 2014). Informal environments can make an ideal place to promote inquiry-based learning allowing for a fulfilling experience (Gutwill &

Allen, 2009). In the informal makerspaces that were explored in this analysis, multiple ways of discovery were cited as a possible link to demonstrate critical thinking skills. As described by the participating facilitators, independent discovery or free exploration leads participants to be more deeply engaged in a task such as hands-on activities, developing their own questions or discovery into a topic. Facilitator Celine described a particular activity often seen within her makerspace in which learners created a small obstacle course called a marble run, a wall mounted track for a marble to move from a start to a finish. Facilitator Celine expanded by saying:

> If you do a marble run or something like that. Like, you can see how they have this goal. So this is my beginning, this is my end. How will I go through? So, some of them throw themselves into it and just say, like, and we'll see what sticks, but often you see that they do that at the beginning, just to kind of get to know their materials and a bit of challenge, but then you're going to start seeing after a few minutes that they, they're really thinking through the steps that you want to take why they're taking some steps.

As described, there are no step-by-step instructions, rather a goal allowing the learner to explore the materials available, the results of the movement and the steps needed to get to the end goal. The Pearson critical thinking framework describes this action as *creation*, the use of design and planning actions (Ventura et al., 2017). Typically, activities within a makerspace are hands-on whether using tools, building using various supplies or working with computer programs. Depending on the audience and overall structure of a makerspace, the format of the activities is varied however all having the common characteristic of utilizing hands-on interactions with tools and materials. As described by Facilitator Celine, activities in the makerspace change often and keep evolving describing that they have:

> Weekly challenges that we roll. And the funny thing is that we keep evolving them like, yes, it's going to be a Flying Machine, but from week to week you see that the staff find new ways of using the material. So, it's not what we did the first week as a challenge. And what we're doing now, there's going to be variations in between. And it's never meant to be the same. It's the whole goal of the space, things in any maker space are not presenting steps.

Activity development that includes numerous steps and clear guidelines generally designed to fit a range of audiences can cause an unfortunate result as these multipurpose lessons can limit free inquiry-based learning. An instructional strategy noted by the participating facilitators was to have programs created that allow for individualistic discovery by the learner. In addition, a program with multiple steps influences the type of inquiry that is occurring (for example, many specific and well-defined steps may be equated to more structured inquiry). Participating facilitators described the style in which an activity or lesson is designed is important to influence the youth who are participating. Facilitator Amir, compared overly structured lessons to prefabricated building projects, describing it as, “Ikea projects, you're just putting it together. So that was another shorthand we use internally like, oh, that's kind of gearing towards an Ikea project rather than an inquiry project”. Therefore, the way a lesson is designed results in the level of inquiry-based learning it can maintain or achieve.

The instructional strategy of allowing for learners to be active participants within the makerspace is related to learner autonomy and open inquiry-based learning. Learners can use independent and unique thought processes to explore within an activity as well as when developing a personalized idea, digging deeper into questions pondered by the learner themself. When discussing learner autonomy with facilitators in reference to developing the learner’s questions or ideas, participating facilitator Jaytee expressed the need to reflect, connecting it to a continuous loop in thinking, explaining that:

> In order to know what question to ask, you need to be reflecting on what it is you expect and what it is you want. And part of the critical thinking loop is hypothesizing and then evaluating. And that's where the inquiry portion, I think comes in. Once students have an idea of what they think is happening, and they have questions about what would actually happen.

Learners in a makerspace gain independence while developing thinking skills, learning to ask the questions needed to solve this issue at hand. To allow for this skill development to occur, the role of the facilitator is key in creating the dynamics of the makerspace. The role of the facilitator combined with the lesson or activity that is being introduced to the learner creates an opportunity to develop critical thinking skills. One facilitator commented on an experience in which overly guided lessons limited the creativity of a learner. Participating facilitator Amir describes this situation during a makerspace session in which the learner is instructed to determine a problem from their daily lives they want to solve for themselves by creating an innovation or invention, "I have them come up with a challenge first. And then come up with the solution after it so that you're not limited by what you think you can create" In this particular example given by Amir, the learner identified that they dislike waking up early in the morning and wanted to create an innovation to make this easier. The facilitator, Amir, describes how they had a realization that the assistance they were providing limited the learners' thinking process:

> This was an A-Ha moment for me, where I started coming up with ideas that I was giving her, like okay, cool, we'll make a really weird alarm clock. It'll be really loud or it'll slap your face with a wet cloth or something, that's really annoying. And it'll really help you get up in the morning, but fortunately, she kind of resisted my solutions and pushed back. And it was realized that her problem actually wasn't waking up, her problem was that her bed was really nice and warm and cozy. And the house was cold, and she didn't want to get out of her warm bed into the cold house. That was the actual problem."
>
> Then there was a kind of click in my brain, like, oh, right. She has to solve her problem. Not what, I think her problem is. Well, how do we solve that? And she came up with an amazing invention where she basically made a clothes tree out of ABS pipes that she would put her clothes on. And there all these holes drilled in it, and then she had a heater with a timer, so that 10 minutes before her alarm went off, this heater would turn on and blow hot air and all of our clothes and warm them all up before she was time to get up.

In this narrative, the facilitator instructed the lesson using open inquiry-based learning showing the possibility of allowing the learner to freely explore their own topic working through a creative challenge and promoting the development of critical thinking in a makerspace. The participating facilitator needed to adjust their role as a leader to ensure the learner was able to freely create the desired outcome. After this discovery the facilitator Amir was able to step back, provide guidance, allowing the discovery to be in the hands of the learner changing the level of engagement. There is importance in having the educator in the makerspace remain as a guide, providing assistance without directing the discovery. Facilitator Amir further describes how they encourage other educators to allow for learners to be independent when in a makerspace:

> By emphasizing to the teachers that the kids have to come up with a plan then making sure that the teachers weren't the ones coming up with the plan or another kind of thing. I would always tell the teachers to keep your hands in your pockets.

The role of an educator in many informal environments is that of a guide, breaking from the traditional classroom idea of an educator allowing for more multidirectional instruction meaning that there is no top-down hierarchy of learning. The non-traditional role of an educator and the elements of social learning are key to the creation of the makerspace community. The facilitator is not the expert and does not make claims to knowing all the answers, however, tries to work collaboratively with learners to develop their ideas. Facilitator Celine echoed this idea that facilitators do not hold all the answers:

> So, we don't say we have all the expertise and I think that's the fun thing about the makerspace as well. It's not something when you present yourself, I'm an expert in something. We're going to try it together kind of thing.

Furthermore, Driscoll (2005) describes the characteristics of an instructor in a social learning environment as they, “should neither present information in a one-sided way nor shape successive approximations to some goal behavior… an instructor should provide the guidance required for learners to bridge the gap between their current skills levels and a desired skill level” (p. 257-258). The facilitator role extends further within a makerspace to include other individuals acting in a leadership role including parents, guardians, and even fellow makers no matter their age. Parents and caregivers within an informal makerspace provide guidance to young learners which is often seen by facilitator Celine:

> It's very interesting to see how parents interact with their kids in the makerspace. We have the parents who are daddy engineers, which are so easy to spot and they're just so happy to have a space where they can share their knowledge with their kids

Social learning is a fundamental aspect within a makerspace, developing knowledge from fellow makers in a community built from shared ideas and knowledge. Facilitator Jaytee explores this ideal as well discussing how ideas are shared among makers in the community:

> We can sit down as a group and discuss it amongst us. And bounce ideas off of each other and that allows all of us to learn more about the different areas to come up with unique ideas.

In an informal makerspace that serves a wide range of ages, youth participants even help guide adults. Facilitator Amir describes that it is not only adult learners who can teach the use of complex tools, “a kid that got certified to use the CNC machine and ended up helping teach adults how to use the CNC machines and seeing his confidence in doing that grow over time.” Learning is multidirectional in an informal makerspace allowing for key aspects of social learning to occur. Discussing, sharing thoughts, and providing multiple perspectives, being able to analyze information is part of the Pearson critical thinking framework as an indicator of critical thinking. These discussions within the makerspace creates an opportunity for learners to gain critical thinking skills.

The instructional strategies that allow for the building of critical thinking skills are a result of the informal learning environment created in the makerspace. This skill development is a result of strategies such as the use of scaffolding and inquiry-based learning, creating learning to occur in stages as seen in the multi-week lesson discussed by facilitator Amir. Furthermore, when the instruction occurs with a social learning perspective, and the facilitators take a non-traditional role, allowing for the learner to steer their own discovery, learners can further build critical thinking skills. The demonstration of critical thinking skills occurs in informal learning environments, particularly within the makerspace explored here, which was evident through multidirectional discovery, free exploration and activities designed to promote the development of critical thinking.

Activation of Critical Thinking

In the informal makerspace explored in this research a variety of activations (i.e., lessons, activities, workshops, and programs) demonstrated the development of critical thinking. The pedagogies often seen included not only inquiry-based learning but other active learning pedagogies such as problem-based learning and project-based learning. At times, there was great overlap between these pedagogies culminating in multiple active learning goals at the same time maintaining the goals set within the informal makerspace. Based on the example described earlier by facilitator Amir, the multi-week lessons provided a way to explore how problem-based learning can activate learner engagement. Problem-based learning combined with freedom to explore various media tools, brings learners the ability to solve questions that they create, aligning with the goals of open inquiry-based learning. The importance of the creation of a lesson was further explored when analyzing problem-based learning. The facilitators used question prompts and engaged learners using real world examples to generate higher level thinking skills among learners in a makerspace. As described by the facilitator Celine:

> Relating it to something that is real life. So, if we're doing nematic, you know, let's find example in real life of nematic. And then trying to relate to that. How can this work, and then they're going to try to fill in the blanks in between?

Relating the task to real world events or situations strengthens the learner's experience creating a pathway for the learner to connect their past experiences or prior knowledge to their current learning.

Often in a makerspace, the activity centres around a question prompt, a challenge, or questions that is provided by the facilitator. To create a deeper level of inquiry-based learner, facilitators encourage learners to develop their own question. Providing this opportunity creates additional experience with critical thinking however the ability to ask strong questions is not always available for youth. Questioning ability changes over time as does the desire to manipulate materials freely without a plan. As noted by the participating facilitators, younger learners seem to ask questions freely while older learners wait for questions to be posed to them. Facilitator Amir describes this:

> The older they are, the more challenges they have coming up with things that are outside of the box. I think the older they are the more used to just being told what to do, and what to learn, but the young kids have no problem coming up with ideas. And they're the ones that the younger they are, the harder it is for them to come up with realistic questions.

However regardless of a well-developed lesson which allows for in depth inquiry-based learning, learners will still seek out free exploration allowable in an informal makerspace. Facilitator Amir expands by saying,

> You know, sometimes a kid will want to just mix paints together to see what colors happen and like sure, okay! That's cool but you're not solving any particular challenge that's okay. You're still thinking critically and figuring stuff out. And then the older they are, we try and get them to apply it to something, some specific challenge that they want to solve.

Facilitator Amir describes this open exploration as not solving a particular task however still developing thinking skills. In an informal makerspace, the learner creates their own path establishing multiple avenues to a particular goal without having a formalized system of what is right or wrong. Rather the focus is on discovery, explaining ways of thinking and developing critical thinking skills.

Critical thinking is activated, developed, and demonstrated through the use of active-based learning pedagogies as witness by the facilitators and reported within this investigation. The facilitators described strategies such as the use of question and questioning behaviors, scaffolding of skills including thinking skills and the dynamic role of the educator to create social learning within the makerspace. The examples provided by the facilitators included having lessons occur over multiple weeks, increasing skills each week and guiding learners to enhance their independence in thinking. Informal makerspaces create an environment that allows for free exploration, discovery and curiosity aiding in the development of critical thinking.

How are critical thinking skills developed?

The development of critical thinking occurs in learners over time which is suggested by many researchers (Ventura, Lai, & DiCerbo, 2017; Loes & Pascarella, 2017). The notion of this extended period of development for critical thinking in learners created a challenge for this research as most informal places do not always see the development of learning over extended periods of times (i.e., years or even over a school year). Within an informal makerspace, there are not always the continuous experiences allowing facilitators to spend extended periods with learners. However, as discussed earlier, the makerspace which offered multi-week lessons provided some insight as to the pedagogies and instructional strategies that are used to assist in the promotion of critical thinking skills. Participating facilitators discussed using problem-based activities, the use of real-world examples, promotion of questions, and allowing learners to use iteration, a combination of testing, failing, and trying again. Facilitator Celine noted that facilitators see a change in the learner after providing them with strategies to develop a thinking process:

> The first challenge takes 30 minutes and then the second one in 10 to 15 mins they got something, you got a result, you know, they have their ideas lot more condensing impact.

> You can see the evolution of how they're thinking through it and how easier it gets, the more to do it.

Through the ability to test and use iteration, learners develop thinking skills, evolving their thought process in a design loop. Facilitator Amir described a process in which learners explore the materials available to them to complete a challenge, design the product and make their solution to the problem. Facilitator Amir describes it as:

> We have a cycle that we use, which is similar to the inquiry learning cycle, but it's just adapted a little bit. We try to have a component where you're playing with something. And then the next step is designing something to solve, some specific challenges and then there's making step where you're actually physically building something and then there's a celebrate step where you're actually using it in some way. Self-iteration and that's the cycle repeats over and over… The design task iterative loop in there just makes for just amazing critical thinking that they're just doing on their own and they're just in flow and figuring out stuff on their own.

Being able to test, use iteration and allow the learner to work through the challenge, helps to develop deeper thinking skills. This cycle that includes iteration is further discussed by Facilitator Celine:

> There's a lot of that iteration and it becomes really easy to just keep on going and try different aspects and then see what changes for the better or worse, but they are going to keep on going back and forth and it's fine.

Regardless of the challenge many informal makerspaces face due to limits on spending extended periods of time with learners, especially those in this study, it was still possible for the facilitators to note changes in the thought process used by the learner. Self-iteration while working within a design cycle creates an opportunity to promote critical thinking skills. Iteration is sited in the Pearson critical thinking framework related to computational thinking, problem solving fundamental to computer science (Ventura et al., 2017). Therefore, this iterative process within the makerspace is essential to developing critical thinking.

As learners interact within the makerspace, using problem-based scenarios relatable to real life, they can expand their thought process, move freely into the flow of the task at hand and expand their critical thinking through an iterative and adaptable process. When the iterative process is combined with the use of questioning, scaffolding of skill and active learning it is possible to see the development of critical thinking in learners. In the following section, a thorough review of the major findings will be explored drawing conclusions on how critical thinking skills are activated, demonstrated, and developed within an informal makerspace.

Chapter 5

Discussion

Discussion of Major Findings

This research sought to investigate the experiences of facilitators who work within informal makerspaces to gain an understanding as to how critical thinking skills are activated, demonstrated, and developed. Multiple patterns emerged indicating the strength in the use of active learning pedagogies, mainly inquiry-based learning, and problem-based learning, in a collaborative social learning environment as seen within the informal makerspace investigated. Through this analysis, the importance of independent exploration and hands-on activations such as lessons and programs in addition to the use of questions both prompted by the facilitator and investigated by the learner allowed for an increase in critical thinking. Further, facilitators noted common strategies such as using scaffolding, building upon important thinking skills, and gaining increasing use of inquiry-based learning as a method to promote an expansion in critical thinking abilities. Throughout the analysis, the connection between the use of inquiry-based learning and critical thinking skills become evident. As learners become confident in inquiry-based learning, they can move into open inquiry. It is important to focus on the interconnectivity seen by facilitators to further develop the understanding of these emerging patterns.

Deep Thinking Skills. Within the informal makerspaces, facilitators noted how questioning was integral to the development of critical thinking skills among learners when inquiry-based learning is utilized. According to the conceptual framework explored in this current analysis, Canada C21 describes the skills needed to use higher order thinking in the development of critical thinking as “the ability to think logically and to solve ill-defined problems by identifying and describing the problem, critically analyzing the information available” and “framing and testing various hypotheses, formulating creative solutions, and taking action”

(Shifting Minds, 2012, p.10). By identifying the problem at hand, thinking logically, and determining the best way to solve the problem, even if the goal has already been established, the learners can engage in inquiry-based learning regardless of depth of the activity. Facilitator Jaytee noted this in relation to a particular program with set steps:

> It was much more of a structured inquiry, partly because we already had a desired outcome, it was a kit that we were building. So we knew exactly what it should look like, how it should work.

With structured inquiry-based learning, the learner follows steps designed by the facilitator however to usher learners further into open inquiry-based learning, the learner must initiate their own questions and be independent, propelling the learner to gain more critical thinking skills. The ability for learners to develop deeper thinking skills requires them to move through the inquiry process naturally, which is dependent on their experience with using the thinking skills. As was discussed earlier, the age of participants was noted by facilitators as creating opportunities in creativity but a challenge in formulating realistic questions in a younger age group of learners. In older learners who may have experienced more inquiry-based learning, they may at times, rely more heavily on the facilitator to guide their exploration. As learners gain more skills in critical thinking, the ability to ask obtainable questions in a makerspace setting is increased; however, limits on their creativity can occur which may not affect a younger learner. In a makerspace, there is significant importance for the learner to be able to ask questions or determine a problem that they want to further explore and solve. Learners using free inquiry-based learning use a tremendous amount of critical thinking skills to work through issues or solve ongoing problems. As explored earlier, the use of iteration is common in a makerspace when learners are testing and using manipulatives to problem solve. Iteration allows for the learner to ask questions within a design process, determine possible outcomes and continue to gain further critical thinking skills. Facilitator Jaytee explored this connection to the design process when describing the questions, a learner asks when trying to complete a makerspace project:

> Why doesn't it fit? What did I do wrong? Oh, right. When I drew this part over here, I forgot to draw this part over here to be the same size. I was thinking of the inner dimension, instead of the outer dimension or I have a bolt that goes in here, except for I literally can't put the bolt in there because there's something in the way on a different parts. These kinds of things come up all the time. As part of the design process you think

> you understand it fully and then you go to actually implement it and realize something didn't turn out and you have to try and figure out why. Why did that happen and what can I do to change it. And that I think involves a lot of critical thinking."

As Jaytee explained, learners are continually using thinking skills, such as questioning and iteration, as they are processing through the design and building stages of a project while constantly adjusting their thinking and developing greater thinking skills. Further, Facilitator Celine, described that iteration is a motivating factor, increasing engagement among learners:

> There's a lot of that iteration and it becomes really easy to just keep on going and try different aspects and then what it changes for the better or worse, but I'm going to keep on going and going back and forth.

Whether using questioning skills or processing through an iterative process learners are engaged using motivation to complete a challenging activity developing greater thinking skills.

Link Between Inquiry-Based Learning and Critical thinking. By analyzing the use of iteration in a makerspace, it is possible to see this link between inquiry-based learning and critical thinking. Within a makerspace, the use of critical thinking aids in the overall process, creating learners that have the tools to think deeply, determine the best way to a solution and the ability to discover and implement solutions, even when the solution does not occur in the first trial (Jarrett, 2016; Bowler & Champange, 2016).

The importance of iteration to the development of critical thinking is further supported through the considerable role social learning has within the makerspace. The beneficial aspect of social interaction and learning within a makerspace allows for meaningful discussions demonstrating critical thinking skills among learners as a result of in-depth conversation regarding modifications and challenges with a learner's project. Within the makerspace learners communicate with each other connecting to a shared goal or interest and are not limited by a hierarchical structure which provides multiple ways in which a learner can grow skills. During this study, it became apparent that collaboration and social learning were important elements in advancing deep thinking skills of learners. In addition, the informal environment creates an opportunity for multiple skill levels, those with differing needs and abilities, as well as diverse backgrounds and cultures to interact in a social learning environment to use the tools and materials available in the space. Facilitator Celine described working with diverse groups and the considerable benefits a makerspace environment can have:

> So in this project, because especially the indigenous community has a relationship with schooling, that's very different from mine, they've been able to leverage the makerspace to make it a lot more open and it's been working really well.

Even further Celine describes another program for young learners who experience challenges:

> And we have another one where it's a group of youth that don't see themselves represented in science and that's a term we're using instead of at risk. So kids don't see themselves represented because often they just haven't been exposed to it. So we do a bunch of projects with them after school or on Saturdays, where we explore different types of science and engineering and art using the makerspace and the type of tools that the makerspace has.

Facilitator Celine described the opportunity within a makerspace for learners to increase their motivation, investigate new skills and develop confidence regardless of past experiences enabling the learners to see themselves represented in a new field.

Open Pathway to Exploration. Makerspaces allow for new experiences in a unique and free environment in which learners can explore their own interests, especially when inquiry-based learning is engaged. The free or open aspect of a makerspace was again explored by Facilitator Celine who described a learner who experienced limitations in the traditional classroom. The facilitator described a classroom excursion within the makerspace, in which an early learner in kindergarten was interacting with a wind-tunnel, an interactive display in which a stationary fan placed horizontal at the bottom of a plastic tunnel with the aim to explore how things move and travel upwards:

> So she took the material and just crumbled it and then threw it in. And she loved it. And just went back and did the same thing for a bit and then she tried different things. To see like, well, if I have one piece of paper to another piece of paper with tape around it, how it work? So she was on the autism spectrum and one of the main things the teacher was telling us after, like tears in his eyes, I haven't seen her smile all year. She hasn't been involved in any of the projects all year until this happened.
>
> The fact that it was a freeing thing. There was no, like you have to take this, you have to know, it was just saying, here's the material, how would you go toward it and I think it was very freeing for this little girl.

Facilitator Celine described an important principle within a makerspace in which the learner is the driving factor in their exploration, aligning within the inquiry-based learning framework and the constructivism pedagogies used within the makerspace. The learner takes on their own pathway to exploration proving an increased level of autonomy aiding in motivation and development of new skills in particular critical thinking as these actions can demonstrate the creation of strategies to solve complex problems.

Beyond the Tools and Space. While a focus can be placed upon the tools and materials in a makerspace the pedagogy used, such as inquiry-based learning, is of more importance, guiding the development of complex learning goals. Within the makerspaces explored in this study, a variety of tools were available to learners however facilitators expressed that the power of the tools and materials is their ability to expand the learner's creativity and use of critical thinking skills. Facilitator Celine describes the importance should be on the accessibility:

> A lot of people think a makerspace, is all about the tools and the big machinery, and you're, like, no, it's about access. It needs to be easily accessible for everyone. If we show them that the maker space is just filled of 3D printers and laser cutters, then go home and think, 'I can be a maker?'. You have to get cardboard and tape and scissors and all of these very, very accessible materials so that they can see themselves represented in that.

A makerspace goes beyond the tools and the physicality into that of the philosophy, purpose, and reason for the makerspace to exist. Facilitator Amir echoed this sentiment.

> I see a lot of people trying to set up makerspaces, thinking that, oh, we just need to create the space and then it will do all these great things. Whereas I see, the space is actually secondary. It's really the culture of innovation that you're trying to create inside of a community and the makerspaces is one of the tools that you use to create that culture of innovation.

This idea that the makerspace itself is a tool is key to developing the idea that the pedagogies used within the makerspace creates the fuel for the learner to expand their skills and develop the ability to critically think about a solution. The importance of social learning and how it can further the use of iteration among learners, moves a makerspace beyond the equipment, tools, and physical aspects to that of the overall goals. The learner then becomes the focus, as a makerspace is about creating a 21st century learner, one that is fluent in the key aspects of critical thinking.

Makerspace beyond 21st Century Skills

Makerspaces, as we know of them today within an educational setting, may have emerged only within the past few decades and are still gaining in popularity however the development of skills needed for the growth of future society has been a constant for millennia. Therefore, when exploring the skills developed within a makerspace while reviewing their close ties to 21st century skills such as critical thinking, it is important to review how the makerspace might expand into the future. The future potential and limitations of makerspace were discussed with the facilitators in this study who offered their insights into the future role of makerspaces in informal education.

Overall facilitators expressed the importance for the development of critical thinking skills among learners as it was thought to be a key aspect needed for the development of society in the future. Facilitator Amir expressed the need for the future learners to have well developed thinking skills, so they are more equipped to decode the information that comes to them through various aspects of information and communication technologies:

> As citizens that can think critically about things, then just all these problems around misinformation becomes so much easier to tackle if the citizenry has the critical thinking as a core skill, then we can help them think this through.

For critical thinking to develop, however, additional connections need to be made with the focus being on the importance of pedagogies that allow for the development of 21st century skills including critical thinking. When looking to the further development of makerspace, it is key to include the ability for makerspace to move beyond tools and resources to that of facilitation from constructivist principles allowing for active pedagogies such as inquiry-based learning. Facilitator Amir, further discussed the future of makerspace who provided insights into what may be required for makerspaces to move further into a formal educational setting:

> I'm really hoping that the next evolution of makerspaces in educational settings is that kind of realization that it's not just about access to equipment. It's actually about a different way of teaching and learning.

This ideology creates an open pathway to the growth of a makerspace that does not require continuous improvement of physical materials promoting a unique perspective into the future of education.

Simply adding alternative methods into an education setting would not come without significant challenges. Afterall, makerspaces are still gaining in popularity in many areas, especially within the formal education setting. Adding to these challenges is the uncertainty in the current times due to many factors including economic uncertainty, varying priorities within educational settings and when the COVID-19 pandemic began in 2019, some of these challenges became even greater. Many informal makerspaces were temporarily closed, offering online programming and communication. When speaking with facilitators regarding issues surrounding restrictions and closures due to the pandemic many expressed frustrations and limitations while still providing solutions to their situation. Jaytee expressed some of these challenges:

> Communicating ideas is a lot more difficult. A lot of what we're describing, and working on things, a lot of it is very physical and visual. So that is definitely a challenge. And I think right now. We just don't have good, remote online tools for communicating. Those sorts of ideas, visual information, aside from a webcam, which a lot of people don't even have right now. We need much better tools to facilitate the kind of in person immediate to social and physical ways that we would teach and learn and explore that we just don't have online right now.

The limitation with communication reinforces the importance of social interaction within a makerspace as it is a key aspect to how learners grow their knowledge and develop thinking skills by creating opportunities to iterate designs and projects. Makerspaces create a community of makers and at times these communities can extend beyond a physical location relying on alternative means of communication. The need for seamless web-based communication as mentioned by facilitator Jaytee was something many industries experienced during the COVID pandemic. The creation of these technologies would again alter the landscape of information and communication technologies impacting future learning.

Chapter 6

Conclusion

Future Research

There are many important opportunities for further research into makerspace, both in formal and informal environments. Additional investigation into areas related to 21st century competencies, in particular creativity. Creativity is another well-researched topic that generates multiple definitions as to the meaning and how it can be acquired, tested, and increased in learners (Austin, 2017). The makerspace environment is one that promotes innovative thinking therefore further research into the promotion and development of creativity in a makerspace learning environment would yield interesting results.

In addition to skills gained within a makerspace, the ways in which learning is promoted is of significant interest. Further investigation into key pedagogies used within a makerspace seeking indications as to how they may affect a learner and the development of these goals in a makerspace. This current investigation found many forms of active learning pedagogies to be present in the informal makerspaces studied. Further to the inclusion of active learning pedagogies, this research sought better understanding of the philosophies, the main purpose and goals that define the makerspace, and comparing these to various locations with differing audiences would be of significant value to understanding how makerspaces are important learning environments. This current research saw that the importance of the makerspaces' overall goal and philosophy is greater than the tools and equipment contained within. Understanding the development of the goals and philosophy would create a further opportunity to expand these valuable environments. Exploring the goals and philosophies used within makerspaces could create a framework, one that could be applied to any learning environment creating a relatable learning space. For this framework to be developed more research is needed to understand the process makerspace use in the creation of their main goals. While a formalized process may not be possible, further understand and insight would be gained into the informal makerspaces.

Lastly, future research exploring the importance of questioning and the use of higher order thinking skills, relating to the age of the learner is limited in current research however came up in this current analysis as an interesting avenue of exploration. Further to this, a longitudinal study involving the same population expanding on how their overall cognitive development expands with exposure to a makerspace learning environment. Limitations with such in-depth studies would exist; however, developing a well-defined understanding of the overall long-term growth of a learner who utilizes a makerspace would strengthen the educational value of a makerspace. Exposure to such environments, especially one that use inquiry-based learning must occur at an early age to allow for the needed scaffolding of skills, awareness of individualistic thinking and the development of the learners' ability to use higher order thinking skills.

Conclusion

Through a qualitative instrumental case study, this investigation explored the development of 21st century skills in an informal makerspace where inquiry-based pedagogies are utilized. This study responded to the questions; *how are critical thinking skills activated, demonstrated, and developed in an informal makerspace where inquiry-based learning pedagogies are used?* In addition to this main question the secondary questions examined further the perspective of the facilitator by investigating *in an informal makerspace where inquiry-based learning pedagogies are used:*

What instructional strategies used appear to help develop critical thinking skills?

How are critical thinking skills activated, demonstrated, and developed?

The qualitative data yielded from the three facilitators created a thorough perspective highlighting several instructional strategies that activate, demonstrate, and develop critical thinking. From this analysis the importance of pedagogies in a makerspace was spotlighted, including inquiry-based learning. The facilitators discussed the instructional strategies which included scaffolding, the importance of collaboration, social learning, iteration, and physical hands-on exploration. Developing the ability in youth to interact in an inquiry-based learning environment was achieved through scaffolding of instruction, creating an environment that allowed for free exploration and placing an emphasis on thinking not creation alone. Makerspaces create an environment of shared experiences and knowledge, adding to the dynamic hands-on environment. The use of questions, either asked by the facilitator or asked by the learner in the process of developing their maker projects, was another key element important in the informal makerspace and demonstrated the use of critical thinking.

Makerspace learning environments offer a media-rich, flexible, cross-curricular and student-directed while activating critical thinking skills, important in 21st century learning. Active learning pedagogies, such as inquiry-based learning, offer further ways to increase the development of critical thinking in youth within a makerspace. As information and communication technology increase in importance, learners will need to develop critical thinking skills to be successful in an everchanging more technologically fluent world. Makerspaces, whether formal or informal may offer an environment to develop 21st century skills and those competencies not yet determined.

Appendix A

Interview Protocol- change to interview questions

Heading	**Main Question**	**Sub questions/ Follow up**
Introductory Questions	How do you define or describe the makerspace you work with? Please describe the makerspace?	Title or name Purpose and goals including epistemology Setting and location Participant (who are the common users) How are youth present or how do they participate? Structure of makerspace (is it a paid membership, engage during visit to venue, classes, rental space/equipment)
	How are youth (participants) engaged in the act of making?	What are some of the programs, services or content you provide? What have you observed including narratives, anecdotes and examples in which learners participated in making (or the process of making)?
Middle Section		
Pedagogy - Inquiry Based Learning	For the purpose of this study, inquiry-based learning is defined as the construction of knowledge, skills and understanding of the world through questioning and experience-based discovery. From your observations as a facilitator or leader, in what ways do participants in your makerspace exhibit Inquiry-based learning?	If youth in a makerspace use inquiry based learning, what level of inquiry would they be in? (Refer back to the image with the pool, what end of the pool are they in?) o What variances have you observed? o Have you observed youth starting in open inquiry and them needing to move to more guided? Or have you seen the reverse? What instructional strategies are used in your makerspace to promote inquiry based learning? o In what ways do you utilize inquiry based learning techniques (or student directed pedagogies)? What observations have you made with youth in a makerspace of youth taking charge to investigate, inquiry or use curiosity to solve or discover a solution?

<table>
<tr><td>Pedagogy - Critical Thinking</td><td>Critical thinking can be defined as the ability to reflect, analyze and evaluate information. Critical Thinking skills can include the ability to: problem solve, reason, make decisions, use computational thinking, plan, design and debate.
Please review the Pearson critical thinking framework.
Can you provide examples, observations or anecdotes from the perspective of a facilitator, of critical thinking skills in the makerspace?
How are critical thinking skills activated, demonstrated and developed in the makerspace?
What instructional strategies (activities) appear to help or promote or increase the development of critical thinking skills?</td><td>Do you see frequently (more than a few times) critical thinking skills being exhibited in the makerspace?
From the point of view of a leader or facilitator, can you identify ways that these skills have developed, grew or changed in a youth at your makerspace?
Are there particular activities/lessons/events that you have observed more critical thinking skills being demonstrated?</td></tr>
<tr><td colspan="3">Further in depth questions – concluding concepts</td></tr>
<tr><td rowspan="2">In Depth questions:

Facilitator Insight on the future of Makerspace education</td><td>What connections do you see between student directed pedagogies (like Inquiry based learning) and development or ability to use critical thinking skills? If so, in what ways do you think they are connected?</td><td>Do you think there is a connection between inquiry-based learning and critical thinking in a makerspace?

From your experience as a facilitator, do you think there are connections between the ways youth are engaged in a makerspace and the development of skills such as critical thinking?</td></tr>
<tr><td>From your experience as a facilitator in a makerspace, are there other future skills (21st century skills) that might grow or flourish in a makerspace?</td><td>Where do you think makerspace environments might grow in the 21st century? And why do you see them in this way?

In general, how do you see makerspaces develop into the future?</td></tr>
</table>

Appendix B
Transcript Release Form

TRANSCRIPT RELEASE FORM

Title: Examining the Development of 21st Century Skills of Critical Thinking in an Informal Makerspace learning Environment

I, ____________________________________, have reviewed the complete transcript of my personal interview in this study, and have been provided with the opportunity to add, alter, and delete information from the transcript as appropriate. I acknowledge that the transcript accurately reflects what I said in my personal interview with **Julie Fisowich**. I hereby authorize the release of this transcript to [name of the researcher] to be used in the manner described in the Consent Form. I have received a copy of this Data/Transcript Release Form for my own records.

___________________________	___________________________
Name of Participant	Date
___________________________	___________________________
Signature of Participant	Signature of Researcher

Appendix C
Invitation to Participate – Recruitment Email

Hello,

My name is Julie Fisowich, and I am a master's Candidate, in Curriculum Studies: Educational Technology and Design Graduate Program, at the University of Saskatchewan. I am working on a research project under the supervision of Dr. Dirk Morrison.

I am writing to you today to invite you to participate in a study entitled *Examining the Development of Critical Thinking Skills in Informal Makerspace Learning Environments*. The purpose of this research is to investigate the specific skill development in a makerspace that utilizes the student directed pedagogy of inquiry-based learning, through a close examination of how facilitators and educators utilize instruction in an informal makerspace to develop critical thinking for school aged youth.

This study involves one 60-minute interview by phone or video call that will take place in a mutually convenient, safe location. With your consent, interviews will be audio-recorded. Through this research investigation, care will be taken to protect your identity. This will be done by keeping all responses anonymous and allowing you to request that certain responses not be included in the final project.

More information about this project can be found in the attached letter. If you know someone else in your organization who may be interested, please forward this email, and attached file. If you have any questions or would like to participate, please contact me atjuf507@mail.usask.ca or my supervisor Dr. D. Morrison, Education, 306-966-6483, dirk.morrison@usask.ca.

Sincerely,
Julie Fisowich

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