ChangeMakers: Exploring Social Consciousness through Making and the Internet of Things

by

Jennifer A. Robb

A thesis submitted to the
School of Graduate and Postdoctoral Studies in partial
fulfillment of the requirements for the degree of

Master of Arts in **Education**

Faculty of Education
University of Ontario Institute of Technology (Ontario Tech University)
Oshawa, Ontario, Canada
December 2021

Thesis Examination Information

Submitted by: **Jennifer A. Robb**

Master of Arts in **Education**

Thesis title:
ChangeMakers: Exploring Social Consciousness through Making and the Internet of Things

An oral defense of this thesis took place on Friday November 19th, 2021, in front of the following examining committee:

Examining Committee:

Chair of Examining Committee	Dr. Ann LeSage
Research Supervisor	Dr. Janette Hughes
Examining Committee Member	Dr. Diana Petrarca
Thesis Examiner	Dr. Jennifer Lock University of Calgary

The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

Abstract

Since the advent of the computer, digital technologies have transformed our engagement with society. Not only are technological competencies required for economic participation, they also facilitate creativity, self-expression, and personal fulfillment. Technology has also broadened citizenship beyond our local communities, necessitating the development of social consciousness and skills to navigate global challenges. Given the need for tools that facilitate digital competencies and social action in schools, this study investigated how passion-based making with the Internet of Things (IoT) could facilitate students' involvement with citizenship and social justice. Over the course of a five-day makerspace camp, this study employed a qualitative multiple case study design to explore the IoT learning and social participation of ten elementary school students. The findings revealed meaningful development in participants' understanding of concepts and concerns related to IoT, as well as thoughtful engagement with societal challenges through the construction of socially oriented IoT artifacts.

Keywords: ChangeMakers; citizenship; critical making; Internet of Things; social justice.

Author’s Declaration

I hereby declare that this thesis consists of original work of which I have authored. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I authorize the University of Ontario Institute of Technology (Ontario Tech University) to lend this thesis to other institutions or individuals for the purpose of scholarly research. I further authorize University of Ontario Institute of Technology (Ontario Tech University) to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research. I understand that my thesis will be made electronically available to the public.

The research work in this thesis that was performed in compliance with the regulations of the Research Ethics Board under project file #13862.

____________________________ Jennifer A. Robb

Statement of Contributions

The research presented in this thesis was conducted within the context of a larger project entitled "Production Pedagogies" (with Dr. Janette Hughes as the principal investigator), funded by the SSHRC Canada Research Chairs (CRC) Program. The study outlined in this thesis is a small component of the larger, longitudinal project, and presents findings specific to the March Break camp that occurred during March 11 – 15, 2019. The research design of this study was informed by past iterations through a design-based research approach, with lessons learned in previous March Break camps being re-invested into subsequent years.

The work described in this thesis was performed in Dr. Hughes' STEAM-3D Maker Lab with her guidance, as well as the assistance of two other research assistants – Laura Dobos and Margie Lam – who helped to facilitate camp activities and provided their insight on participants' work through conversations and documented field notes.

Parts of Section 2.4 Social Justice & Citizenship Education were adapted for a white paper written for the COVID Education Alliance and published as:

Hughes, J., Robb, J., & Butler-Ulrich, T. (2021). *Building global digital citizenship.* COVIDEA White Paper.

Parts of this study's findings were presented at the 4th EAI International Conference on Design, Learning & Innovation (DLI '19) and have been subsequently published as:

Hughes, J., Robb, J. A., & Lam, M. (2020). Designing and learning with IoT in a passion-based constructionist context. In A. Brooks & E. I. Brooks (Eds.), *Interactivity, Game Creation, Design, Learning, and Innovation: ArtsIT 2019, DLI 2019* (pp. 760-771). Springer Nature. https://doi.org/10.1007/978-3-030-53294-9_59

Hughes, J., Robb, J. A., Lam, M. (2019). Making future-ready students with design and the Internet of Things. *EAI Endorsed Transactions on Creative Technologies, 6*(21), e1. https://doi.org/10.4108/eai.13-7-2018.163096

I performed most of the data analysis for these works, wrote the greater part of each of the manuscripts, and presented the work at the DLI ’19 conference in Aalborg, Denmark (November 6-8, 2019).

Apart from these declarations, I hereby certify that I am the sole author of this thesis. I have used standard referencing practices as outlined in the *Publication Manual of the American Psychological Association, 7th Edition* (American Psychological Association, 2020) to acknowledge ideas, research techniques, or other intellectual materials that belong to others. Furthermore, I hereby certify that I am the sole source of the creative works and/or inventive knowledge described in this thesis.

Acknowledgements

Completing this thesis was a journey, fraught with the numerous potential research problems that failed to materialize, the unexpectedly intensive demands of the ChangeMakers March Break camp, and the emotional impact of the COVID-19 pandemic during which the majority of this paper was written. While I am the sole author of this text, I could not have accomplished this feat without the support of my community for whom I am eternally grateful.

First, I offer my sincerest gratitude to my thesis advisor and research supervisor, Dr. Janette Hughes. Despite finding my way back to academia after a seven-year interlude, you welcomed me into the STEAM-3D Maker Lab and provided me with unwavering support and guidance as I reacclimated. The opportunities I've had to work with diverse educational communities, present at conferences, and explore my educational philosophies under your supervision have been invaluable. Thank you for not only supporting the development of this thesis, but also for lending your wisdom and expertise to shaping my future career trajectory.

I also wish to thank Dr. Laura Morrison, the research project manager of the STEAM-3D Maker Lab. Our frank and honest discussions about research and education helped keep me grounded during chaotic times, and your advocacy for preserving a healthy sense of work-life balance prevented me from burning out on numerous occasions.

The camp that served as the foundation for this thesis would not have been successful without the contributions of numerous individuals. To Laura Dobos and Margie Lam, thank you for your assistance in planning and facilitating the ChangeMakers camp, as well as documenting your observations during those few spare moments. To the pre-service teacher candidates who volunteered their time to supervise lunches and energize campers during their breaks, thank you for giving me, Laura, and Margie the time we needed to grab a bite, organize data, and rebound. To Dr. Diane Tepylo and Iain Brodie, thank you for lending your patience, technological expertise, and problem-solving capabilities to support campers' varied projects. To Dr. George Gadanidis (Western University) and InkSmith, thank you for your financial and material support of the camp. Without your contributions, campers would not have had access to all of the amazing technologies that helped bring their visions into reality. And finally, to the 17 campers that attended the ChangeMakers March Break camp, thank you for your willingness to try something new! I was inspired by each and every one of you, and can't wait to see what kind of change you make in the future.

In addition to my wonderful thesis advisor, I would also like to extend my sincerest thanks to Dr. Diana Petrarca for joining my thesis committee, and Dr. Jennifer Lock (University of Calgary) for serving as the external examiner. You can never have too many eyes on a document like this, and the feedback you both provided was invaluable for making this thesis the best it could be.

Last but certainly not least, I wish to thank my family for their unwavering support of my academic journey. My mom (Cathie), dad (John), and brother (Dan) have always motivated me to be the absolute best version of myself, and their demonstrated interest in my graduate work provided inspiration to continue through the challenging times. Finally, to James, my husband. Thank you for everything: for being a sounding board at all hours of the day (and night), for keeping our lives together when things got busy, and for your endless love and support over the past four years. It hasn't been easy (for either of us!), but I mean it when I say that I could not have done it without you.

Table of Contents

List of Tables

List of Figures

List of Abbreviations, Definitions, and Symbols

3D	three-dimensional (e.g., 3D printing)
AI	artificial intelligence
AR	augmented reality
DBR	design-based research
DIY	do-it-yourself
IoT	the Internet of Things
MOOC	massive open online course
OME	Ontario Ministry of Education
RFID	Radio-Frequency Identification
SDGs	Sustainable Development Goals (United Nations, n.d.)
STEM	Science, Technology, Engineering, and Mathematics
STEAM	Science, Technology, Engineering, the Arts, and Mathematics
tertiary	post-compulsory education (i.e., programs at the college and university level)
VR	virtual reality

1 Introduction

Digital technologies have transformed the ways that we live, work, and play over the last several decades (Banica et al., 2017), and with emerging developments like the Internet of Things (IoT), they will continue to impact our experience of the world for the foreseeable future. Consequently, schools have been tasked with preparing students to be digital innovators, facilitating access to skills and knowledge requisite for their eventual participation in society (Aldowah et al., 2017; Blikstein, 2013). Given the rate at which technology continues to evolve (Leiserson et al., 2020), students need more than fixed digital skillsets; they must also learn to be creative, analyze problems, adapt, and direct their own learning in order to keep pace (Bekker et al., 2015; Green, 2020; Vongkulluksn et al., 2018).

Since the development of the first IoT device in the 1980s (Teicher, 2018), the naming of the technology in 1999 (Abdel-Basset et al., 2018; Cajide, 2015), and IoT's rapid expansion beginning in the late 2000s (Banica et al., 2017), the number of connected devices is currently estimated to have outnumbered the Earth's population (Freeman et al., 2017; Rainie & Anderson, 2017; Sinha, 2021). With no signs of slowing its progression, some reports anticipate between 27 billion (Sinha, 2021) and 50 billion (Ronen et al., 2017) IoT devices to be in use within the next several years, and for good reason. IoT minimizes the barriers that exist between technology and society (Gershenfeld, 1999), enabling digital information to impact our lives directly through the connection of things and services (Rainie & Anderson, 2017). Not only does IoT have the capacity to make our lives more convenient through smart home devices and digital personal assistants (Atzori et al., 2010; Gershenfeld, 1999), it also enhances children's toys (Manches et al., 2015), improves municipal operations (Abamu, 2017; Atzori et al., 2010), and creates accessible conditions for individuals with special needs (McRae et al., 2018). Schools have also begun to adopt IoT systems to reduce operational costs and improve administrative functions like school security monitoring, providing access to curricular materials, and conducting responsive student assessments (Aldowah et al., 2017; Meola, 2020; Selinger et al., 2013).

Overall, education has been successful in responding to advancements in socially impactful technologies, albeit slowly (Selinger et al., 2013). For example, while tools and strategies for teaching computer programming have been in development since the 1970s (Blikstein, 2013), coding at the elementary school level was only recently adopted into Ontario's provincial curriculum (Ontario Ministry of Education, 2020). While modifying formal curricula for each new critical technology is neither practical nor realistic, the need for students to possess transferable skills and competencies to scaffold their engagement with emerging technologies has been recognized in research (Blikstein, 2013; J. S. Brown & Adler, 2008; Carroll et al., 2010; Vongkulluksn et al., 2018) and educational practice (Ontario Ministry of Education, 2016). In addition to creativity, critical thinking, collaboration, and communication – defined as the four Cs of 21st century education (Zimmerman, 2018) – students are expected to develop digital literacies and a sense of digital citizenship to support their involvement in society. While specific technological skillsets are beyond the scope of compulsory education, *digital literacies* enable students to "use, understand, an[sic] evaluate technology, and also to understand technological principles and strategies required to *develop solutions* and realize specific goals" (Bekker et al., 2015, p. 29, emphasis in original). *Digital citizenship* promotes "thinking critically, behaving safely, and participating responsibly in the digital world" (Vega & Robb, 2019, p. 9). Experience with various digital tools throughout students' educational careers can not only facilitate the development of these global competencies (Vega & Robb, 2019), but also provide access to powerful discourses and means of creative production (Blikstein, 2013; Halverson & Sheridan, 2014). Similarly, meaningful integration of technologies can provide students with agency and ownership over their education, enabling greater accessibility and interactive engagement with curricular materials, which can promote deeper learning (Artut, 2018; McRae et al., 2018). However, teachers' perceptions of the role of technology in education can mediate its impact (Vega & Robb, 2019), and superficial applications like digitizing traditional pen-and-paper tasks “fail to harness technology’s potential to more fully engage students and promote deeper thinking” (Gallup, 2019, p. 18). To facilitate the development of vital global and digital competencies, educational technologies must be integrated in ways that support inquiry, active learning, and the construction of technological products (Blikstein, 2013; Selinger et al., 2013; Vega & Robb, 2019).

A shift towards active, transformative models of education has begun to accommodate these diverse educational needs. De-emphasizing intellectual competition in favour of collaborative knowledge-building in schools forefronts innovation, learning, and skills development over traditional practices like memorization that fail to support students in evolving societal conditions (Garcia & Cano, 2014; Selinger et al., 2013). Moreover, widespread access to information through the internet has rendered transmissive pedagogies obsolete (Artut, 2018; Banica et al., 2017; Garcia & Cano, 2014), making space for student-driven, interdisciplinary approaches like STEM or STEAM that leverage the authentic interplay of Science, Technology, Engineering, the Arts, and Mathematics in our everyday lives (Perignat & Katz-Buonincontro, 2019). STEAM education can broaden participation, interest, and achievement in STEM disciplines, as well as promote the development of global competencies and technological skills (Hughes, 2017; Perignat & Katz-Buonincontro, 2019). Emerging from the recent do-it-yourself (DIY) social movement (Freeman et al., 2017), making and maker pedagogies are closely associated with STEAM, applying skills and knowledge from multiple disciplines in the construction of tangible or digital products (Halverson & Sheridan, 2014; Tan & Barton, 2018). Making not only promotes creativity and self-expression (Bieraugel & Neill, 2017; Sheridan et al., 2014), but also enables students to draw from individual and collective banks of knowledge to produce artifacts that reflect their learning (Blumenfeld et al., 1991; Cocciolo, 2011; Noss & Clayson, 2015; Ratto, 2011). While technology is not inherent to the maker movement, creative engagement with maker technologies can facilitate the development of digital competencies and promote a participatory orientation towards technology (Akiyama et al., 2017; Artut, 2018; Nascimento & Pólvora, 2018). Designing and making with technology can also facilitate an understanding of the ways in which these tools could be used to address persistent societal challenges (Bekker et al., 2015; R. C. Smith et al., 2015).

Although education has begun to embrace technology and the need for digital literacies and competencies, emerging technologies like IoT have not yet factored into students' learning. The *Horizon Report* (Freeman et al., 2017), which analyzes trends and technological developments with the potential to impact education, predicted that IoT would become relevant in K-12 schools by 2022. Given the prevalence of IoT in society and the rate at which it continues to grow, students need opportunities to interact and work with the technology in order to understand it (Akiyama et al., 2017; Selinger et al., 2013). IoT's flexibility and integration with other technologies can also prepare learners to adapt to a dynamic technological landscape (Kortuem et al., 2013) and promote the development of broad digital literacies and skills (J. Chin & Callaghan, 2013; Penzenstadler et al., 2018; Selinger et al., 2013; Voas & Laplante, 2017). The expanding influence of IoT has been accompanied by the development of tools and procedures for working with the technology at various levels of expertise (Divitini et al., 2017). Products like the *Tiles IoT Inventor Toolkit* (Mora et al., n.d.) enable learners to design and prototype IoT systems without technology, while maker construction kits like the *littleBits Rule Your Room Kit* (Sphero Inc., n.d.-b) provide an accessible entry point for making with IoT. In combination with maker pedagogies, these tools promote low-stakes exploration and experimentation with an otherwise sophisticated technology (Penzenstadler et al., 2018) in an authentic, interdisciplinary context (Charlton & Avramides, 2016; Kortuem et al., 2013). To this point, however, educational making with IoT has been limited to post-secondary computer science and engineering courses (Burd et al., 2018), with only a few documented exceptions in other disciplines (e.g., Akiyama et al., 2017) and levels of schooling (e.g., Charlton & Avramides, 2016; Davis, 2017; Maia & Filho, 2018).

Beyond the influence on our personal lives and contexts, technological advances have also minimized the impact of geographical boundaries on our concept of community. Globalization has diversified North American communities, bringing together families with a myriad of cultures, languages, experiences and perspectives (Guo, 2014). Through the internet and increasingly affordable information technologies, we have also become interconnected with the global community, having near-constant access to international news and events. These transcultural connections – and the resultant awareness of global social issues – have reignited a need for citizens to become actively involved in social justice and citizenship initiatives, beginning with the current generation of students (Carlisle et al., 2006; DiCicco Cozzolino, 2016; Feinstein & Carlton, 2013). While social activism has always been important, the challenges faced by the global communities to which we belong are more salient than ever before (Guo, 2014; Ontario Ministry of Education, 2018). Historically, schools have been accused of reproducing inequitable social conditions, but as sites of learning and socialization they are uniquely positioned to challenge existing barriers and promote social action (Carlisle et al., 2006; Giroux, 2004; Luksha et al., 2018). Educators are ready as well; a recent survey of early-career teachers and pre-service teacher candidates highlighted a focus on values, ethics, and social justice in education (Green, 2020). As with technology, transformative pedagogies that promote inquiry and active engagement are best suited for citizenship and social justice learning (Bell, 2016; Luksha et al., 2018). Tools that enable students to analyze and respond to social challenges promote an active orientation towards citizenship (Hackman, 2005; Harshman & Augustine, 2013) as well as the development of skills and knowledge to support future social action (Lyles, 2018). Critical maker pedagogies can facilitate students' engagement with social justice and citizenship through design activities that elicit a creative response to challenges of personal or social significance

(Chounta et al., 2017; Nascimento & Pólvora, 2018; Ratto, 2011). Educational environments that encourage learners to critique and explore social issues through the production and sharing of cultural artifacts (Hughes, 2017; Ratto, 2011) can be transformative for students and their communities (Marsh et al., 2018; W. Smith & Smith, 2016), positioning them as capable of affecting meaningful social change (Kwon & Lee, 2017). Maker technologies can provide an additional layer of empowerment, promoting valuable digital competencies (Divitini et al., 2017; Psenka et al., 2017) and an appreciation for the role of technology in creating a better future (Bekker et al., 2015; R. C. Smith et al., 2015). These hands-on, student-centered opportunities are pivotal for preparing the current generation of learners to become engaged citizens of both their local and global communities (Harshman & Augustine, 2013; Ontario Ministry of Education, 2016), with the ability to analyze and respond to challenges of varying scale (Guo, 2014).

1.1 Gaps in Previous Research

As will be explored in greater depth in Section 2.5, there were several gaps in the current body of research that informed the development of this study. First, there have been few empirical accounts of IoT as an educational technology at the elementary school level. It remains uncommon in post-secondary curricula (Burd et al., 2018), but faculties of engineering and computer science have begun program adjustments to ensure their students are capable of developing and working with IoT systems (e.g., Ali, 2015; Koo, 2015; Kortuem et al., 2013; Raikar et al., 2016). Of the few studies conducted with elementary-aged students, programs have been constrained by their short duration (e.g., Manches et al., 2015) or restricted focus on smart gardens or cities (e.g., Charlton & Avramides, 2016; Davis, 2017; Maia & Filho, 2018), limiting a thorough understanding of what younger students are capable of learning about and creating with IoT. Second, maker pedagogies lack extensive research in formal educational contexts. Studies from informal settings like museums, community makerspaces, and after-school camps have highlighted numerous affordances for education, but their flexible structures limit direct transferability to classroom learning (Freeman et al., 2017; Halverson & Sheridan, 2014; R. C. Smith et al., 2015). While the present study was conducted as a five-day camp (see: 4.2.2) and therefore cannot account for all contextual dissimilarities to a classroom, its design was modelled after best practices for maker education from existing research (e.g., Harron & Hughes, 2018; Kafai & Peppler, 2011; Lock et al., 2020; J. A. Marshall & Harron, 2018; Sheridan et al., 2014) and previous camp iterations (e.g., Hughes et al., 2019; Hughes & Morrison, 2018). Additionally, the structure of the camp was constrained by several factors common to formal schooling, including a fixed timetable and designated learning objectives. Finally, as social justice and citizenship education become more prevalent, there remains a need for practices that elicit active engagement with social consciousness (Harshman & Augustine, 2013; Ontario Ministry of Education, 2016). Critical maker pedagogies invite reflection, analysis, and creative production in response to societal issues (Chounta et al., 2017; Nascimento & Pólvora, 2018; Ratto, 2011), and can be further amplified through technologies that facilitate design and making (Nascimento & Pólvora, 2018; Scott & White, 2013; R. C. Smith et al., 2015). However, with the exception of Babson College's (n.d.) IoT for Good Lab, IoT has not yet been explored as a tool for citizenship and social justice.

1.2 Research Goal

Given that digital literacies and social consciousness have been identified as essential learning objectives, and the affordances of IoT for K-12 education have been relatively unexplored, this study was designed to investigate what happens when the two are combined. Specifically, the goals of this research were to explore what elementary-aged students might be capable of learning about IoT, and how they might engage with citizenship and social justice through critical making with IoT construction kits. The following two questions guided the research presented in this thesis:

- How do students' understandings and perceptions of the Internet of Things evolve over the course of a week-long maker passion project?
- How might being immersed in an IoT-oriented passion project facilitate engagement with citizenship and/or a social justice mindset?

As little research has been conducted in this area, developing an understanding of the ways in which younger students might engage with IoT and performative social justice action through making can provide pedagogical insight for their integration into classroom learning.

1.3 Thesis Organization

In this initial chapter, I have outlined the educational and social conditions that inspired this project, including an overview of the gaps in the literature I aspired to address. I also briefly described the goal of the research, as well as the two research questions that guided its progression. The remainder of the thesis is organized as follows:

Chapter two provides an overview of the literature related to the study's key themes of IoT, making, and education for social justice and citizenship. First, IoT is broadly defined (2.2) followed by an examination of the technology's role in society (2.2.1) and education (2.2.2). The section concludes with a discussion on the security and privacy concerns related to IoT (2.2.3), which are often considered its greatest weakness. Secondly, a summary of the literature on the maker movement is presented (2.3), highlighting critical making (2.3.1), issues of equity (2.3.2), and educational making (2.3.3) as focal points. Finally, approaches to social justice and citizenship education are explored (2.4), with connections to maker citizenship (2.4.1) as a transformative practice. Following this overview, I explore the limitations and gaps in the existing body of research (2.5), which informed the development of the research questions underlying this study (2.6).

Chapter three presents the theoretical framework underlying this study and its subsequent analysis. Constructionism (3.1), critical theory (3.2), passion-based learning (3.3), and design-based learning (3.4) are integral to maker pedagogies and therefore guided the design of all camp and research activities.

Chapter four outlines the research methods and methodological design of the current study. First, I describe the qualitative research design (4.2.1), followed by the design of the camp activities and overall structure (4.2.2). Next, I introduce the participants (4.3), including an overview of the camp recruitment and sampling procedures, before describing the context (4.4) in which the ChangeMakers March Break camp took place. I then describe the five sources of data for this study (4.5) as well as the procedures (4.6) for conducting ethical research and collecting data to inform the findings. I conclude this chapter by outlining my approach to the data analysis (4.7), including measures taken to enhance the credibility of the findings.

Chapter five presents the findings of the study organized by research question. I first analyze participants' IoT learning over the course of the maker camp (5.2), beginning with an overview of the full participant pool (see: participant pool A) before describing three illustrative cases (5.2.1) in greater depth. I then explore the ways in which participants engaged with citizenship and social justice (5.3), again highlighting the overall findings prior to three case studies (5.3.1) that exemplified participants' social consciousness during the week. Finally, I summarize the salient findings (5.4) derived from within- and cross-case analysis.

Chapter six contextualizes the research findings within the existing body of literature. With regard to participants' making with and learning about IoT (6.2), I discuss the progression in their understanding of fundamental IoT concepts (6.2.1), the impact of making on their engagement with IoT (6.2.2), and their concerns about the security and privacy implications of the technology (6.2.3). Analyzing participants' engagement with citizenship and social justice over the course of the camp (6.3), I explore the agentic lens through which they came to understand these concepts (6.3.1), the ways that they engaged with social issues over the week (6.3.2), their embodiment of the ChangeMaker ethos (6.3.3), and their understanding of the ways in which IoT and other technologies could influence social change (6.3.4). I then reflect on the educational implications (6.4) and describe the limitations (6.5) of the study, before proposing several directions for future research (6.6) to validate and extend the results.

Finally, chapter seven concludes the thesis, revisiting the current demand for educational programs that promote digital literacies and competencies, as well as social consciousness, to support students' ability to participate in an increasingly interconnected society. I briefly summarize and situate the findings in relation to previous literature and the four components of the conceptual framework underlying the study. I ultimately contend that, while this is an emerging area of study requiring additional research, elementary-aged students are capable of understanding sophisticated technologies like IoT, and that access to kits and components to facilitate its development can promote sought-after digital competencies. Moreover, critical making with IoT enables students to actively engage with issues of local and global significance, positioning the technology as an invaluable tool for social consciousness.

2 Literature Review

2.1 Overview

As society has become increasingly interconnected through advances in technology and globalization, the need for students to engage with concerns beyond their local community has increased in turn. In addition to the growing diversity of North American classrooms (Guo, 2014), there are escalating social and economic demands for citizens to not only understand, but to actively engage with globally-relevant challenges (Carlisle et al., 2006; Hackman, 2005; Luksha et al., 2018). The need for these competencies has been recognized at the governmental level (Ontario Ministry of Education, 2016) as well as in research (e.g., Carlisle et al., 2006; DiCicco Cozzolino, 2016; Dover, 2009; Guo, 2014; Harshman & Augustine, 2013; Luksha et al., 2018; Marsh et al., 2019), but empirical accounts of teaching for social justice and citizenship are limited.

Given the call for tools that enable active, applied engagement with citizenship and social justice (Hackman, 2005; Harshman & Augustine, 2013), the burgeoning maker movement in education is timely. Making, particularly critical making (Ratto, 2011), includes practices of research, reflection, and critical discourse that promote a deeper understanding of, and connection to, social and political issues (Chounta et al., 2017; Nascimento & Pólvora, 2018). Whether facilitated by technology (e.g., robotics, 3D printing, circuitry) or unplugged materials (e.g., knitting, woodworking, painting), making facilitates a shift from cultural consumption to cultural production (Artut, 2018; Halverson & Sheridan, 2014; Marsh et al., 2018). As such, "*critical* making goes beyond simply creating objects for the sake of creating objects … it concerns itself with technologies and their relationship to social life, with an emphasis on their emancipatory potential to bring about change and improvement" (Hughes, 2017, p. 2).

One technology that has been largely absent from the conversation on making for social justice and global citizenship is IoT. Over the past ten years, IoT has become an indispensable component of modern society (Banica et al., 2017; Gómez et al., 2013), yet has only recently been adopted into educational programming. This has primarily occurred at the post-secondary level (e.g., Akiyama et al., 2017; Ali, 2015; Babson College, n.d.; Koo, 2015; Kortuem et al., 2013; Raikar et al., 2016), however elementary and secondary school offerings are slowly coming into fruition (e.g., Charlton & Avramides, 2016; Davis, 2017; Maia & Filho, 2018). Although IoT has vast potential for improving economies, infrastructure, and individual quality of life (Rainie & Anderson, 2017), there are currently few documented cases of IoT being leveraged for social justice and global citizenship education (exception: Babson College, n.d.).

To situate the study conducted for this thesis, the remainder of this chapter will present a review of the literature relevant to its three central themes: IoT, the maker movement, and social justice and citizenship education. In Section 2.2, I briefly introduce the concept of IoT and its most common components before discussing the role of IoT in society (2.2.1) and the role of IoT in education (2.2.2), as both a tool for educational management (2.2.2.1) and for learning (2.2.2.2). I also provide an overview of common privacy and security concerns (2.2.3) relevant to learning and working with IoT. Section 2.3 describes the recent maker movement, with careful attention paid to critical making (2.3.1), current inequities within the maker movement (2.3.2), and applications of making to education (2.3.3). Finally, I address the current state of social justice and citizenship education in Section 2.4, including the concept of maker citizenship (2.4.1) that could be used to scaffold instruction with maker technologies like IoT. Following the discussion of these themes, I will provide an overview of the limitations and gaps in the literature (2.5) that informed the research questions (2.6) and design of this study.

2.2 The Internet of Things

Although IoT is rapidly becoming an essential fixture of modern society, the term was conceptualized over two decades ago when only 4% of the world's population was online (Rainie & Anderson, 2017), a far cry from the internet's current designation as a basic telecommunications service in Canada (Kupfer, 2016) with a global demand for universal access (Andriole, 2020; International Telecommunication Union, 2018). Kevin Ashton, co-founder of the Auto-ID Center at the Massachusetts Institute of Technology (MIT), is credited as having invented the phrase *Internet of Things* in 1999 (Abdel-Basset et al., 2018; Cajide, 2015) during a supply-chain management proposal to his then employer, Procter & Gamble (Ashton, 2009). In the context of this proposal, IoT began as a system of Radio-Frequency Identification (RFID) tags – small microchips, typically embedded in an adhesive sticker, with a unique identification code capable of being scanned and interpreted by RFID software (Atzori et al., 2010) – that could be linked to an online platform for more effective and efficient inventory management and distribution (Ashton, 2009). However, despite IoT's relatively early emergence in the information age, widespread adoption and use of the term did not occur for another ten years (Banica et al., 2017), when the ways in which the internet could interface with our physical environment began to multiply (Manches et al., 2015). Now, IoT is all around us; from digital personal assistants like Alexa (Amazon.com Inc., n.d.) and Siri (Apple Inc., n.d.) to smart agricultural systems that can sense and adjust plant moisture and nutrient levels, this technology has had an observable impact on modern society.

To reflect the diversity evident in current IoT systems, recent definitions of the concept are necessarily vague. Atzori et al. (2010, p. 2787) describe IoT as a "pervasive presence" of objects connected through RFID tags, sensors, and other technological systems that enable the physical environment to interact with itself and the people within it toward a series of defined goals. Networks of Things (NoTs) and IoT are often used as synonymous terms to describe configurations of connected devices, however the internet is generally considered to be an integral part of IoT while NoTs can operate locally or online (Voas, 2016). Nearly any *thing* can be incorporated into an IoT network – from technologically-inert objects (e.g., doorways, furniture) to electronic devices (e.g., lighting, temperature control, vehicles) – through the integration of sensors, processors, and/or actuators that imbue the necessary computing power for these objects to communicate across online or local networks (Freeman et al., 2017). In the context of IoT, these basic augmentations serve different, albeit equally important, roles:

- *Sensors:* Devices capable of measuring physical properties, such as position of an object, temperature, light level, and proximity of people or things (Voas & Laplante, 2017). These components typically function as the *input* in basic IoT systems. Smart doorbells such as the Amazon Ring (n.d.) and Google Nest (n.d.) Doorbell, for example, use motion sensors to activate video streaming and recording.

- *Processors:* Similar to the processor in a laptop or desktop computer, these devices – sometimes referred to as *aggregators* – interpret or transform the input data received from sensors (Voas & Laplante, 2017). In many modern IoT configurations, processing occurs within cloud-based platforms (Akiyama et al., 2017).

- *Actuators:* These function as the *output* of a basic IoT system, with their resultant action(s) dependent on the processing of sensor data. Common actuators include lightbulbs, motors, and digital displays (Akiyama et al., 2017). In a conventional smart garden, the irrigation system functions as an actuator, turning on or off in response to data from moisture sensors.

While NoTs can, and often do, vary in complexity, these three components are considered the “basic building blocks” required for objects to communicate and interact with their surrounding environment (Selinger et al., 2013; Voas & Laplante, 2017). However, IoT is comprised of more than an interconnected network of physical objects; it also contains virtual things, including the data that is collected, processed, and acted upon within the system (Abdel-Basset et al., 2018). Furthermore, real-world IoT systems (as explored in 2.2.1 Role of IoT in Society) integrate additional technologies designed to make the network more accessible for both programmers and end-users, including (a) *object abstraction* to make devices from different manufacturers usable within a network; (b) *middleware* to simplify the connection of different devices through the removal of extraneous information; and (c) *end-user applications* that consolidate access to the devices and collected data for use by consumers (Atzori et al., 2010). The increasingly blurred lines between the physical and digital components have inspired calls for an alternative concept – the Internet of Everything (IoE) – to reflect this evolution in smart technology (Selinger et al., 2013), while others recognize the fluidity of and subsequent challenge to define IoT due to continuous technological advancements (Voas & Laplante, 2017). Regardless of how IoT is conceptualized, research illustrates a number of integral features: (a) universal connectivity; (b) heterogeneity of networks and devices; and (c) things-related services to organize data and protect users (Abdel-Basset et al., 2018).

2.2.1 Role of IoT in Society

Over the past ten years, bilateral development in smart devices and widespread interconnectivity has contributed to a surge in societal interest surrounding IoT (Banica et al., 2017; Gómez et al., 2013). In 2011, market research company Gartner Inc. added IoT to their "Hype Cycle" for emerging technologies, and only three years later, it had reached their "Peak of Inflated Expectations," indicating extensive adoption and piqued social expectations (Gartner 2011, 2014 as cited in Banica et al., 2017, p. 54). Described by some as an "automation and analytics system" (Abdel-Basset et al., 2018, p. 1) given its use of networking, sensors, and artificial intelligence (AI), it may be no coincidence that IoT is becoming prolific during industry 4.0, considered to be "the last significant evolutionary step industry will do with just human operators" (Simionescu, 2017, p. 1).

As of 2017, the number of connected things worldwide was estimated at 8.4 billion, outnumbering the current global population (Freeman et al., 2017; Rainie & Anderson, 2017). Within the next five years, that number is projected to exceed 50 billion (Ronen et al., 2017), with the majority of new devices supporting the everyday operation of businesses, governments, and social infrastructure, and thus being largely imperceptible to the general public (Rainie & Anderson, 2017). Meanwhile, less than half of the world's population has reliable access to the internet (Rainie & Anderson, 2017), highlighting the relative concentration of IoT – and all of its purported benefits – in wealthy, developed countries.

Proponents of IoT suggest that it has the potential to transform not only the ways that we compute, but also the ways in which we live, by embedding communication, sensing, and web-based technologies into all aspects of our everyday lives (Atzori et al., 2010; J. Chin & Callaghan, 2013). Numerous sectors have experienced a shift toward IoT (Freeman et al., 2017), including health care, where wearable fitness trackers and other monitoring devices can directly update digital patient records (Atzori et al., 2010), and in retail, where smart stores use digital wallets and automated product detection to facilitate cashier-less shopping experiences (AWM, n.d.). Looking to the future, IoT integration is expected to expand in areas such as assisted living, electronic health monitoring, automation of manufacturing and logistics, as well as education (Atzori et al., 2010). While these sectors have been equipped with technologies to boost efficiency and convenience, the expanded intelligence and communicative capabilities of IoT are already having a significant impact on society through measures such as reduced food waste during transport and minimizing carbon emissions through intelligent metering (Abdel-Basset et al., 2018).

Beyond global sustainability, IoT is also relevant at the local community and consumer levels. Movement within society is largely influenced by sensors in roadways and intersections (Rainie & Anderson, 2017), and *smart city* initiatives around the world have adopted IoT to address challenges with public safety, population growth, environmental responsiveness, and interconnectivity (Abamu, 2017; Freeman et al., 2017). In the home, common quality-of-life devices include voice-activated assistants (e.g., Amazon's Alexa, Apple's Siri, Google's Assistant, Microsoft's Cortana), smart appliances, and personal health and fitness trackers (Rainie & Anderson, 2017), while toys such as Activision's Skylanders and Disney's Infinity utilize IoT to interact with designated video games, enhancing both interactivity and entertainment value for children (Manches et al., 2015). Some toys, such as Teddy the Guardian (Biggs, 2015), are even capable of measuring children's heart rate, stress level, body temperature, and other health parameters in an unobtrusive manner, converting an otherwise neutral plush toy into a useful instrument for the health care sector (Manches et al., 2015). In addition to the conveniences offered by IoT for the general population, these connected systems could potentially eliminate barriers to accessibility faced by individuals with disabilities in both physical and virtual contexts (McRae et al., 2018). Gershenfeld (1999) even speculated that IoT could eventually have an impact on human evolution, augmenting the physical body with implanted technologies to enhance its role as "the ultimate wearable computer" (p.121). It remains to be seen whether Gershenfeld's vision will become reality, but the conveniences offered by IoT are likely to guarantee its continued expansion as the demand for devices to simplify our increasingly complex lives means that both businesses and consumers will benefit (Rainie & Anderson, 2017).

2.2.2 Role of IoT in Education

As has been the case with other socially impactful technologies (e.g., computer programming), the educational landscape is shifting in response to IoT's rapid growth (Kortuem et al., 2013). Changing perspectives on the skills necessary for recent graduates to be competitive in the modern job market as well as increasing global demands for access to education have compelled stakeholders to re-evaluate their educational offerings (Kortuem et al., 2013; Selinger et al., 2013). The most recent publication of the *Horizon Report: K-12 Edition* (Freeman et al., 2017) anticipated that advancing cultures of innovation and digital fluency would enable IoT to begin producing substantial change in primary and secondary institutions as early as 2021. While the literature suggests that this process is underway, much of the integration to date involves IoT supporting the day-to-day operation of schools, with limited instances of innovative curriculum that empower students to learn with and about this burgeoning technology. To illustrate the current role of IoT in education, I will first examine the ways in which schools have utilized it to both implicitly and explicitly support the teaching and learning process (Section 2.2.2.1). I will then explore recent examples of curricular programming that immerse students into designing and working with IoT systems, before making a case for expanded implementation of these programs in the K-12 context (2.2.2.2).

2.2.2.1 IoT in Schools

Educational institutions at the tertiary level are widely regarded as spaces of disruption and innovation, positioning them as ideal contexts to appraise the applications and limitations of IoT in a learning environment. To fully understand the role that IoT could play in education, Selinger et al. (2013) proposed four key pillars for consideration: (a) people; (b) process; (c) data; and (d) things. Each of these pillars, they argue, have a distinct impact on the implementation of IoT in educational contexts, informing the supports needed, the scale of certain practices, and more. For example, understanding how people currently use the internet to facilitate learning (e.g., massive open online courses [MOOCs], attending virtual talks from field experts) should inform areas of opportunity as well as potential barriers to IoT integration (Selinger et al., 2013). Similarly, identifying the types of data that would be useful to different members of an educational community could create novel opportunities for personally meaningful learning, research, and interdisciplinary collaboration through IoT (Selinger et al., 2013).

Putting these pillars into practice, researchers envision the development of *smart schools*, in which IoT would be employed throughout the institution for the benefit of students, staff, educators, and administration. Commonly identified features include enhanced security made possible by sensors and locks on all entryways, monitoring and automatic reordering of supplies, wearable devices for accurate attendance tracking, adaptive textbooks and learning materials, and opportunities for remote learning through virtual classrooms or robot-enabled presence on campus (Abdel-Basset et al., 2018; Banica et al., 2017; Putjorn et al., 2018). Current implementations highlighted in the literature reflect a gradual consideration of these ideas, suggesting that IoT is not yet being used to its full potential. However, the operational cost savings, security measures, classroom management tools, and avenues for personalized learning afforded by IoT to date have made a marked improvement in higher education (Aldowah et al., 2017; Freeman et al., 2017).

One area that has seen widespread IoT adoption is in managing operational and logistical challenges for schools. A school district in Connecticut, USA, employed sensors and data monitoring for energy conservation purposes, enabling the lighting in their schools to respond to human presence and daylight conditions, and to automatically shut down overnight when schools are empty (Freeman et al., 2017). Others have turned an eye toward student safety, developing applications that allow students to monitor school transportation schedules and make informed decisions about time spent traveling and waiting for the bus (Meola, 2020). IoT could also be used to scale global access to education. Selinger et al. (2013) propose that instructional content could be recorded and later replicated in various formats and venues, making content experts accessible without mandating their physical presence. Although work is needed to expand internet infrastructure in rural communities and underserved countries, remote access through IoT could revolutionize the current educational landscape (Pei et al., 2013).

IoT can also alleviate some of the time pressures facing teachers, particularly in the areas of assessment and differentiation of instruction. Cloud-based software designed to collect and grade students' work presents an alternative to some forms of manual assessment, allowing teachers to instead allocate their time to adjusting lesson plans and providing additional support to students, informed by the provided data (Aldowah et al., 2017; Freeman et al., 2017; Meola, 2020; Selinger et al., 2013). Wearable devices with integrated electrocardiography (ECG) and electroencephalography (EEG) sensors can also inform classroom interventions through heart rate and brain activity data (Aldowah et al., 2017). Responsive applications on students' computing devices could provide automatic interventions (e.g., calming exercises) in response to the information gathered, or a cloud-based teacher dashboard could provide insight into what students might be feeling at a given time, allowing for strategic, just-in-time support. Furthermore, the ubiquitous interconnectivity of IoT could allow for truly individualized educational programming. Through access to crowd-sourced content, students could more easily access resources appropriate to their developmental level or exceptional need (Selinger et al., 2013), minimizing the work needed from teachers to individualize educational content.

In addition to the benefits possible for schools' operational management and teaching, IoT has much to offer for students themselves. Engagement in authentic, personally-relevant activities has an established impact on students' learning (J. S. Brown et al., 1989; Hung et al., 2008; Robertson, 2013; Selinger et al., 2013), which can be facilitated through meaningful technology integration. IoT could also promote a shift toward collaborative, student-driven learning (Banica et al., 2017; Selinger et al., 2013), through access to personalized learning materials and technologies to automate note-taking and other mechanical tasks (Cajide, 2015). The potential for immediate interpretation and feedback on students' learning can promote sustained engagement and flow, such as in the case of sensor gloves used to facilitate sign language learning in Australia (Selinger et al., 2013). Similarly, the affordances of IoT can support students with exceptionalities in managing their educational needs through timely access to information, learning materials, services, and in some cases, feedback and strategies pertaining to immediate behavioural or attentional needs (McRae et al., 2018; Selinger et al., 2013).

Specific applications of IoT have also been developed to support technology-enhanced learning across a range of curricular subject areas. *One-to-one computing* is an educational initiative aimed at minimizing the digital divide by providing individual students with access to tablets, netbooks, or other devices. However, as the case of a rural community in northern Thailand illustrates, these programs are not always successful at invigorating student learning (Putjorn et al., 2018). Having little prior experience with tablet computers, students experienced anxiety trying to navigate unfamiliar technologies and families found the content provided on the devices to be too generic. In response, the research team developed a child-friendly anthropomorphic device with integrated sensors and connectivity that resulted in better science learning outcomes and reduced stress associated with use of the technology (Putjorn et al., 2018). In other cases, students have used IoT to explore social issues relevant to their local communities. To give students ownership over the food production process in hopes of reducing local food waste, Valpreda and Zonda (2016) developed an IoT prototype with light, temperature, and moisture sensors that aggregated data into web-based application. The developmentally-appropriate presentation of growth progress, health status, and a gamified checklist of garden maintenance activities improved students engagement with and understanding of the gardening process (Valpreda & Zonda, 2016).

As internet and technology infrastructure is expanded through primary, secondary, and tertiary institutions around the world, so too will the influence of emerging technologies like IoT (Banica et al., 2017; Selinger et al., 2013). However, the increasing social relevance of IoT demands an educational system in which students are given opportunities to explicitly learn with and about IoT, not just alongside.

2.2.2.2 IoT as a Tool for Learning

An established educational directive, particularly at the college and university level, is to prepare students to become productive members of society, including the development of skills necessary to contribute to the modern workforce (Aldowah et al., 2017). The rapid growth of the IoT industry requires that the next generation of graduates are capable of designing, creating, and/or working within these interconnected systems (J. Chin & Callaghan, 2013; Kortuem et al., 2013; Selinger et al., 2013). Beyond the fields of computer science and engineering, introducing students to IoT through an interdisciplinary context can redefine computing as a participatory activity through which students become producers, rather than just consumers, of technology (Akiyama et al., 2017; Burd et al., 2018). In order to support these programs, institutions must re-evaluate their digital strategies to advocate for much-needed technology funding that is often redirected from the education sector (Cajide, 2015). There is also a need to determine where IoT fits in the curriculum. Program developers must consider whether IoT concepts (including associated legal, social, and ethical issues, explored in 2.2.3 Privacy & Security Concerns) can be integrated into existing programs or if new curricula are necessary, as well as which equipment and industry standards will be utilized (Burd et al., 2018). Within the past eight years, educators have begun taking up the challenge of bringing IoT into the classroom. Abamu (2017) suggested that "students in both K-12 and the university space are increasingly involved in building smarter communities by planning and programming technology, analyzing data, and cultivating design thinking methodologies as part of research groups or special programs" (para. 2). However, in their review of presently available IoT courses at formal institutions, Burd et al. (2018) found only 24 reports of teaching experience in addition to 39 theoretical or propositional papers. As I will highlight in the remainder of this section, much of the current educational engagement with IoT has occurred at the tertiary level.

One of the most comprehensive examples to date of an IoT-oriented curriculum was implemented at the United Kingdom's Open University. In addition to reconstructing their undergraduate computer science curriculum to address IoT throughout the program, they also designed an introductory course for first-year students structured entirely around IoT concepts (Kortuem et al., 2013). In doing so, they aimed to situate IoT as a tool for students to critically examine and challenge their world, as opposed to a disparate, technical concept. Their curriculum emphasized creativity, collaboration, and making IoT accessible for students, regardless of their programming background (Kortuem et al., 2013). Other post-secondary offerings have been predominantly limited to individual courses for students who wish to specialize in developing IoT systems. India's KLE Technological University (formerly the B. V. Bhoomaraddi College of Engineering and Technology) designed an elective course on introductory IoT architecture and prototyping to be made available to computer science and engineering students in their eighth semester (Raikar et al., 2016), while Ali (2015) described their experience teaching two special topics courses with similar learning objectives. Despite these courses having been developed for computer science students, the latter example emphasized the interdisciplinarity inherent to IoT systems, requiring a balance of programming, engineering, communications, and data processing and visualization (Ali, 2015). The same was true in a graduate-level course at California's Santa Clara University. Designed with fewer hands-on experiences, this theory-based pilot course emphasized the complex interplay of different disciplines in supporting IoT (Koo, 2015).

There are even fewer examples of IoT integration outside of computer science and engineering faculties. One notable course was developed for undergraduate Social Sciences and Humanities students to learn about and systematically construct each of the components necessary for an IoT system prototype (Akiyama et al., 2017). Simplification of the technical concepts was necessary for the course to be accessible to its target demographic, but a pilot test with early childhood education students in Japan found that the course enabled them to understand how IoT networks functioned, despite not having the background traditionally associated with these technologies (Akiyama et al., 2017). Similarly, Babson College (n.d.) in Massachusetts, USA, launched its IoT for Good Lab in 2017. Designed around the United Nations' (n.d.) Sustainable Development Goals (SDGs), this action tank aimed to unite interdisciplinary student teams through a vision of using IoT to prototype solutions for a variety of social issues (Babson College, n.d.). The success of these initiatives illustrates that IoT can be meaningfully integrated outside of the undergraduate computer science context by situating activities in authentic social applications.

Available literature on K-12 implementations of IoT curricula are scarce but promising in terms of the possibilities for sophisticated engagement with younger students. Programs at this stage of schooling are often rooted in community improvement and smart city initiatives, making this complex, multidimensional technology more accessible to students by situating it within an identifiable context. Maia and Filho (2018) tested this approach with K-12 students from a lower-income community in São Paulo, Brazil. Identifying a need for efficient local food production, students worked in mixed-age groups to prototype rooftop and vertical gardens using an Arduino-based IoT probe that measured sunlight level, soil pH, temperature, and moisture content in both the air and the gardens. The project played an essential role in students' environmental education, and the researchers noted that the low-cost hardware made it possible to introduce IoT concepts to K-12 students in socioeconomically disadvantaged communities (Maia & Filho, 2018). Similarly, Charlton and Avramides (2016) introduced IoT to K-12 students through a four-tiered design-based approach involving a small-scale workshop, a school-wide brainstorming session for project ideas, a two-day *hackathon*, and a sharing session where students presented their visions and prototypes. As students engaged in team-based collaborative making activities, they were able to develop collective funds of knowledge around IoT which supported not only their engagement with the technology, but their smart city designs overall. The authors indicated that the relatable theme of the smart city project emphasized the interdisciplinarity and personal relevance of IoT, effectively detaching it from computer science and engineering silos and making it more widely accessible to younger students (Charlton & Avramides, 2016).

The literature also contains evidence of successful implementations with students as young as ten years old. Manches et al. (2015) hosted a 90-minute workshop with children between the ages of 10 and 11 and found that, while the timeframe was insufficient to promote deep understanding of IoT concepts, the workshop did enable students to begin deconstructing IoT toys and experimenting with the components' potential applications to different social situations. Likewise, Davis (2017) presented the case of a fourth-grade maker-oriented classroom in which students were tasked with designing a smart plant pot over the course of eighteen 90-minute sessions. Working in a variety of mixed- and matched-ability groups, students engaged in mathematical and technological inquiry during Davis' (2017) explore-create-share process. They were given opportunities to tinker with the IoT technology, apply their understanding to the plant growth process, design and iterate on their smart planters, and share their creations with an authentic audience, which added purpose to their making and consolidated their learning (Davis, 2017).

As illustrated in this section, IoT is gradually becoming more pervasive in education, paralleling its increasingly fundamental role in society. This transition is to be expected; to fully benefit from the affordances of IoT, schools must be responsive to the skills, competencies, and conceptual understandings that are necessary to support the next generation workforce (Voas & Laplante, 2017). However, students require more than mere exposure to IoT in their educational environment to facilitate the development of these skills. Opportunities for active learning and engagement with the technology can facilitate not only understanding, but the ability to work with IoT in numerous interdisciplinary capacities (Maia & Filho, 2018). Although courses in tertiary computer science and engineering faculties are beginning to reflect this demand, integration at the elementary and secondary levels could inspire interest in students who may not otherwise consider these technological pathways (Freeman et al., 2017; Kortuem et al., 2013; Manches et al., 2015). Recently, low-floor tools for designing and prototyping with IoT have become available, including the card-based Tiles IoT Inventor Toolkit (Mora et al., n.d.) and affordable technology kits geared to children of all ages (Davis, 2017). While these tools, and pre-tertiary IoT curricula more generally, have not yet been widely studied, the work presented in this thesis aims to contribute to an understanding of how IoT could be integrated at this level.

2.2.3 Privacy & Security Concerns

In addition to learning about the role of IoT in society, as well as its technological components, critical approaches to education must include a focus on the relevant privacy and security concerns associated with universal connectivity. As the priorities for K-12 education have shifted to reflect the social significance of technology, digital literacies and digital citizenship have been emphasized as foundational competencies linked to critical thinking and problem solving (Ontario Ministry of Education, 2016). Current studies identify programs in higher education as responsible for addressing issues pertaining to trust, identity, privacy, protection, safety, and security as they relate to IoT (Aldowah et al., 2017), but as these technologies are integrated into earlier levels of schooling, so too should the responsibility for engaging students in critical discussions around these topics (Bekker et al., 2015; Vega & Robb, 2019).

Despite the omnipresence of IoT in society, the average user is largely unaware of how their personal information is captured, stored, used, and shared amongst corporations (Manches et al., 2015). Given their role as responsive and even predictive technologies, devices on the IoT are designed to continually collect data, transmitting and responding to it as stipulated by the managing software (McRae et al., 2018; Ronen et al., 2017). IoT affords society numerous benefits because it is always listening; however, this is also what makes it so dangerous (Rainie & Anderson, 2017). The data obtained by these devices are typically stored in the cloud. There are numerous points throughout the wireless transmission process during which data could be unknowingly intercepted, redirected, or modified if privacy or security measures are deficient (Atzori et al., 2010; McRae et al., 2018; Rainie & Anderson, 2017). IoT components themselves are also susceptible to interference through physical modification of devices left unattended (Atzori et al., 2010), or by taking advantage of insecure wireless protocols granting remote access to the device (Rainie & Anderson, 2017; Ronen et al., 2017). Due to the challenges associated with adequately securing networks of connected devices, McRae et al. (2018) posit that, "because of their small size, ability to transmit their data without a 'line-of-sight' scan, and their increasing ubiquity, RFID tags – and the IoT by implication – form the most serious threat to our privacy in the modern era" (p. 17). Security expert Bruce Schneier (2016) emphasized that these threats go beyond data:

> With the advent of the Internet of Things and cyberphysical systems in general, we've given the internet hands and feet: the ability to directly affect the physical world. What used to be attacks against data and information have become attacks against flesh, steel, and concrete. (para. 5)

Although society has become increasingly comfortable with social surveillance through widespread adoption of social media, smartphones, and personal assistants (McRae et al., 2018), IoT's privacy and security vulnerabilities have far-reaching implications beyond the sharing of mundane personal details. Given the projected growth of the IoT market, abstaining from interaction with these devices will be impossible (Rainie & Anderson, 2017). Therefore, developing an understanding of prevalent security, privacy, and ethical concerns – as well as how to mitigate them – must be a fundamental component of any IoT curriculum.

2.3 The Maker Movement

The past decade has seen a resurgence of the DIY approach (Freeman et al., 2017), with growing numbers of "hobbyists, tinkerers, engineers, hackers, and artists committed to creatively designing and building material objects for both playful and useful ends" (Martin, 2015, p. 30). Transformed into what is now widely known as *the maker movement*, this agency-driven orientation toward creating, modifying, repairing, or even deliberately deconstructing artifacts has inspired the emergence of supportive communities worldwide (Halverson & Sheridan, 2014; Nascimento & Pólvora, 2018). The maker movement embodies two fundamental ideals: (a) participants shift from being consumers to producers of artifacts through self-defined goals and outcomes (Artut, 2018; Nascimento & Pólvora, 2018); and (b) connections are fostered by sharing perspectives, processes, and finished products in physical or virtual environments, such as maker faires (Marsh et al., 2019). A *maker culture* is central to the success of the maker movement, nurturing creativity and communal drive (Halverson & Sheridan, 2014), sustainability through the promotion of a "fix it" culture (Artut, 2018), and valuable 21st century skills (or *global competencies*) such as risk-taking, perseverance, critical thinking and problem solving (Hughes, 2017), in addition to the ideals described above.

Research into the progression of the maker movement must consider its three primary components: making, makers, and makerspaces (Halverson & Sheridan, 2014). *Making* refers to "a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a 'product' of some sort that can be used, interacted with, or demonstrated" (Martin, 2015, p. 31). These activities often combine disciplines that are traditionally distinct – such as crafting, computer programming, and electrical engineering (Chounta et al., 2017) – and emphasize tinkering and experimentation over a complete final product (Godhe et al., 2019). While some authors differentiate *tinkering* from making to highlight the necessity of playful, iterative practices that may not culminate in a presentable artifact (Gutwill et al., 2015; Martin, 2015;

Resnick & Rosenbaum, 2013), the work in this thesis is predicated on tinkering being an essential component of making. As explained by Smith and Smith (2016), "providing experiences for students to tinker allows them to think with objects, whether they are toys, tools, or materials to use" (p.32), and the ability to think and express oneself through objects is central to making.

People within the maker movement are often referred to, or refer to themselves, as *makers*, signifying their connection with a particular identity of participation (Halverson & Sheridan, 2014). According to Nascimento and Pólvora (2018), makers go beyond simply producing artifacts,

> taking their own steps in that direction by learning how and choosing to modify, assemble, create, disassemble, recreate, duplicate, and sharing objects and systems through open and collaborative networks from their homes, garages, schools, businesses, museums, libraries, makerspaces, hackerspaces, Fab Labs, and other emerging innovation-oriented spaces. (p.928)

To be a maker is to be both self-directed and collaborative, drawing from available resources in your own practice and supporting others with your relevant expertise (Marsh et al., 2019). However, not all those who make ascribe to the maker identity. Some argue that the dominant representations of making and makers perpetuate problematic values of dehumanization and materialism (Chachra, 2015), while others illustrate how the current maker movement contributes to the marginalization of communities by devaluing authentic cultural practices in favour of expensive technologies and corporate agendas (Blikstein, 2013; Tan & Barton, 2018; Vossoughi et al., 2016). As one of this research project's primary goals was to explore how students engage in citizenship and social justice through making, these concerns are particularly relevant and will be explored further in 2.3.3 Issues of Equity in the Maker Movement.

Makerspaces are the third pillar of the maker movement. They are considered to be "informal sites for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (Sheridan et al., 2014, p. 505). Makerspaces take many forms – from public drop-in spaces in libraries and museums to membership-based organizations (Halverson & Sheridan, 2014) – and act as a dedicated space for participants to access tools and materials, realize imagined projects, and collaborate with other users (Artut, 2018; Chounta et al., 2017). While available equipment should reflect the evolving needs of users and their surrounding communities (Artut, 2018; Hughes, 2017; Sheridan et al., 2014), makerspaces typically contain a range of digital fabrication tools (e.g., laser cutters, CNC machines, 3D printers), traditional crafting materials (e.g., sewing, woodworking, textiles), and other technologies such as programmable robots, electronics kits, and circuitry components (Artut, 2018; Martin, 2015). The rapid growth of the maker movement has resulted in a corresponding increase in the number of accessible spaces worldwide; as of 2016, over 1,400 active makerspaces had been registered by users (Freeman et al., 2017), and that number continues to grow. However, the exact specifications of a makerspace are less important than the access they provide to creativity through design and exploration (Bieraugel & Neill, 2017), opportunities for collaboration and social learning (Chounta et al., 2017; Freeman et al., 2017), and "powerful ideas about mathematics, logic, computational thinking, and scientific experimentation" (Martin, 2015, p. 32).

Although the maker movement originated in homes and community spaces, educators and researchers recently began to take notice of its value for extending hands-on learning through student-driven, interdisciplinary activities (Blikstein, 2013; Martin, 2015; W. Smith & Smith, 2016). At present, research on making in formal education institutions is limited; however, numerous studies conducted in transitional learning spaces such as after-school programs, libraries, and community makerspaces offer insight into the role making could play in the classroom. One fundamental difference is the degree of choice available to would-be makers; in community spaces, projects are idealized and completed entirely on the maker's volition (Artut, 2018), whereas making in schools must align with prescribed curriculum expectations (Sheridan et al., 2014). Despite this perceived limitation, research suggests that the transition from informal to formal learning contexts is made possible by capitalizing on the subject-integrated nature of making (W. Smith & Smith, 2016) and the use of scaffolded, personally-meaningful projects pursued under a larger curricular umbrella (Sheridan et al., 2014). Educational makerspaces also have incredible potential as sites of critical engagement with society, uniting powerful critical thinking and problem-solving skills with processes of design and production.

2.3.1 Critical Making

Although making can exist as a fulfilling practice in itself, based on freedom of creativity and manifesting one's own skills and capabilities, engagement in *critical making* can both reflect and strengthen our understanding of complex social issues (Nascimento & Pólvora, 2018). Critical making involves "theoretically and pragmatically connect[ing] two modes of engagement with the world that are often held separate – critical thinking, typically understood as conceptually and linguistically based, and physical 'making', goal-based material work" (Ratto, 2011, p. 253). Research, reflection, and critical discourse are indispensable to this manner of making (Chounta et al., 2017; Ratto, 2011), which enables students to respond creatively to personal and shared experiences of social phenomena (Tan & Barton, 2018). Furthermore, the practice of critical making deemphasizes notions of technological proficiency and flawless execution (Ratto, 2011), focusing instead on "technologies and their relationship to social life (with an emphasis on their emancipatory potential to bring about change and improvement)" (Hughes, 2017, p. 2). Engaging in this process of active cultural production and dissemination of critical maker works can be transformative not only for the student, but also their local community (Marsh et al., 2018), facilitating "a form of socially engaged and socially networked DIY citizenship" (Orton-Johnson, 2014, p. 142).

Critical making projects can be inspired by scholarly literature (Ratto, 2011), current events (Kwon & Lee, 2017), or students' observations of community needs (Tan & Barton, 2018). By harnessing their creativity to make change in response to personally-meaningful phenomena, students could be classified as engaging in maktivism (Mann, 2014) or DIY citizenship (Orton-Johnson, 2014). As students design, create, and share personally meaningful artifacts, they "strengthen humanistic values through projects and experiences that require the use of their heads, hearts, and hands" (W. Smith & Smith, 2016, p. 31). The accessibility of the maker movement permits widespread engagement with pressing social issues, inviting the presentation of multiple perspectives, critical commentary, and prototyped solutions to persistent challenges, from local security to the global water crisis (Kwon & Lee, 2017). Bringing these critical practices to the classroom provides an avenue through which students can exercise creativity and agency over issues pertaining to themselves or their communities (Tan & Barton, 2018). Scholars also recommend the development of critical maker literacies (Godhe et al., 2019; Marsh et al., 2018) which invite students to examine their maker practices, technologies, and products. By equipping students to question the intentionality, media, message, and audience of their own work (Marsh et al., 2018) in addition to the dominant political, societal, and cultural characteristics of making and maker technologies in general (Godhe et al., 2019), they will be better positioned to confront social issues through critical making practices. Moreover, educational engagement with critical maker literacies can promote citizenship and a social justice orientation by challenging dominant discourses in the maker movement to avoid reproducing existing inequities in participation (Godhe et al., 2019).

2.3.2 Issues of Equity in the Maker Movement

Making is often celebrated for its democratization of access to powerful technologies and discourses of cultural production (Blikstein, 2013; Halverson & Sheridan, 2014), but substantial debate exists as to the diversity and representation of the dominant maker culture (Tan & Barton, 2018). Nascimento and Pólvora

(2018) identify maker cultures as sites of "not only the ultimate ideas of liberation and unlimited empowering action through technology, but also a complex relationship with more socially or collectively aware values and practices" (p. 932). While progress in realizing this vision is being made due to the shift towards critical making and maker literacies, Vossoughi et al. (2016) argue that prevailing conceptions of making are detrimental to the development of accessible and emancipatory pedagogies for marginalized students.

The ethos of making as learner-centered and passion-driven contributes to the perspective of makerspaces as sites of equal opportunity, privileging diverse voices, experiences, and ways of making (Godhe et al., 2019). However, the literature provides insight into the ways in which dominant maker practices and identities are legitimized at the expense of others. In some cases, this marginalization is publicly visible, such as the extensive representation of white male adults in maker publications (Tan & Barton, 2018) or the perpetuation of skills and practices that are more closely aligned with corporate and consumer cultures than personal or social empowerment (Vossoughi et al., 2016). Even within the field of education, students' authentic and personal making experiences have been dismissed as irrelevant to their in-school practice given a lack of explicit connections to STEM subject areas (Blikstein, 2013) or economic viability (Vossoughi et al., 2016). Schools and communities also run the risk of reproducing inequities in STEM by providing digital making opportunities for technologically-oriented students over those without access to the resources or knowledgeable others needed to begin developing proficiency (Scott & White, 2013; Tan & Barton, 2018).

Recent maker research has endeavoured to represent diverse perspectives and practices, but the impact of race, culture, and other intersectional identities on participation in making is often overlooked (Sheridan et al., 2016; Tan & Calabrese Barton, 2018). Without adequate consideration of the social and cultural barriers to participation, systemic inequities in the maker movement will persist regardless of attempts to increase access (Nascimento & Pólvora, 2018; Vossoughi et al., 2016).

Scott and White (2013) identify a need for culturally responsive maker contexts that enable underrepresented youth to develop digital literacies through critical engagement in projects relevant to themselves or their local communities. These spaces could both accommodate and advance non-dominant maker values, broadening prevalent conceptions of making and expanding access for marginalized groups. As an example, persistence, perseverance, and failure-positivity are often cited as invaluable to the making process (Freeman et al., 2017; Hughes et al., 2019; Martin, 2015). However, this characteristic can be problematic for students who have been inaccurately portrayed as failures on account of their socioeconomic status, physical or mental health, familial structure, or other perceived deficits (Godhe et al., 2019; Vossoughi et al., 2016). Similarly, minimizing the role of educators and facilitators in making risks alienating students without access to powerful technologies and intrinsic STEM competencies (Vossoughi et al., 2016). While making should be student-driven, interactions with educators are valuable for scaffolding inquiry, design activity, and technological engagement, especially for students who lack opportunities in their out-of-school lives. Makerspaces that fail to account for students' lived realities in this way may inadvertently replicate conditions of oppression and marginalization. These detrimental effects extend beyond participation in the maker movement, as the lack of responsive opportunities and subsequent "loss of technological potential also inhibits our society's ability to truly be innovative" (Scott & White, 2013, p. 659).

Although making is often depicted as a socially liberative movement, reinforcing individual and collective agency (Marsh et al., 2018), facilitating access to processes and technologies of production (Blikstein, 2013), and providing a space for engagement with complex social issues (Nascimento & Pólvora, 2018; Ratto, 2011), critics suggest that these affordances may be limited to a select privileged group. To facilitate critical and equitable engagement with making in education, students' authentic experiences with out-of-school fabrication must be validated and encouraged to inform their classroom activities (Vossoughi et al., 2016).

Furthermore, educators must reconceptualize making as a sociocultural practice, drawing upon diverse community resources to inform classroom funds of maker knowledge that students can utilize as needed (Godhe et al., 2019; Marsh et al., 2019). In order for students to engage in meaningful critical making, they must be supported in an equitable environment that challenges dominant maker stereotypes and systems of marginalization (Godhe et al., 2019; Vossoughi et al., 2016).

2.3.3 Making in Education

The act of creating tangible representations of learning is not new to the field of education. Science experiments, dioramas, and artwork are classic examples of how hands-on learning has been done for decades, however these activities are often situated within a single curricular subject, failing to represent the multidisciplinary complexity of everyday life. The maker movement integrates STEAM subject areas in ways that challenge the current disciplinary borders in formal education and reflect authentic practice in these fields of study (Hughes, 2017; Papavlasopoulou et al., 2017; Sheridan et al., 2014). The advent of *maker technologies* – digital tools that facilitate the creation of physical or digital artifacts (Godhe et al., 2019) – promote the composition of multimodal and multimedia texts (Hughes, 2017), which is an essential skill for the next generation of digital citizens. However, scholars caution that making is not defined by the use of high-powered technologies; tools – from 3D printers to scissors and cardboard – are second to the creative process of making and the learning that occurs as a result (Bevan et al., 2014; Halverson & Sheridan, 2014).

The transition of the maker movement into formal education is supported by numerous theories of learning. With its focus on active engagement in the design and creation of personally meaningful artifacts (Resnick & Silverman, 2005), constructionism (Papert, 1980) is considered by many to be the underlying theoretical framework of making (Blikstein, 2013; Halverson & Sheridan, 2014; R. C. Smith et al., 2015). Piaget (1950, cited in Martin, 2015) spoke to the importance of experimenting with ideas and challenging one's own understanding in order to attain cognitive equilibrium through adaptation. The social and collaborative conditions around making reflect Vygotsky's (1978) perspectives on social constructivism, in which learning is elevated by orienting individuals with different levels of experience toward a common task (Martin, 2015). Making also integrates elements of experiential education and critical pedagogy (Blikstein, 2013). Although evidence-based implementations of making are relatively new, the movement has well-rounded theoretical support, suggesting a need for further research and investigation into classroom applications.

However, learning through making challenges the boundaries of what we understand to be formal education, including the activities that take place, the spaces in which learning occurs, and the roles of people in the system (Halverson & Sheridan, 2014). Educational maker activities strike a balance between the spontaneous, whim-driven projects of community makerspaces and the prescribed learning activities of a traditional classroom (J. A. Marshall & Harron, 2018), finding opportunities for students to pursue personal interests within the context of the curriculum (Sheridan et al., 2014). Making also redefines what counts as a classroom, utilizing a variety of spaces to fit students' learning needs. School libraries have undergone a significant transformation, becoming technological hubs of making and innovation while maintaining space for traditional literacies learning (Bieraugel & Neill, 2017; Freeman et al., 2017; Halverson & Sheridan, 2014). In doing so, libraries and other communal spaces become hybrid learning contexts, emphasizing design, collaborative ideation, reflection, and the significance of the making and learning process over product (Resnick & Rosenbaum, 2013; R. C. Smith et al., 2015). While a dedicated makerspace where projects can be left in varying stages of completion can promote momentum and continuity (Bevan et al., 2014), cultivation of a school-wide maker culture can facilitate authentic connections between formal curriculum and real-world learning (Freeman et al., 2017). According to Martin (2015), a *maker culture* in education should exhibit four key characteristics: playfulness, asset- and growth-orientation, failure-positivity, and collaboration. The development of these cultures also necessitates a shift in the roles of teacher and learner. Given the significant role of inquiry in making, the responsibility for learning becomes shared, enabling students to actively engage in the construction of knowledge with teacher-provided scaffolding (Artut, 2018; Papavlasopoulou et al., 2017; W. Smith & Smith, 2016; Stager, 2013).

As making becomes engrained in the classroom, *maker pedagogies* are needed to support students' inquiry. In contrast to unidirectional teacher-centered approaches, maker pedagogies are multidirectional, allowing learning to occur through interactions between the learner and themselves, peers, technology, teachers, and more (Hughes et al., 2017). Teachers become facilitators in the learning process (Cocciolo, 2011), enabling students to "engage (multi)literacy, artistic, and/or practical design challenges and aptitudes *through* the making of authentic cultural artefacts – and with correspondingly real audiences similarly enabled to witness such acts of art and knowledge production" (Thumlert et al., 2015, p. 797). Maker pedagogies utilize students' prior experiences and current knowledge as a base from which to build competency (Thumlert et al., 2015), supporting learning in process with just-in-time interventions rather than a broad, decontextualized approach to education (W. Smith & Smith, 2016). While this pedagogical approach requires time, effort, and resources to both implement and sustain (Godhe et al., 2019), it can promote lucrative principles and skills, such as innovation, critical thinking, problem solving, collaboration, inquiry, and personalized learning (Hughes, 2017).

Research highlights the role of maker technologies such as design construction kits to support students' engagement with new and unfamiliar technological concepts (Psenka et al., 2017). Although some fabrication skills benefit from being taught directly (e.g., threading a needle, connecting wires to a circuit board; Bevan et al., 2014), construction kits can provide the scaffolding needed to promote excitement and self-efficacy, as well as momentum to continue learning (Psenka et al., 2017). Optimal kits are designed with low floors, high ceilings, and wide walls (Papert, 1980; Resnick & Silverman, 2005). Low floor technologies have user-friendly interfaces and are accessible for novices to begin using with little knowledge or prior experience, while high ceilings enable complex, multidimensional projects and the development of expertise. Wide walls provide space for the technology to be used in various ways, including projects that reflect students' personal interests or compatibility with other technologies to extend their applications (Resnick & Silverman, 2005). Kits that fulfill these characteristics can scaffold students' understanding of otherwise sophisticated tools, providing multiple points of entry into working with socially relevant technologies across disciplines (Sheridan et al., 2014).

The concept of design plays a pivotal role in making. In both community makerspaces and maker cultures established in schools, design emphasizes "the entire creative process from early ideation, sketching, and mock-up creation to the initial presentation of a prototype, in which [physical or] digital fabrication becomes a vehicle and resource for addressing personal or complex societal issues" (R. C. Smith et al., 2015, p. 20). Designing maker projects enables students to be deliberate and reflective about their choices, engaging in research, conducting needs assessments, and collaborating with others to inform their designs (Bekker et al., 2015; Hughes et al., 2019; R. C. Smith et al., 2015). Despite its significance, design does not come naturally to most. Students need to be supported in developing connections between the abstract thought processes, physical execution, and digital literacies related to design through their thoughtful integration into making activities (Bekker et al., 2015; R. C. Smith et al., 2015). Students also need "constraints for creativity" (Marsh et al., 2018), framing their design activity within an overarching mission or challenge that leaves space for choice and agency without being overwhelmingly open-ended. Without these foundations, students may have difficulty conceptualizing their designs, progressing through challenges, accessing necessary resources and technologies, or reflecting and iterating on their designs (R.

C. Smith et al., 2015). However, when implemented effectively, design can act as a fundamental support for making (Hughes et al., 2019), promoting student agency and engagement (R. C. Smith et al., 2015).

IoT's increasing relevance in curricular programming has inspired parallel growth in the availability of maker technologies that support ideation and prototyping of IoT artifacts. To date, educators have been reluctant to make with IoT due to restrictive, expensive technologies that have limited functionality and are challenging to learn (Divitini et al., 2017). A growing body of research combined with advances in the field have begun to shift this trend, resulting in a range of technology kits such as the littleBits cloudBit Starter Kit (Sphero Inc., n.d.-a) and the GrovePi Starter Kit (Dexter Industries, n.d.), as well as low-tech prototyping tools like the Tiles IoT Inventor Toolkit (Mora et al., n.d.), to facilitate making with IoT across age and experience levels (Davis, 2017; Divitini et al., 2017). Although research into classroom-based implementations is limited, particularly at the K-12 level (see: 2.2.2.2 IoT as a Tool for Learning), these emerging tools "allow students to learn [about IoT] by iteratively testing, rebuilding their designs, and working collaboratively. Further, by involving children in the design decisions, they begin to develop technological fluency and the needed competences, in a joyful way" (Divitini et al., 2017, p. 758). Additionally, given the increasingly widespread integration of IoT into everyday life, tools that enable students to grapple with the design and prototyping of these systems can promote critical analysis and engagement with issues in their local and global communities (R. C. Smith et al., 2015) where IoT could be leveraged to assist.

2.3.3.1 Implications of Making for Education

While research to inform evidence-based maker pedagogies is still emergent, the current body of literature on making across a range of educational contexts presents valuable insight into the implications for formal schooling, from rationale for inclusion to potential challenges that educators may face.

Making harnesses creativity (Chounta et al., 2017), a natural extension of learning situated in the upper levels of Bloom's revised Taxonomy (Anderson et al., 2001; Bieraugel & Neill, 2017). Creating involves "putting elements together to form a novel, coherent whole or to make an original product" (Anderson et al., 2001, p. 30), which requires learners to integrate each of the preceding cognitive processes of the Taxonomy: remember, understand, apply, analyze, and evaluate. Providing opportunities for students to demonstrate their understanding through physical or digital artifacts affirms and strengthens their learning through conceptual engagement (Blumenfeld et al., 1991; Cocciolo, 2011; Ratto, 2011), creates space for experimentation and complex thought (Freeman et al., 2017), and makes learning more accessible for marginalized students (Stager, 2013). Furthermore, making contributes to more authentic learning experiences (Blikstein, 2013), by broadening the panel of classroom experts to include community resources (Sheridan et al., 2016) and situating learning within real-world design challenges (Artut, 2018; Godhe et al., 2019). As a result, explicit connections are made between students' in-school learning and out-of-school lives (Freeman et al., 2017), bolstering intrinsic motivation to learn (Bekker et al., 2015). Making can also act as a bridge between education and the technology-driven economy (Hughes et al., 2017) through engagement with powerful technologies that promote the development of essential employability skills (Freeman et al., 2017) and innovative forms of thinking (Martin, 2015).

In the classroom, making deconstructs the barriers between curricular subjects, facilitating interdisciplinary education that better reflects out-of-school learning. The process of making necessarily integrates elements of engineering, artistic design, and mathematics which can be subsequently applied to any other curricular focus (Blikstein, 2013; Freeman et al., 2017; Hughes et al., 2019). Although making is most commonly associated with STEM disciplines, the tools, technologies, and methods are easily applicable to the arts, humanities, and other subject areas (Blikstein, 2013). While some argue that the ill-defined structure and objectives of making are incompatible with our formal schooling system (e.g., Godhe et al., 2019), Halverson and Sheridan (2014) suggest that there are several areas of overlap between the goals of education and the maker approach. Making promotes numerous skills that are considered educational benchmarks, such as researching, synthesizing, and applying information to solve problems (Chounta et al., 2017; Hughes, 2017), metacognition, critical thinking (Hughes et al., 2017), inquiry, perseverance (Hughes et al., 2019), collaboration, and agency (Marsh et al., 2019). The use of programming languages or *coding*, a common maker activity, enables students to understand and "manipulat[e] formal systems – experience that can be important in many other domains (from mathematics to grammar to law)" (Resnick & Silverman, 2005, p. 4). Although best practices in using maker pedagogies are yet to be determined, current research suggests that making affords a range of valuable opportunities for learning and the development of global competencies.

Despite these affordances, there are numerous challenges associated with integrating making and maker pedagogies into our current education system. As research in this area is still limited, teachers and administrators remain unclear as to how making should best be implemented into classrooms (Godhe et al., 2019). A lack of appropriate infrastructure to support a maker culture in schools is an oft-cited concern (Chounta et al., 2017), as making utilizes a diverse range of tools and technological devices that require storage, monitoring, maintenance, and connectivity. This, in combination with a lack of professional learning opportunities for integration, has often resulted in isolated maker classrooms rather than widespread adoption and a network of supportive practitioners (Godhe et al., 2019). Beyond infrastructure, teachers also struggle with connecting making to the curriculum. Maker projects can be easily trivialized, focused primarily on the timely creation of a presentable and attractive product (Blikstein, 2013) over emphasizing the process of learning that occurs through making. However, what is recognized as valid learning under maker pedagogies is still being negotiated (Halverson & Sheridan, 2014). The ways in which conceptual understanding and skill development are assessed in a maker classroom differs significantly from a traditional, teacher-centric classroom; projects and learning outcomes may vary between students, therefore teachers must become more adaptive in their assessment and draw upon student-centric methods (e.g., reflection, pedagogical documentation) to capture students' learning-in-progress (Chounta et al., 2017). Collaboration and *remixing* – extending or modifying previously created work – further compound the issue of assessment, as it can be difficult to tease out individual students' contributions (Godhe et al., 2019).

Transitioning to the use of maker pedagogies presents other logistical challenges for educators, such as time management. Meaningful making requires time for students to brainstorm ideas, conduct research, design, and eventually create their maker projects. Given the time allotted per class period in North America's regimented school-day schedule, it can be difficult to orchestrate a coherent timeline that enables students to stay connected to their making around classes with other subject teachers (Psenka et al., 2017). Making also demands a level of self-efficacy from students which can dwindle over time. To prevent discouragement and disengagement, teachers must support students' confidence by (a) reframing mistakes as important learning opportunities, and (b) structuring activities with tiered difficulty levels to build momentum through small, consistent successes (Vongkulluksn et al., 2018). As it stands, the maker movement could be transformative in formal education; however, transformation takes time. Educators and administrators must "think pragmatically and strategically about how the educational potential of maker technologies can be realized in the *current* realities of school systems and classroom contexts" (Godhe et al., 2019, p. 8, emphasis in original). The addition of time, material, and content constraints could enable educators to leverage the educational benefits of making within the formal structure of a school environment.

2.4 Social Justice & Citizenship Education

Globalization has prompted a shift in classrooms across North America, resulting in an increasingly diverse student body (Guo, 2014) with strong connections to people, places, and knowledge from around the world. This interconnectedness, in combination with an economic demand for innovative graduates who are capable of tackling significant global challenges (Ontario Ministry of Education, 2016), has motivated schools to include social justice, citizenship, and the development of global competencies in their curricular programming (Bell, 2016). While these topics have not yet been widely integrated across North America (Feinstein & Carlton, 2013; Luksha et al., 2018), research highlights a need for educational practices that enable students to deconstruct the underlying systemic factors (Andreotti, 2015) and challenge dominant political ideals (Feinstein & Carlton, 2013) associated with global issues. Correspondingly, a recent global survey of new teachers and pre-service teacher candidates revealed that 47% anticipated dedicating more classroom time to global issues than had been done in the past (Green, 2020). To achieve this, Bell (2016) recommends the use of transformative pedagogies that are action-oriented, inquiry-based, interdisciplinary, and use technology meaningfully and creatively over traditional teacher-driven, instructive methods. However, in empowering students to be agents of social and global change, Andreotti (2015) cautions against doing so with an ethnocentric lens that prioritizes personal perceptions of global issues over others' lived realities.

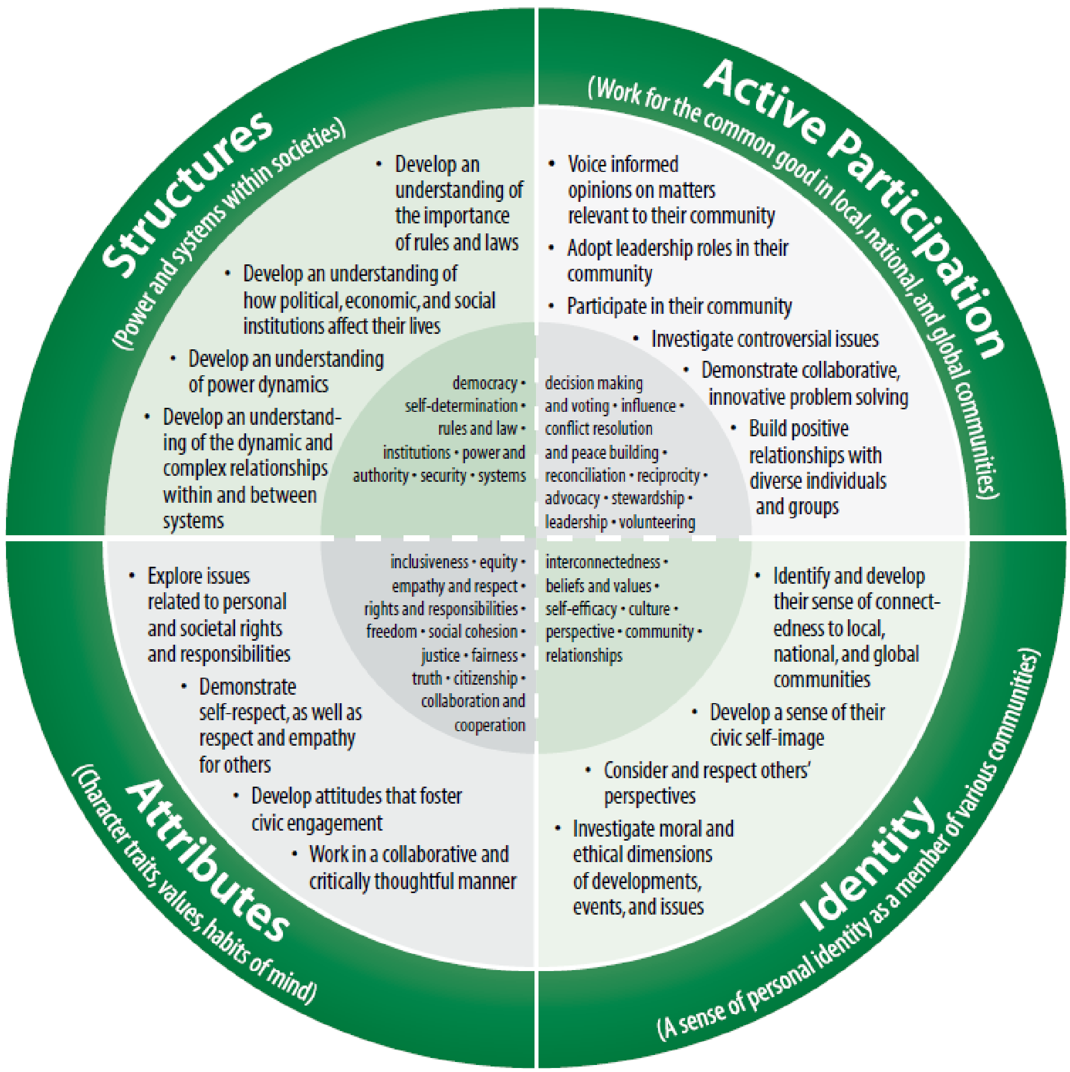
Carlisle et al. (2006) draw attention to the fact that, "as socializing institutions, schools both manifest and perpetuate the social injustices woven throughout our society" (p. 57). However, given the amount of time students spend in school during their formative years, education has the potential to challenge the various social and economic barriers that have been established over the course of history (Luksha et al., 2018). Shifting to a focus on social justice education requires that teachers and administrators collectively disrupt the status quo in schools (Garber, 2004; Luksha et al., 2018) to create student-centered learning environments that are "empowering, democratic, and critical" (Hackman, 2005, p. 103) through the use of active, responsive pedagogies (Dover, 2009; Garber, 2004). Although an exact definition of social justice education has yet to be agreed upon, it is described in the literature as an equity-oriented approach (Carlisle et al., 2006) that "pays careful attention to the systems of power and privilege that give rise to social inequality, and encourages students to critically examine oppression on institutional, cultural, and individual levels in search of opportunities for social action in the service of social change" (Hackman, 2005, p. 104). Principles for engaging students in social justice learning include: (a) promoting equity and inclusion, both locally and internationally; (b) valuing all students as participants in knowledge construction and sharing processes; (c) having high expectations for all students; (d) establishing district-wide policies and procedures to support social justice education; (e) establishing reciprocal partnerships with students' families and the local community; and (f) explicit integration of social justice issues, such as activism, inequity, and power imbalances, into the curriculum (Carlisle et al., 2006; Dover, 2009). Fundamentally, social justice education aims to promote student empowerment, an understanding of how our values are shaped by our culture, and recognition of how discrimination is also rooted in cultural beliefs and values (Garber, 2004; Hackman, 2005).

Similarly, the interconnectedness of modern society necessitates that students become skilled at identifying, analyzing, and responding to issues that are relevant not only to their local communities, but also on a global scale (DiCicco Cozzolino, 2016; Guo, 2014). Experts indicate that developing this sense of global citizenship is important for students to recognize their membership in various communities, including the global community (Ontario Ministry of Education, 2016), and to establish agency and ownership in regards to global sustainability goals (A. Chin & Jacobsson, 2016). Although citizenship is commonly defined in relation to one's local or national affiliation (Marsh et al., 2018), globalization has resulted in a need for education that engages students in "learning about the world and its structural inequalities, learning about the histories, political systems, religions, and languages of other countries, and learning to sympathize with and feel for fellow human beings" (DiCicco Cozzolino, 2016, pp. 2–3). Like social justice, global citizenship is an active, ongoing process through which individuals apply their understanding of global responsibility in their everyday lives (Guo, 2014; Harshman & Augustine, 2013).

One example of how global citizenship has been translated into education can be seen in the Ontario Ministry of Education's (2016) presentation of essential competencies. Identified as one of six domains considered indispensable for students' personal development and future economic success, they define global citizenship as: (a) responsibly and ethically contributing to society and the local, global, and digital communities; (b) participating in local and global initiatives; (c) welcoming and learning from diverse perspectives; (d) being cognizant of one's digital footprint; and (e) engaging with the environment and all living things in respectful and responsible ways (Ontario Ministry of Education, 2016). These principles have been explicitly integrated into Ontario's social studies, history, and geography curriculum for Grades 1 to 8 in the form of the citizenship education framework (Ontario Ministry of Education, 2018, p. 10), reproduced in Figure 2.1. Citizenship, in addition to the other global competencies, is intended to be interwoven into and assessed alongside students' curricular learning objectives to emphasize its importance and relevance to a range of disciplinary work (Harshman & Augustine, 2013; Ontario Ministry of Education, 2016, 2018). Recognizing the value of these principles, the Canadian government partnered with UNICEF from 2009 to 2012 "to increase the number of Canadian teachers and students practicing global education and to enhance teachers' abilities to integrate curriculum-mandated teaching and learning for human rights, peace, social justice, cultural competency, environmental awareness, and global citizenship in their classrooms" (Guo, 2014, p. 4). A more recent framework that has been used to inspire citizenship education at the K-12 level is the United Nations' (n.d.) list of SDGs. Presented as part of the *2030 Agenda for Sustainable Development*, 17 core goals were identified as a blueprint towards "a better future for all people, including the millions who have been denied the chance to lead decent, dignified, and rewarding lives and to achieve their full human potential" (United Nations, 2015, "A call for action", para. 2).

Figure 2.1

Ontario's Citizenship Education Framework



Note. Reproduced in accordance with Crown copyright, © Queen's Printer for Ontario, 2018.

These goals – including eradicating global poverty, achieving gender equality, and combatting climate change (United Nations, n.d.) – have inspired the development of various educational tools and programs, such as InkSmith's (n.d.-b) Land Climate Action Kit and TheGoals.org (Internationella Stiftelsen Young Masters Programme, 2017), a web-based social platform designed to "support the implementation of the SDGs by communicating them to young people across the globe and by engaging concrete actions to fulfill the SDGs" (A. Chin & Jacobsson, 2016, p. 228).

Both social justice and global citizenship education are important for the development of skills, community connections, and career aspirations (Lyles, 2018) in students of all ages. Research has identified a need for schools to integrate opportunities for students to critically engage with topics including sustainability (Bell, 2016), inequity, and injustice (Luksha et al., 2018) to promote a more comprehensive understanding of their communities and empower them to challenge global issues (Tan & Barton, 2018). As described by Luksha et al. (2018), "knowledge becomes contextualized and collectively constructed, therefore specific skills become less relevant than the meta-skills necessary to construct knowledge, including the diversity of thinking styles, collective intelligence, [and] empathy" (p. 12).

2.4.1 Maker Citizenship

For the principles of social justice and citizenship education to be meaningful for students, it is important to facilitate active engagement with issues of global concern (Harshman & Augustine, 2013) through tools designed to spark action and social change (Hackman, 2005). Making, particularly critical making, concerns itself with the interplay between social life, culture, ethics, and politics (Nascimento & Pólvora, 2018), providing authentic means through which to engage with citizenship and social justice. Similarly, Leydens et al. (2014) note that engineering – an integral part of making – can relate to social justice through "practices that strive toward an equitable distribution of **opportunities and resources** in order to

enhance human capabilities while **reducing imposed risks and harms** among the citizens of a society" ("Introduction", para. 4, emphasis in original). To that end, Marsh et al.'s (2018) conception of *maker citizenship* can be employed to leverage the social and educational benefits of making and provide active, hands-on opportunities to engage with issues of social justice and global citizenship. As described by Nascimento & Pólvora (2018),

> the ability to make something from start to finish … is seen as a possible enabler of users to become creators and producers, and through this process have a disruptive impact, not only on the invention and production cycles, but also on the social, cultural, political, and ethical cultures in which they are inserted. (p. 935)

Historically, creative citizenship practices have taken the form of activities such as flash mobs and guerilla knitting (Marsh et al., 2018), but the growing popularity of the maker movement and its associated tools and technologies offer virtually unlimited manifestations of maker citizenship. This approach invites students to explore issues pertaining to citizenship and social justice that have personal relevance (e.g., race-based bullying) and exercise their agency through making (Tan & Barton, 2018). Sharing the process and resultant artifacts from one's participation in maker citizenship can also contribute to stronger, more socially-engaged communities (Scott & White, 2013).

As technology becomes increasingly integral to our globalized society, maker citizenship becomes a framework through which students can explore the applications of technology to societal issues (Bekker et al., 2015) and engage actively in processes of global citizenship and social justice (Harshman & Augustine, 2013). Through this approach, students stand to learn not only the practical skills associated with fabrication and technology (e.g., coding, building circuits), but also how these tools can be used for the betterment of society (Bekker et al., 2015).

2.5 Limitations & Gaps in Previous Research

While the body of literature reviewed in Sections 2.2, 2.3, and 2.4 represents an overview of the work done in the fields of IoT, making, and education for social justice and citizenship, there exist numerous limitations and gaps which have consequently informed the design of this thesis.

At the time of writing, curricular programming for IoT has not yet been widely developed (Burd et al., 2018). As such, few studies have evaluated the efficacy of IoT as a tool for learning or potential structures for classroom implementation, and those that have been published are limited by a number of factors. One substantial limitation of the research consulted for this thesis involves the sparse description of research methodologies and methods. Although this is an emerging area of study characterized primarily by exploratory research, descriptive accounts are necessary to establish credibility and allow for replication in qualitative inquiry (Creswell, 2013; Lincoln & Guba, 1985). However, many studies featured only a limited description of data sources, analysis procedures, sample characteristics, and other methodological concerns (e.g., Akiyama et al., 2017; Ali, 2015; J. Chin & Callaghan, 2013; Davis, 2017; Maia & Filho, 2018; Manches et al., 2015; Raikar et al., 2016). Similarly, issues with sampling emerged in several of the studies, including sample size (e.g., Akiyama et al., 2017; Penzenstadler et al., 2018), characteristics inconsistent with the target population (e.g., J. Chin & Callaghan, 2013), and unique contextual factors (e.g., Kortuem et al., 2013) that restrict transferability of the study's findings. As few instances of curricular programming at the elementary and secondary school levels have been documented, studies from tertiary education were included to inform potential course progression, strategies for technology implementation, and overall considerations. Two of these studies (Aldowah et al., 2017; J. Chin & Callaghan, 2013) were preliminary curriculum concepts, featuring no or limited supporting data. The remainder (Akiyama et al., 2017; Ali, 2015; Koo, 2015; Kortuem et al., 2013; Raikar et al., 2016) evaluated new courses, in only their first or second run, which provided useful curriculum design considerations but limited feedback from a small group of students (exception: Kortuem et al., 2013, whose online context welcomed 1,967 students in the course's first iteration). Additionally, little pedagogical justification was provided for most of the post-secondary courses, with curricular designs oriented around marketable IoT skills or the various technological components of an IoT system. Finally, several of the course evaluation studies from post-secondary education were conducted and reported by the course instructor and designer (Ali, 2015; Koo, 2015; Raikar et al., 2016). While not inherently problematic, discussion of the potential biases and mitigation strategies were absent from the research.

Despite being an even more recent area of study, the research conducted with elementary-aged students posed fewer limitations. Two of the four studies available at the time of writing were sufficiently descriptive (Charlton & Avramides, 2016; Davis, 2017), with rich pedagogical designs and clear study procedures. As with the post-secondary research, several studies lacked methodological details including sources of data for analysis (e.g., Davis, 2017), as well as analytical processes, sample characteristics, and guiding methodologies (e.g., Maia & Filho, 2018; Manches et al., 2015). In contrast with the research from higher education, these studies generally provided pedagogical justification for their curricular programming grounded in educational theory, but little rationale for the use of IoT as a tool for learning.

Apart from the limitations of previous research, many of which might be expected from an emerging area of study, there were also numerous gaps in the literature on making, IoT, and social consciousness in education that the current study sought to address. First, although IoT is becoming a prominent feature of many post-secondary education programs, few studies had been conducted on students' learning *about* and *with* IoT at the elementary school level at the time of the writing. Research on tertiary implementations of IoT curricula suggest numerous potential benefits, including interdisciplinary learning (Ali, 2015; J. Chin & Callaghan, 2013; Koo, 2015), creative thinking and design skills (Abamu, 2017;

Kortuem et al., 2013), learning principles of engineering and computer science (Ali, 2015; Kortuem et al., 2013), empowering novice technology users (Akiyama et al., 2017; Kortuem et al., 2013), and understanding the functionality and applications of IoT (Kortuem et al., 2013; Raikar et al., 2016). However, these affordances have only recently begun to be studied at the elementary and secondary school levels (see: Charlton & Avramides, 2016; Davis, 2017; Maia & Filho, 2018). As such, this study was designed to contribute to an understanding of how IoT could be utilized in education with a younger demographic.

Second, while the field is growing, there is still limited research on the affordances of making in formal educational contexts. Numerous authors (e.g., Freeman et al., 2017; Halverson & Sheridan, 2014; J. A. Marshall & Harron, 2018) have highlighted a need for evidence-based practices that facilitate meaningful learning and engagement through making in the classroom. These studies are beginning to emerge (in elementary and secondary education, see: Charlton & Avramides, 2016; Marsh et al., 2019; Vongkulluksn et al., 2018; in post-secondary education, see: Artut, 2018; Garcia & Cano, 2014; R. C. Smith et al., 2015; J. A. Marshall & Harron, 2018); however, they are largely informed by research from informal learning environments such as camps, museums, and other community settings. This work contains valuable insight into potential applications and affordances for education but making in schools is constrained by several factors absent from these contexts, including regimented timetables, prescribed curriculum, and mandated assessment. While the study presented in this thesis was also conducted in an out-of-school setting, its design was informed by pedagogical practices and learning objectives borrowed from classroom practice with the goal of highlighting implications for making in schools.

Finally, minimal research has been conducted on the use of IoT to explore issues pertaining to social justice and global citizenship. Each of these concepts represents the future of society. IoT has been positioned as an essential technology for urban infrastructure (Abamu, 2017; Freeman et al., 2017; Rainie & Anderson, 2017), health and accessibility (McRae et al., 2018; Rainie & Anderson, 2017), quality of life (Gershenfeld, 1999; Rainie & Anderson, 2017; Simionescu, 2017), and even entertainment for children (Manches et al., 2015). Likewise, global citizenship and a social justice orientation have been identified as necessary for citizens of an interconnected society (Bell, 2016; A. Chin & Jacobsson, 2016; Luksha et al., 2018; Lyles, 2018; Ontario Ministry of Education, 2016; Tan & Barton, 2018). When these areas do overlap, it is often in the form of designing smart gardens for sustainability (e.g., Davis, 2017; Maia & Filho, 2018; Valpreda & Zonda, 2016) or ideating smart cities (e.g., Abamu, 2017). These design challenges are undeniably related to global citizenship and, to a lesser extent, social justice, but address only a few of the barriers to equity and sustainability identified by the United Nations (2015). This study sought to expand on previous work by broadening the scope of social justice and citizenship concerns that could be addressed with IoT, inspired by Babson College's (n.d.) IoT for Good Lab.

2.6 Research Questions

To explore these gaps in the literature and begin developing an understanding of how making and IoT might contribute to global citizenship and social justice education, I developed the following research questions:

- How do students' understandings & perceptions of the Internet of Things evolve over the course of a week-long maker passion project?
- How might being immersed in an IoT-oriented passion project facilitate engagement with citizenship and/or a social justice mindset?

3 Theoretical Framework

As described by Miles et al. (2020), “a theoretical framework utilizes theory/theories and their constituent elements as the presumed ‘working model’ that drives the investigation and analysis of a social phenomenon … [abstracting] a study’s ideas based on the literature” (p.15). The research presented in this thesis was situated within a framework of constructionism (Papert, 1980), critical theory (Freire, 2005; Giroux, 2004; Kincheloe et al., 2017), passion-based learning (J. S. Brown & Adler, 2008; Mas’ud et al., 2019; Robertson, 2013), and design-based learning (Bekker et al., 2015; Carroll et al., 2010; R. C. Smith et al., 2015). Each of these perspectives plays a significant role in the process of learning through making and, taken together, form a supportive foundation upon which this study was developed.

3.1 Constructionism

Historically, learning has been perceived as a unidirectional, didactic process whereby teachers provide information, often in the form of lectures or presentations, and students are expected to receive and understand the information as presented. Maker pedagogies, however, are informed by theoretical perspectives which are inquiry-based and learner-driven, positioning students as active participants in the learning process (Artut, 2018). The origins of making in learning have been attributed by many to Seymour Papert (Halverson & Sheridan, 2014; Psenka et al., 2017), identifying his theory of constructionism (Papert, 1980) and work at the Massachusetts Institute of Technology (MIT) Media Lab as instrumental in highlighting the processes of learning that occur through the construction of tangible and digital objects (Papert & Harel, 1991; Psenka et al., 2017).

Constructionism has been embraced within education research to illustrate the quality of learning that occurs when students design and create projects that are personally or socially significant (Halverson & Sheridan, 2014; Resnick & Silverman, 2005). Papert, inspired by his work with constructivist theorist Jean Piaget, believed that using technology and/or physical media to construct artifacts created a context in which students could concurrently construct their understanding of associated concepts and curriculum (Papert, 1980; Psenka et al., 2017). Elaborating on the relationship between these two progressive theories, Vossoughi and Bevan (2014) wrote:

> *Constructivism* refers to the ways in which understanding is constructed by the individual learner through a wide variety of experiences … *Constructionism* posits that the experience and process of *building* something physical or digital provides a rich context for developing and representing understanding. (p. 8)

As evident in this excerpt, constructionism shares the constructivist perspective that both knowledge and intelligence are actively and contextually constructed through students' interactions with their surrounding environments, in contrast to previous theories which described intelligence as fixed and innate (Ackermann, 2001; Papert & Harel, 1991; Piaget, 1952). Students' backgrounds, cultural experiences, and interactions with others are considered significant contextual factors in the constructionist view of learning, as with Vygotsky's (1978) socio-constructivist perspective. Where constructivism and constructionism diverge is in the way that learning is conceived. While Piaget's developmental stages depict knowledge as gradually progressing towards cohesion and stability, Papert's theory is concerned with how knowledge is continually reshaped and reimagined over time (Ackermann, 2001; Kynigos, 2015). This point of contention aside, effectively, "constructionism … is the application of constructivist learning principles to a hands-on learning environment" (Kurti et al., 2014, p. 8).

Constructionism emerged in response to computers and other technologies becoming prevalent in education. While these tools were initially used to support an instructionist approach to learning by imparting knowledge to students, Papert (1980) saw their potential as tools that could be used to produce things and facilitate learning in the process. In his research with the LOGO programming platform, Papert (1980) emphasized that technologies with low floors and high ceilings (later expanded by Resnick and Silverman, 2005, to include wide walls) were essential for reducing barriers and multiplying opportunities for students to learn in this way. While the tools currently available in makerspaces extend beyond digital coding environments, these principles are still relevant for modern education and informed the selection of technologies made available for this study.

In addition to the ideation and creation of artifacts in learning, Kynigos (2015) highlighted student-centered processes of active engagement, metacognition, and sharing ideas, prototypes, and finished products as integral to constructionist learning. Sharing, whether through words or demonstration, is particularly valuable, as "expressing ideas makes them tangible and shareable which, in turn, informs, i.e., shapes and sharpens these ideas" (Ackermann, 2001, "Papert", para. 3). Beyond the refinement of conceptual structures, sharing and other social processes were initially conceived as integral to constructionist learning, with Papert and Harel (1991) describing students' resultant knowledge and constructed artifacts as a "public entity." In the decades following, an emphasis on computational thinking positioned learning with technology as primarily beneficial for individual skills development (Kafai & Burke, 2013). However, Kafai and Burke (2013, 2017) have since highlighted a shift toward social and collaborative engagement in programming, termed *computational participation*, with broad applications for STEM education (Sivaraj et al., 2020). Coding, or constructing other physical or digital artifacts, with and for others provides scaffolding for students' creative engagement, an authentic audience and purpose for making, and both personal and political empowerment (Kafai & Burke, 2013, 2017). Furthermore, computational participation promotes collaborative problem-solving and technological engagement in ways that mirror professional STEM contexts (Sivaraj et al., 2020), increasing the authenticity and relevance of students' making. Students further refine and affirm their knowledge and ideas through the active production of physical or digital representations (Blumenfeld et al., 1991; Cocciolo, 2011; Noss & Clayson, 2015; Ratto, 2011). Constructionist learning environments also promote inquiry which, with the support of their teachers and peers, enables students to conduct research, utilize problem-solving and logic-based reasoning skills, and continually iterate upon their learning (Abdi, 2014; Ackermann, 2001; Kurti et al., 2014). These processes can help make seemingly abstract subjects, such as science and mathematics, more concrete and relevant for students as they learn to apply them to their projects in new and interesting ways (Kynigos, 2015; Noss & Clayson, 2015). Given these potential affordances, continued research into educational applications of learning-through-making is necessary to evaluate the impact of constructionist learning on long-term retention and transfer of knowledge and skills (Godhe et al., 2019).

3.2 Critical Theory

With a focus on the ways that learners explore issues of citizenship and social justice through maker technologies, the design of this study was also influenced by contemporary critical theory. Originating from the Frankfurt School, a select group of theorists from the University of Frankfurt's Institute for Social Research (Kincheloe & McLaren, 2011; McLaughlin, 1999), critical theory emerged from the fundamental belief that "injustice and subjugation shape the lived world" (Kincheloe & McLaren, 2011, p. 286). Today, critical theory informs the research and practice of various disciplines, analyzing "issues of power and justice and the ways that the economy, matters of race, class, and gender, ideologies, discourses, education, religion, and other social institutions, and cultural dynamics interact to construct a social system" (Kincheloe & McLaren, 2011, p. 288). Although the numerous traditions and ever-evolving nature of critical theory make it difficult to define, critical work challenges problematic social structures, recognizing the roles of power and privilege in knowledge production and dissemination, and the impact of context and other subjectivities on both the experience and interpretation of what is commonly construed as fact (Freire, 2005; Kincheloe et al., 2017; Kincheloe &

McLaren, 2011). Communication and dialogue are integral to the critical perspective, as it is within conversation that knowledge is collaboratively constructed and negotiated (Freire, 2005; Kincheloe et al., 2017). Teachers and their students, as well as researchers and their participants, become co-constructors of understanding, each teaching and learning from the other in reciprocal dialogue (Freire, 2005; Kincheloe et al., 2017). Through these relationships and the aforementioned principles, critical theory aspires to improve social conditions through empowerment and the dismantling of oppressive social structures (Kincheloe et al., 2017; Kincheloe & McLaren, 2011).

In opposition to traditional transmission-based models of education, critical pedagogies leverage the assumptions of critical theory to position students as actively engaged in processes of learning with an orientation toward societal change (Kincheloe et al., 2017). Freire (2005) described the narrative character of conventional schooling, where teachers, in positions of classroom authority, unidirectionally impart knowledge onto their students. In what he termed the "'banking' concept of education, … the scope of action allowed to the students extends only as far as receiving, filing, and storing the deposits" (Freire, 2005, p. 72). Giroux (1985) identified similarly problematic discourses of education, including the "discourse of management and control" (p. 25) and the "discourse of relevance and integration" (p. 28). The former is characterized by a prescribed curriculum which "is taken as the cultural currency to be dispensed to all children regardless of their differences and interests" (Giroux, 1985, p. 25) Disengagement and disinterest are met with attempts to maintain order and discipline rather than modifications to the subject or methods of teaching. Within Giroux's (1985) discourse of relevance and integration, learning objectives are informed by students' needs and experiences as perceived by the educator. However, this typically results in a narrow perception of students' academic needs, informed by dominant cultural and political ideals (Giroux, 1985). Each of these models operates from a deficit perspective, devaluing students' rich cultural and experiential frameworks for learning in favour of prescribed skills and knowledge that enable students' assimilation into society through the reproduction of existing power dynamics (Freire, 2005; Giroux, 1985). Moreover, these educational discourses preclude the development of *conscientização*, or critical consciousness, necessary to engage the complex social issues they will encounter throughout their lives (Freire, 2005).

In contrast, critical pedagogies aim to empower and emancipate learners, drawing from feminism, postmodernism, and other radical perspectives to engage students in the critical exploration of social conditions (Giroux, 2004). In Giroux's (2004) words,

> it seems imperative that educators revitalise the struggles to create conditions in which learning would be linked to social change in a wide variety of social sites, and pedagogy would take on the task of regenerating both a renewed sense of social and political agency and a critical subversion of dominant power itself. (p. 33)

As with critical theory, student engagement plays a pivotal role in critical pedagogies. Students' diverse banks of knowledge and experience form the basis of inquiry into socially significant issues (Kincheloe et al., 2017), positioning both students and teachers as "transformative intellectuals" (Giroux, 1985, p. 35). Knowledge and critical understanding are advanced through reflective work and ongoing dialogue between students and their teachers, as well as their peers (Freire, 2005). This process not only validates, but also highlights, the underrepresented experiences and perspectives of marginalized youth (Kincheloe et al., 2017). Eschewing the traditional position of classroom authority, teachers adopt a facilitator role, creating an environment in which students feel safe to challenge dominant ideals (Kincheloe et al., 2017), as well as "providing students with the skills, knowledge, and authority they need to inquire and act upon what it means to live in a substantive democracy, to recognize anti-democratic forms of power, and to fight deeply rooted injustices" (Giroux, 2004, p. 35). Respecting learners as knowledge producers, critical pedagogies forefront student-defined experiences, interests, and questions as the impetus for learning (Freire, 2005; Giroux, 2004). As Freire (2005) explained,

> students, as they are increasingly posed with problems relating to themselves in the world and with the world, will feel increasingly challenged and obliged to respond to that challenge. Because they apprehend the challenge as interrelated to other problems within a total context … the resulting comprehension tends to be increasingly critical, and thus constantly less alienated. Their response to the challenge evokes new challenges, followed by new understandings. (p. 81)

In addition to having their perspectives validated, students are more likely to be motivated by critical engagement with social challenges of personal relevance than by decontextualized curriculum (Giroux, 2004). Moreover, Giroux (2004) describes that the resultant "agency becomes the site through which power is not only transcended but reworked, replayed, and restaged in productive ways" (pp. 33-34), redefining the classroom context as the foundation for social transformation.

In a constructionist learning environment, critical pedagogies are implemented through critical making (Blikstein, 2013; Ratto, 2011). In addition to dialogue and reflection (Freire, 2005; Giroux, 2004; Kincheloe et al., 2017), learners participate in emancipatory analysis and action through the creation of culturally relevant artifacts. As with the learner-driven context of critical pedagogies, Bevan et al. (2014) noted that maker activities

> can accommodate a wide variety of interests and experiences, they blend intellectual and socioemotional engagement, and they provide opportunities for young people to develop, pursue, persist with, and accomplish original ideas and solutions in which they can take pride and ownership. (p. 28)

Merging processes of critical thinking and reflective making (Chounta et al., 2017; Ratto, 2011), critical maker pedagogies engage students in the exploration of complex social issues and the construction of physical or digital products intended as a form of personal expression (Ratto, 2011), cultural production (Marsh et al., 2018; Tan & Barton, 2018), or to facilitate meaningful change (Hughes, 2017; Kwon & Lee, 2017).

3.3 Passion-Based Learning

As society evolves, so too do the needs of its populace. The services, career paths, and technologies developed to respond to these needs are ever-changing, meaning that students must be equipped with the desire and skills to continue learning beyond their years in formal schooling (J. S. Brown & Adler, 2008). Student-centered models of education that emphasize inquiry, collaboration, creativity, and agency over learning have been identified as effective for promoting the development of skills that enable citizens to adapt and thrive in these variable conditions (Buchanan et al., 2016). A recent survey found that 36% of parents and 40% of teachers considered students' development of curiosity to learn beyond the classroom as one of the most important learning objectives for schools, ranked between critical thinking and problem-solving skills (Gallup, 2019). Despite an emphasis on the need for student-driven education, *passion-based learning* is still relatively unexplored in the literature (Mas'ud et al., 2019). However, over a decade ago, Brown and Adler (2008) noted that engaging with content and a community "that ignites a student's passion can set the stage for the student to acquire both deep knowledge about a subject … and the ability to participate in the practice of a field through productive inquiry and peer-based learning" (p. 28), highlighting the relevance of passion-based learning for formal education.

With inquiry and authentic learning as some of its central tenets (J. S. Brown & Adler, 2008; Buchanan et al., 2016; Mas'ud et al., 2019; Robertson, 2013), passion-based learning is inspired by the PBLs that came before it: namely, project- and problem-based learning. *Project-based learning* was designed around Kilpatrick's (1918, as cited in Chounta et al., 2017) "project method", inviting educators to step back from their typical role as classroom leaders and facilitate students' pursuit of solutions to predefined issues (Blumenfeld et al., 1991; Chounta et al., 2017).

Projects begin as open-ended questions, and are “relatively long-term, problem-focused, and meaningful units of instruction that integrate concepts from a number of disciplines or fields of study” (Blumenfeld et al., 1991, p. 370). Activities are structured within a context authentic to the proposed problem, and students gradually learn relevant concepts as they engage in inquiry, synthesis, and application of their research (Blumenfeld et al., 1991).

Similarly, *problem-based learning* “embeds students’ learning processes in real-life problems” (Hung et al., 2008, p. 486), and was originally developed for use as an alternative approach to medical education at McMaster University in Hamilton, Ontario (Baker, 1999). In contrast to traditional approaches whereby students memorized important facts and procedures, problem-based learning sought to equip students with the skills needed to engage in active, adaptive, and lifelong learning (Baker, 1999; Hung et al., 2008). Adopting values from constructivist and situated learning perspectives, problem-based learning recognizes the role of context in knowledge development. As such, learning is positioned as a highly individualistic process, co-constructed between the student and interactions with their environment and peers (Hung et al., 2008). In this approach, students are presented with an ill-structured problem, to which they respond by pooling their collective understanding and devising a plan to fill any knowledge gaps before investigating possible solutions (Baker, 1999; Hung et al., 2008). As with project-based learning, teachers act as facilitators, posing thoughtful questions and modelling reasoning processes to guide student-driven learning (Baker, 1999; Hung et al., 2008). However, while both project- and problem-based learning are centered around relevant problems to be investigated in authentic contexts, they differ in both complexity and agency over the orienting problem. Project-based learning typically involves numerous distinct tasks to be completed over a period of time within a project that has been assigned by the teacher, whereas problem-based learning tends to be more fluid, occurring within the context of an open-ended, ill-defined central problem (de Graaff & Kolmos, 2007).

Although project- and problem-based learning are both described as student-driven approaches with the responsibility for learning shifted to students, the orienting project or problem is most often provided by the teacher, structured to achieve mandated learning objectives (Robertson, 2013). Passion-based learning emulates the problem-centric approach of these strategies, but students are provided the freedom to pursue personally meaningful projects of their own selection (Buchanan et al., 2016; Mas'ud et al., 2019; Psenka et al., 2017). This approach is supported by a recent report which found that "most students say they would like to spend more time on activities that give them input on their educational path, such as choosing what they learn in class and learning more about topics that interest them" (Gallup, 2019, p. 14). Being afforded this level of agency can have a substantial positive impact on students' engagement in learning (Blumenfeld et al., 1991; Psenka et al., 2017; Ratto, 2011; Robertson, 2013), subsequently improving markers of academic achievement (Buchanan et al., 2016) and the development of self-confidence, critical thinking, and problem-solving skills (Gallup, 2019). Passion-based learning can also promote student empowerment, "allow[ing] them to find their voices, understand their own learning processes and challenges, develop greater autonomy in their learning, and begin to recognize their own strengths and talents" (Robertson, 2013, p. 211), which can be particularly transformative for marginalized students.

Passion-based learning is particularly compatible with constructionist approaches to education. As articulated by Resnick and Silverman (2005), "the best learning experiences, for most people, come when they are actively engaged in designing and creating things, especially things that are meaningful to them or others around them" (p. 1). If students are personally motivated by their topic of study and, consequently, the artifact they create as a representation of that learning, they are likely to develop a deeper understanding of those concepts (Papert & Harel, 1991; Ratto, 2011). The inquiry component of passion-based learning enables students to engage in creative and innovative practices of experimentation, failure, and iteration (Buchanan et al., 2016), much like the learning process in making and makerspaces. Similarly, meaningful applications of technology in passion-based learning are thought to help students personalize their process, take ownership over their learning, and make connections between their in-school learning and the real world (Gallup, 2019).

3.4 Design-Based Learning

Design thinking is framed as an approach to problem solving that encourages playfulness, tinkering, creativity, and positive risk-taking (Psenka et al., 2017; Spencer & Juliani, 2016). Defined as "the ability to thoughtfully engage in design processes of digital fabrication [and] knowing how to act and reflect when confronted with ill-defined and complex societal problems" (R. C. Smith et al., 2015, p. 21), design can bolster students' creative confidence (Carroll et al., 2010) and provide a meaningful framework in which they can individually or collaboratively bring abstract ideas to life (Psenka et al., 2017; R. C. Smith et al., 2015). It may also enable students to critically examine complex issues, equipping them with the empathy and problem-solving competencies needed to propose equity-oriented solutions (Carroll et al., 2010; Leydens et al., 2014; Razzouk & Shute, 2012). While design has been thoroughly integrated into post-secondary education, particularly within engineering programs, it has only recently begun to find traction at the K-12 level in the form of designing scientific inquiry (Psenka et al., 2017). However, as design plays a pivotal role in the thoughtful construction of physical and digital artifacts (R. C. Smith et al., 2015), makerspaces and pedagogies provide an avenue through which the affordances of design-based learning could be brought to pre-tertiary education.

The creativity, critical thinking, and problem-solving components of design-based learning are applicable throughout education, from engineering to the interdisciplinary contexts emphasized by maker pedagogies (Razzouk & Shute, 2012). Design also provides a coherent structure for students' making, enabling them to better understand the process from ideation to completion, offering a vocabulary to describe their creative processes, and guidance to think reflectively about their work (R. C. Smith et al., 2015). Socially relevant design challenges (or briefs) can empower students to enact change in their local communities (Carroll et al., 2010) and recognize how technology can be leveraged to address social issues (Bekker et al., 2015). Contrary to its name, design thinking is more concerned with the human experience than aesthetics (Gobble, 2014), drawing inspiration from the concerns and challenges expressed by people in their everyday lives (Carroll et al., 2010; Leydens et al., 2014). Authentic design learning is student-directed, inviting learners to identify a personally-meaningful problem to investigate and ideate solutions (Doppelt, 2009). Through engagement with these human-centered challenges and their underlying systemic conditions, design-based learning can facilitate a social justice mindset (Leydens et al., 2014), making it a valuable addition to citizenship-oriented education.

Numerous models have been proposed to scaffold the design thinking process (e.g., T. Brown, 2009; Cahn et al., 2016; Doppelt, 2009; Gobble, 2014), but while the specific language, organization, challenges, tools, and final products may vary (Spencer & Juliani, 2016), they tend to include similar phases: (a) coming to understand the problem; (b) observing the problem in reality; (c) clarifying the problem; (d) brainstorming and ideation; (e) prototyping a solution; and (f) testing and improving upon the design (adapted from Carroll et al., 2010). In addition to these stages, Bekker et al. (2015) advocated for reflection to be integrated into the design process to support students' learning and evaluation of their design's potential impact (R. C. Smith et al., 2015). Although Doppelt (2009) suggested that students are capable of engaging in thoughtful, effective design without a specific framework, others disagree. Without an explicit focus on the design process, students may not fully understand how to use the framework to evaluate their progress and guide their next steps (Bekker et al., 2015; R. C. Smith et al., 2015). This can inhibit students' sense of direction for their projects, and consequently their engagement (R. C. Smith et al., 2015). Students may also need to revisit earlier phases to improve their prototypes, which can be challenging without the guidance of a model that highlights the cyclical process of design (Spencer & Juliani, 2016).

In addition to its value for making and social justice, design-based learning facilitates the development of numerous skills that are relevant across the curriculum and beyond. Through design, students engage in theoretical learning about a particular place or phenomenon and compare that information to real, lived experiences (Carroll et al., 2010), prompting critical thinking and recognizing the value of multiple perspectives to inform our understanding. Design also resembles scientific experimental processes, enabling students to hone their research, observation, testing, and reflection skills (Doppelt, 2009). Students' willingness to listen to others' experiences and perspectives throughout the design process – from the identification of a problem to obtaining feedback on their designs – strengthens their collaborative abilities with peers and mentors alike (Carroll et al., 2010; Psenka et al., 2017). Finally, design thinking promotes valuable metacognitive skills through ongoing documentation and reflection (Carroll et al., 2010).

As technology has facilitated a shift towards people becoming producers, rather than solely consumers, of cultural artifacts, design thinking processes have become increasingly relevant for the average citizen (Gobble, 2014). However, beyond aesthetic appeal and facilitating a deeper understanding of the challenges faced by society, design-based learning can have significant implications for students. As Razzouk and Shute (2012) described,

> Although the design process involves in-depth cognitive processes – which may help our students build their critical thinking skills (e.g., reasoning and analysis) – it also involves personality and dispositional traits such as persistence and creativity. If we are serious about preparing students to succeed in the world, we should not require that they memorize facts and repeat them on demand; rather, we should provide them with opportunities to interact with content, think critically about it, and use it to create new information. (p. 345)

Design-based learning is an active, student-centered approach to education that not only lends structure and coherence to making, but also integrates the global competencies that have recently become an educational focal point (Ontario Ministry of Education, 2016; Vega & Robb, 2019; Zimmerman, 2018). Moreover, its emphasis on designing solutions to real-world problems encourages critical analysis and engagement (Razzouk & Shute, 2012), and scaffolds authentic problem-solving processes (Doppelt, 2009; R. C. Smith et al., 2015), all of which will benefit students' participation in society beyond education.

4 Methods

4.1 Overview

The study presented in this thesis was conducted within the context of Dr. Janette Hughes' (principal investigator) five-year, multidimensional research project entitled "Discover, Design, Develop: Exploring Production Pedagogies in Teaching and Learning", funded by the SSHRC Canada Research Chairs (CRC) program. The larger study (see: Hughes et al., 2018; Hughes et al., 2019; Hughes & Morrison, 2018) sought to investigate how production (i.e., maker) pedagogies utilize makerspace principles of design, discovery, and development to promote and impact STEAM learning through the following research questions:

- How does an emphasis on creative production pedagogies in a makerspace environment facilitate engagement, understanding, and reflection on teaching and learning?
- How does the use of emerging digital media and interactive tools (such as 3D printing, electronic circuits, programmable robots) disrupt traditional curricular and teaching/learning assumptions and practices?
- How do constructionist production pedagogies potentially work to build students' and teachers' 'performative' competencies in digital literacies?
- How do production pedagogies potentially promote critical literacy development, civic engagement, and an awareness of social justice issues?

This larger project was conducted in multiple research settings, including various Ontario school boards, the STEAM-3D Maker Lab at Ontario Tech University's Faculty of Education, and online, using social networking websites and video-conferencing applications. However, the research presented in this graduate thesis is an isolated component of the larger, longitudinal study, reporting specifically on the design and findings associated with the ChangeMakers March Break camp that took place during the week of March 11 – 15, 2019.

4.2 Design

4.2.1 Research Design

The larger study (see: 4.1 Overview) employed a design-based research (DBR) approach to explore the implementation of maker pedagogies across a variety of educational contexts. DBR is described as “a series of approaches, with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings” (Barab & Squire, 2004, p. 2) through “iterative [microcycles] of development, implementation, and study” (The Design-Based Research Collective, 2003, p. 7). Over the five-year duration, numerous microcycles were conducted, each informed by the evaluative findings of preceding iterations (Kennedy-Clark, 2013). As a microcycle of that parent project, this study was designed in accordance with the lessons learned over the previous three years (e.g., Hughes et al., 2019; Hughes & Morrison, 2018), including: (a) the structure of the daily schedule to offset cognitive fatigue with breaks and energizing activities; (b) the provision of just-in-time support during inquiry-based work; (c) the integration of a multimodal reflection medium; and (d) the research design, including data collection and analysis strategies. Since “each of these micro cycles is a stand-alone study that may focus on fine-tuning a particular aspect of the [overall] study” (Kennedy-Clark, 2013, p. 28), the remainder of this thesis will focus exclusively on this microcycle, independent of the larger research project.

This study was designed from a social constructivist perspective, with the understanding that “[individuals] develop subjective meanings of their experiences … these meanings are varied and multiple, leading the researcher to look for the complexity of views” (Creswell, 2013, p. 24). Context plays a significant role in the development of these subjectivities, including participants’ interactions with the researcher, the physical environment, and other participants (Creswell, 2013; Harrison et al., 2017; Patton, 2015). To account for these varied and constructed meanings, qualitative case study methodology was deemed appropriate for this study. Given that elementary-aged children designing and making with IoT is a relatively understudied phenomenon, qualitative research enabled the exploration of possibilities and the presentation of rich, descriptive accounts of participants' experiences (Creswell, 2013; Harrison et al., 2017). As Patton (2015) explained,

> qualitative inquiry documents the stuff that happens among real people in the real world in their own words, from their own perspectives, and within their own contexts; it then makes sense of the stuff that happens by finding patterns and themes among the seeming chaos and idiosyncrasies of lots of stuff. (p. 12)

This study aimed to not only chronicle the "stuff" that occurred during the ChangeMakers March Break camp, but also investigate patterns in participants' IoT learning and social action through making, which was made possible through qualitative research methods.

Within this qualitative framework, the research questions were explored using multiple case study methodology, in which each participant constituted a case within the bounded context of the March Break camp (Creswell, 2013; Harrison et al., 2017; Miles et al., 2020). The multiple case study approach constitutes "a special effort to examine something having lots of cases, parts, or members. … The cases have their stories to tell … but the official interest is in the collection of these cases or in the phenomenon exhibited in those cases" (Stake, 2006, p. vi). Through a social constructivist lens, this allowed for "inductive exploration, discovery, and holistic analysis" (Harrison et al., 2017, para. 8) of participants' learning processes, supported by rich data from multiple sources (Creswell, 2013). Selecting multiple cases for analysis provided a series of diverse perspectives and experiences, facilitating a multidimensional understanding of the research questions (Creswell, 2013; Stake, 2006). Furthermore, exploring the issues under study from varied (and in some cases, contrasting) positions enables researchers to "understand a single-case finding, [ground] it by specifying *how* and where and, if possible, *why* it carries on as it does. We can strengthen the precision, validity, stability, and trustworthiness of the findings" (Miles et al., 2020, p. 29, emphasis in original). The impact of any educational intervention is subject to innumerable factors, both internal and external, therefore multiple cases consisting of multiple data sources will provide a nuanced understanding of the ways in which elementary-aged children learn and critically make with IoT.

4.2.2 Camp Design & Structure

Educational day camps differ from formal schooling programs in a variety of ways that could impact learning, including: (a) student-facilitator ratio; (b) facilitators with diverse areas of expertise; (c) physical infrastructure; (d) expanded access to educational technologies; (e) scheduling flexibility; (f) environmental culture; and (g) disciplinary measures. However, engineering- and maker-oriented camps are one way to link the growing maker movement with project-oriented education, albeit in an informal context (Chounta et al., 2017). The design of the ChangeMakers March Break camp was informed by best practices in maker education, design-based learning, and passion-based learning (see: 3 Theoretical Framework), as well as previous iterations of the larger project (see: 4.1 Overview).

4.2.2.1 Schedule of Activities

Each of the camp's five days were organized around a similar structure, outlined in Table 4.1. Camp activities were scheduled from 9:00am to 3:00pm, but campers began arriving after 8:00am and departed as late as 4:00pm. These before- and after-care hours consisted of supervised leisure time, during which campers were encouraged to explore various plugged (i.e., digital) and unplugged maker tools. While some used this time to experiment with programmable robots, 3D printing pens, or a digital loom, most gravitated towards using iPads, on which they created and shared levels in the Bloxels (Pixel Press Technology, n.d.) game creator or coloured digital pixel art.

Table 4.1

Daily Schedule for ChangeMakers March Break Camp

Time	Activity
8:00am	Before-care began
9:00am	Community-building activity
9:30am	Pre-learning and discussion related to day's activities
10:30am	Break and energizer activity
10:45am	Passion project work time
12:00pm	Lunch break
1:00pm	Passion project work time
2:15pm	Break and energizer activity
2:30pm	Reflection and next-day planning for passion projects
3:00pm	After-care began

Note. Hands-on passion-project work did not formally begin until day three, so these time periods were allocated differently on days one and two. On day one, campers engaged in work related to a separate research project. On day two, campers were engaged in learning the three primary IoT technologies in use at the camp.

Daily community-building exercises promoted physical activity, global competencies including collaboration, problem-solving, and communication (Ontario Ministry of Education, 2016), and socioemotional competencies such as relationship skills and social awareness (CASEL, 2013). Examples include:

- *Get to Know You Bingo:* Campers are given a Bingo-style grid with 20 physical attributes (e.g., "wears glasses"), favoured activities (e.g., "loves ice-skating"), and skills (e.g., “speaks more than two languages”) with the goal of having a different person sign each box.

- *Web of Commonalities:* Holding a ball of yarn, a camper declares something about themselves (e.g., a personality trait, a hobby). People who share that in common raise their hand, and one is tossed the ball of yarn. The game continues until the resulting web links everyone together (Shapiro & Levy, 2009).

In addition to establishing trust and rapport between campers, these exercises were used to transition between unstructured leisure time and structured camp activities.

A 30- to 60-minute pre-learning period established context for each day’s activities and provided depth to campers’ IoT passion projects. These consisted of an introduction to coding and community (day one), an introduction to IoT (day two), an introduction to citizenship and social justice (day three), themes of collaboration and perseverance (day four), and concerns of data security and privacy related to IoT (day five). Discussions of each topic were supported with informational videos or read-alouds. For example, the first day’s theme of community was introduced through a read-aloud of *Anno’s Magic Seeds* (Anno, 1999), and on the second day campers were introduced to IoT through two videos (Flanagan et al., 2014; Fw:Thinking, 2013) interspersed with discussion and hands-on engagement with the Vector personal assistant robot (Digital Dream Labs, n.d.).

To reduce physical inactivity and cognitive fatigue associated with prolonged concentration, camp facilitators and/or volunteers led mid-morning and mid-afternoon energizer games. These activities promoted similar competencies to the morning community-building exercises, but with an emphasis on physical activity. As an example, campers played a “Floor is Lava” game, in which they were provided with five pieces of scrap cardboard (approximately 50cm x 50cm in size) and were instructed to work in teams of three to cross a room without contacting the floor.

Between two-and-a-half and three hours per day (on days three, four, and five) were allocated for work on campers' IoT passion projects. These projects were conceptualized on day two, following an introduction to IoT concepts and hands-on exploration of three maker technologies that could be used to prototype IoT inventions:

- *littleBits:* Electronic "Bits" with magnetic connectors, enabling the construction of simple devices with little circuitry knowledge and no wiring (Sphero Inc., n.d.-c). This tool was considered to have the lowest floor of the three provided.

- *Micro:bit:* A "pocket-sized computer" featuring 25 LED lights, built-in sensors, buttons, and the ability to be coded with either block-based or Python programming languages (Micro:bit Educational Foundation, n.d.).

- *Arduino:* A sophisticated microcontroller that can be wired to a breadboard and a variety of sensors and actuators (Arduino, n.d.). With its physical wiring and text-based Arduino programming language, this tool was considered to have the highest floor of the three.

Campers were instructed to select one of these three technologies as the basis for their project, with the understanding that they would be permitted to take it home upon culmination of the camp. While not an exhaustive list of IoT-capable maker technologies, these tools were selected to provide a range of age-appropriate entry points and because they upheld Resnick and Rosenbaum's (2013) principles for learning-oriented construction kits: (a) they provided immediate feedback, preventing lengthy delays in campers' making; (b) they enabled fluid experimentation through easily modifiable components; and (c) they were flexible enough to support open exploration across a variety of projects. Following these hands-on learning sessions, we asked campers to begin designing[1] an IoT passion project that could help others, adding a citizenship and social justice component on day three. The term "passion project" is used deliberately; in recognition of the literature on passion-based learning (see: Section 3.2), campers were challenged to design and create projects with personal relevance. As described by Resnick and Silverman (2005), "we do a much better job as designers when we really enjoy using the systems that we are building" (p. 4). Inviting campers to design and fabricate something related to a personal passion was intended to sustain their engagement with unfamiliar technologies and challenging concepts (J. S. Brown & Adler, 2008) to produce meaningful IoT learning. It is important to note that campers were encouraged to be imaginative and ambitious with their designs. They were advised that the prototype they constructed during camp would be an approximation of their final design – depending on time and resource availability – but I wanted to minimize the impact of logistical constraints on participants' engagement with IoT concepts and challenges related to citizenship or social justice.

Finally, each day's activities culminated in a period of reflection and planning, guided by a series of prompting questions. Reflection is a fundamental part of the creative process (Bieraugel & Neill, 2017), enabling makers to critically engage with both the subject and emerging product of their making activity (Marsh et al., 2018; Ratto, 2011), as well as to develop coherence and confidence in their design decisions (Resnick & Rosenbaum, 2013; R. C. Smith et al., 2015). Therefore, reflection was emphasized as an integral part of the design process,

> that combines learning with designing, that follows steps that support diverging and converging … and that examines open-ended design problems that require coming up with a good combination of a product with specific working principles that has value for the user. (Bekker et al., 2015, p. 31)

---

[1] While strict adherence to a formal design process was not a focus of this study, The Works Museum's (2015) engineering design process was employed as a scaffold for all camp making activities.

As many learners struggle with reflection (R. C. Smith et al., 2015), each day's prompt featured multiple questions to guide their thinking and provide choice for their responses (Appendix B). These questions, in combination with a digital design journal that offered multiple modalities for recording (described in 4.5.5 Artifact Collection), were intended to provide added support for campers' reflective processes (Bekker et al., 2015). On the final day of the study, semi-structured interviews were conducted in place of reflections.

4.2.2.2 Camp Facilitators

In addition to myself, the day-to-day operations of the ChangeMakers March Break camp were facilitated by two graduate students who were also members of the research laboratory in which the camp was situated. Five pre-service teacher candidates volunteered their time to lead energizer activities and supervise lunch breaks, for which they received a signed letter of participation. On limited occasions, two instructors from the adjoining Faculty of Education also made themselves available to provide technological support and lend their expertise to extend campers' designs. Each peripheral member of the facilitation team volunteered between one and two hours of their time, while the core facilitators each spent approximately 30 hours leading community-building and educational activities, providing just-in-time support for campers during passion project work periods, and managing basic health, safety, and comfort needs. With the exception of the Faculty instructors, none of the camp facilitators or volunteers had any prior experience making or teaching with IoT. However, this was not considered detrimental to the study as their limited expertise was assumed to be comparable with that of an average elementary school teacher. Given that one of this study's primary goals was to explore how IoT might be integrated in the K-12 education system, it was reasonable to involve facilitators with a rudimentary level of IoT experience.

4.2.2.3 Situating Myself in the Research

In accordance with recommendations for qualitative research (Creswell, 2013; Patton, 2015), I wish to situate myself as the primary designer, researcher, and author of this study. I recognize that my background and experiences constitute their own framework through which the research was conducted, and the data were analyzed and presented in this thesis. As a Master's student at Ontario Tech University, I have completed graduate-level studies in educational theory, research methods, and analytic techniques, and have been closely supervised throughout the duration of this project by researchers and Faculty members with demonstrated expertise. I am both personally and professionally interested in the ways in which technology affects students' learning, as well as how students become involved in social justice activity, which inspired the foci of this study. I believe that learning is best achieved through interactive, student-driven processes and, as such, align myself with the constructionist lens of this research project. The operational and research-based activities of this study were designed and conducted collaboratively with two other graduate students and with the supervision of an experienced researcher to ensure the appropriateness and integrity of the methods, data collection, and analysis processes.

While this study was personally fulfilling as both a researcher and educator, it was also labour-intensive and both physically and mentally exhausting. Each day challenged my ability to balance research duties with the need to support students' learning and engagement in camp activities. In retrospect, the scope of the activities planned for the camp were beyond our capacity as a small team of facilitators and, on days where volunteer support was limited, my duties as a camp facilitator often took precedence over research activities, resulting in a relative shortage of in-the-moment observations compared with other data collection methods. However, this potential for over-extension was accounted for in the research design and informed the preparation and use of data collection tools that required little manipulation during camp hours.

4.3 Participants

The ChangeMakers March Break camp was advertised through numerous platforms, including the STEAM-3D Maker Lab website and social media channels, the Ontario Tech University digital events calendar, physical posters displayed prominently throughout Ontario Tech University's Faculty of Education building, and word-of-mouth communications. An example of the poster used in both digital and physical advertising can be viewed in Appendix A. Students who were enrolled in Grade 4 (age 9) through Grade 9 (age 14) were invited to attend the camp, which took place during standard school hours over students' mid-winter school holiday in March. Before- and after-care services were offered to reduce employment-related barriers associated with guardian drop-off and pick-up.

Study recruitment took place during the camp registration process; in addition to the camp registration form, guardians were provided with a letter of information about the study and a consent form to be completed with their child (Appendix C). As outlined in the letter of information, children were welcome to attend the camp and engage in the full schedule of activities without participating in the research component, however consent was freely given for all children who were registered. This resulted in a total of 17 participants between the ages of 7 and 14, with a mean age of 10 years[2]. According to registration data, eight participants identified as female and nine as male. Additionally, 10 participants had an established relationship with at least one other camp participant in the form of siblings, extended family members, classmates, or friends outside of school. This existing rapport resulted in natural partnerships during the passion project phase of the camp. Previous experience with technology was not required upon camp registration, therefore participants varied in computing competencies as well as knowledge of and experience with different technologies.

[2] An exception to the age range of the camp was made for a seven-year-old participant to attend with their older sibling.

Although data were gathered from each of the 17 registered participants, this number was reduced through two phases of purposeful sampling (Creswell, 2013; M. N. Marshall, 1996). First, participants without a full data set were excluded from consideration for this study. The passion-based focus for participants' IoT projects resulted in a wide range of both technological complexity and time required for project completion. This meant that, on the fifth and final day of camp, many participants opted to continue working on their passion projects rather than engaging in a post-study interview. As a result, only 10 of the 17 registered campers were considered valid participants for this study (participant pool A).

Table 4.2

Summary of Participants

Participant Pseudonym	Age	Gender	ChangeMakers IoT Project
Aaron	9	M	Soccer skill-development robot
↳ Luca	9	M	Soccer skill-development robot
Aileen	9	F	Smart mood bracelet
Amalya	13	F	Texting-and-driving deterrent
Anisha	10	F	Home security monitoring system
↳ Derick	9	M	Home security monitoring system
Arshad	10	M	Mars smart garden
Emily	9	F	Endangered species tracker
Isabelle	10	F	Family alarm clock
Shaelyn	12	F	Eye strain prevention device

Note. Participants who chose to work with a partner (i.e., Aaron and Luca, Anisha and Derick) have been grouped together in the table with their data highlighted.

The second phase of sampling was conducted in accordance with recommendations for multiple case study research (Creswell, 2013; Miles et al., 2020; Stake, 2006). In order to provide rich, detailed accounts of participants' experiences and allow for cross-case analysis within the scope of this thesis, the data set was further reduced from 10 participants to eight, comprising six total cases (participant pool B). A summary of the study's participants, organized alphabetically by the first initial of their researcher-provided pseudonym, is presented in Table 4.2.

The six focused cases were selected for their ability to address the research questions in as much depth and breadth as possible. The inclusion of both confirming and disconfirming cases (Creswell, 2013; Stake, 2006) was prioritized, as well as cases that highlighted trends in the data (Miles et al., 2020) and offered considerations for inclusion of these or similar activities in educational environments. In Chapter 5, an overview of the insights into each research question will be informed by participant pool A, followed by an in-depth analysis of the themes evident in cases selected for participant pool B.

4.4 Context

The ChangeMakers March Break camp was hosted primarily in the STEAM-3D Maker Lab, a makerspace research facility located within Ontario Tech University's Faculty of Education. Camp activities often spilled out into the hallway and nearby unoccupied classrooms, honouring the flexibility of making (Chounta et al., 2017; Freeman et al., 2017; Halverson & Sheridan, 2014) and providing different levels of contextual support (e.g., the Maker Lab was energetic and social, while nearby classrooms became quiet spaces for small-group activity). In addition to littleBits, micro:bit, and Arduino (described in Section 4.2.2.1), participants had access to Apple MacBook Pro and Dell Latitude laptops, iPads, and a variety of plugged (e.g., 3D printers, electronic cutting machines) and unplugged (e.g., cardboard, paint, textiles) materials to facilitate the development of their IoT passion projects.

Participants were given the option to work on their passion projects independently or with a partner of their choosing. While pairs were able to leverage the components of two IoT maker kits (one per camper), they also had to reconcile how their projects would be divided at the end of camp. Only three partnerships were formed: one between a set of cousins, and two that emerged organically when a common interest was discovered. Regardless of their working arrangement, socialization and collaboration were encouraged throughout the design and creation process.

As outlined in Section 4.2.2, there are numerous contextual differences between the ChangeMakers March Break camp and formal educational environments that may limit the interpretation of this study's findings. Learning, as with any human activity, is substantially influenced by the context in which it occurs (Patton, 2015). However, the Ontario Ministry of Education (2016) recognized that informal learning environments "can be used to teach cognitive, interpersonal, and intrapersonal competencies in ways that promote deeper learning and the transfer of learning" (p. 37). As such, the findings of this study are reported alongside contextual nuance that might impact its transferability.

4.5 Data Collection Tools

4.5.1 Overview

Consistent with the "hallmark of a good qualitative case study" (Creswell, 2013, p. 98), multiple sources of data were utilized to facilitate comprehensive analysis of the study phenomena and lend credibility to the study's findings through triangulation (Lincoln & Guba, 1985; Patton, 2015). Furthermore, I prioritized data collection tools that amplified participants' voices and experiences in the study. As knowledge is both socially and contextually developed (Luksha et al., 2018), the use of multiple data sources highlighted the personal and contextual nature of participants' engagement with IoT and social justice activity and enabled the painting of a more complete, authentic picture. Over the five-day camp, a combination of open-ended questionnaires, participant-observations, audio/video recordings, artifacts, and post-study interviews were collected to inform the research questions. The relation of each data source to the study's research questions has been outlined in Table 4.3.

Table 4.3

Alignment of Data Sources to Research Questions (RQ)

Data Source	**RQ1**	**RQ2**
Pre-study questionnaire	X	X
Participant-observations		X
Audio/video recordings (i.e., overhead cameras, focused videos)	X	X
Collected artifacts (i.e., digital design journals, reflections)	X	X
Post-study interviews	X	X

4.5.2 Pre-Study Questionnaire

A qualitative pre-study questionnaire was developed in collaboration with another graduate student who was conducting research on an unrelated project during the ChangeMakers March Break camp. The final questionnaire (Appendix D) contained a total of 20 questions: five related to campers' demographic information and general technology use, nine associated with the aforementioned independent research project, and six that were relevant to this study. To account for any potential impact of the questionnaire's length on campers' response quality (Galesic & Bosnjak, 2009), two versions with a modified question order were administered randomly. Except for those gathering demographic information, all questions were either fully open-ended or asked for elaboration on a yes/no/maybe response.

The pre-study questionnaire was designed to establish a baseline for campers' knowledge of and identification with the study's overarching concepts. Demographic information and details about campers' technology use frequency and preferences created a context in which their digital making activities and engagement with IoT concepts and technologies could be situated. Two of the six relevant questions assessed campers' pre-study understanding of IoT, including ways in which it could be leveraged to improve quality of life. Two additional questions probed campers' conceptual understandings of social justice and global citizenship, including examples of their participation in social action if applicable. Finally, two questions explored campers' self-efficacy related to making for change, specifically asking whether and how they could create a technological artifact to improve the lives of themselves and others.

4.5.3 Participant-Observation

During daily camp activities, field notes and focused observations were recorded by myself and my two co-facilitators to highlight salient working processes, interactions, or points of reflection as well as to triangulate data from other sources. These in-the-moment observations were documented with personal mobile devices, including smartphones and tablet computers, to minimize loss of data due to delays in locating an appropriate recording device. The convenience afforded by using personal devices to record observations also partially alleviated challenges associated with balancing the duties of research and camp facilitation (Creswell, 2013).

Field notes were documented during breaks in facilitation (e.g., energizer breaks, lunch breaks) using an audio-recording app with speech-to-text transcript capability. To ensure accuracy, these transcripts were reviewed and revised following the conclusion of each camp day. Additionally, photographs and focused video recordings were captured during campers' passion project work periods, highlighting points of progress in the development of their IoT prototypes, as well as interactions and reflective utterances deemed relevant to the research questions.

4.5.4 Audio/Video Recordings

The STEAM-3D Maker Lab is outfitted with six ceiling cameras and microphones that were used as the primary method of data collection during the ChangeMakers March Break camp. Strategically positioned over the main working spaces in the Maker Lab, each of these cameras recorded the work processes and interpersonal interactions of between two and four campers. Although seating was not assigned and campers were invited to work wherever they felt they could be productive, most worked in a consistent location across the five-day camp allowing for uncomplicated tracking of cases across camera recordings. These ceiling camera recordings were supplemented with focused audio/video recordings of notable interactions and utterances (see: 4.5.3 Participant-Observation), as well as recordings from a singular stationary camcorder on select occasions when camp activities were conducted in alternate locations.

Apart from the need to manually start and stop recording, this method of data collection was largely passive, enabling me to prioritize camp facilitation duties while concurrently obtaining valuable data from all participants. In addition to recording audio/video files to be transcribed at a later date, all six cameras were connected to an AXIS Camera Station S2008 computer (Axis Communications AB, n.d.) on which camera views could be zoomed and repositioned, and live feeds could be viewed. Following each day of the project, the recordings from each camera were transferred to an external hard drive and erased from the AXIS system. A networking complication prevented the ceiling cameras from recording on the final day of camp, so a series of camcorders and iPads were set up in their place. One limitation of this passive approach to data collection is the sheer volume of data that was produced. Over the five-day project, approximately 126 hours of video data were collected, of which 117 were generated by the ceiling cameras. Following data collection, each video was transcribed prior to undergoing data analysis.

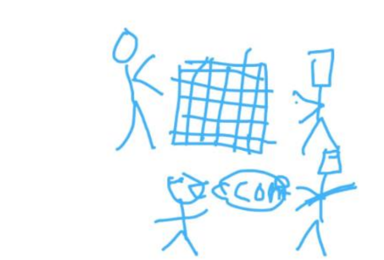
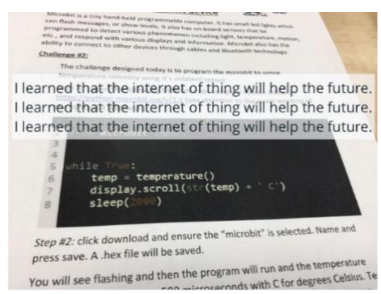
4.5.5 Artifact Collection

Two types of artifacts were collected for analysis: digital design journal entries and other process documents (including photographs) related to students' IoT prototype development.

To support and consolidate campers' design and reflection processes, I employed *Seesaw Class* (n.d.), a multimodal classroom platform that enabled campers to document their responses to assigned reflection prompts as well as record personal entries as desired. Entries could be created as a typed note, a video recording, a photograph (annotated with text, drawing, or an audio recording), a sketch, or an uploaded file. Examples of reflection entries created with each modality can be viewed in Table 4.4. *Seesaw Class* (n.d.) was installed on the Maker Lab iPads and introduced to campers as their digital design journal for the week. In addition to daily reflections (as described in 4.2.2.1 Schedule of Activities), campers were encouraged to use the app for learner-driven pedagogical documentation (Buldu, 2010; Hughes et al., 2017), highlighting the design, making, and learning processes they felt were most important or needed to revisit. However, this purpose was not re-emphasized beyond the first day of camp due to time constraints, therefore the majority of digital design journal entries (75/101) were direct responses to the reflection prompts (Appendix B). Remaining entries consisted of screenshots of their digital brainstorming exercise (detailed below; 15/101), unprompted reflections (6/101), tests of the app's various functions (4/101), and a copy of The Works Museum's (2015) engineering design process (1/101) that was provided to each camper.

Table 4.4

Examples of Participants' Digital Design Journal Entries

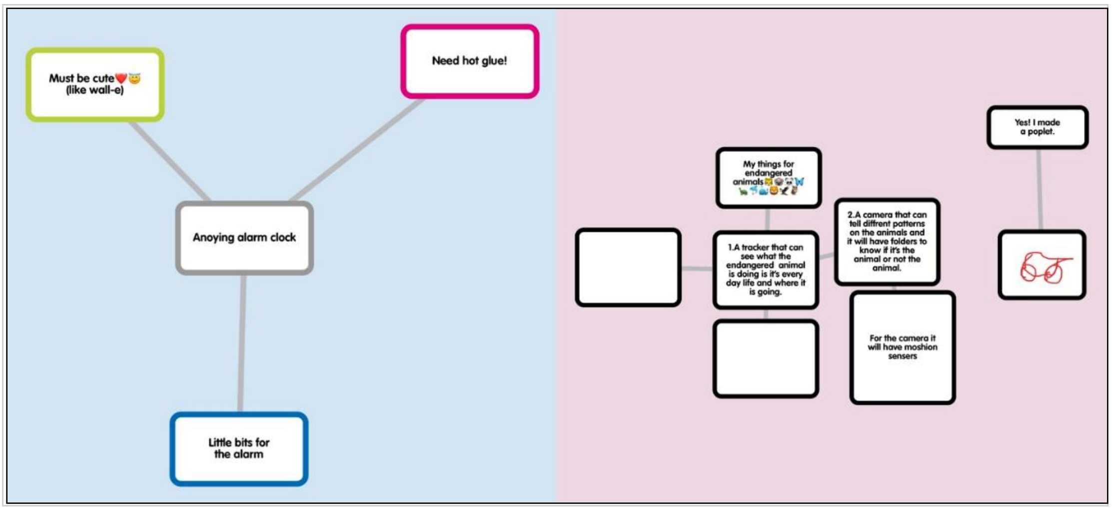
Modality	Example
Text	If I was able to design my own civilization, I would include the major basic needs that help us to be happy and healthy in our everyday life. The main one is enough food and fresh water for everyone. I will also invent new and helpful technologies that will make our everyday life easier. For example self driving cars, so that our everyday transportation will be easier. I would make technologies that would help us to do our everyday tasks. For example I would make technology for farming, so that you don,t have to waste all your time farming. Instead you can do other important things in that time. I would create a technology to make a really powerful medicine that can cure all the diseases and health problems. Everyone will take this medicine when they are little, so that it prevents them from having any health problems while growing up.
Video with Narration	
Drawing	
Annotated Photograph	

As campers were permitted to bring their IoT passion projects home following the five-day camp, other process documents were collected as artifacts of participants' work. At the beginning of day three, campers used the mind-mapping application *Popplet Lite* (n.d.) to begin brainstorming ideas for their IoT prototypes.

They were first asked to identify at least one social issue of personal importance, and then how IoT could be used to address this issue. From this starting point, campers were encouraged to plan their IoT passion projects, including details about its appearance, the materials and technological components needed to build it, and anything else they felt was important for inclusion in this document. As can be seen in Figure 4.1, campers' brainstorming documents varied in level of detail.

Figure 4.1

Examples of Participants' Brainstorming Documents



Note. Campers' *Popplet* brainstorming documents varied in detail, illustrated by the two examples provided here.

Since these mind maps were stored locally on each iPad, campers were encouraged to add to their *Popplet* document as their design evolved throughout the week. Upon completion of the camp, a screenshot of each camper's mind map was uploaded to their digital design journal before clearing the local data. In addition to campers' brainstorming documents, other artifacts were collected as evidence of their learning and design work, including photographs of their prototype at various stages of completion, physical sketches, and handwritten notes.

4.5.6 Semi-Structured Interviews

On the final day of camp, semi-structured interviews were conducted to explore shifts in participants' understandings of IoT and their experiences with maker citizenship. An eight-question schedule was developed (Appendix E) to guide the conversation, with departures from this schedule being considered reflective of participants' experiences and given adequate time for exploration. Open-ended questions were prioritized to elucidate participants' individual understanding of and engagement with the concepts under study.

As few campers had completed their prototypes by this point, several declined the invitation to interview, preferring instead to use that time to make further progress. Those participants who accepted were interviewed individually, with the exception of any working in a dyad who were invited to interview together. Interviews were conducted in a quiet office adjacent to the main working space of the STEAM-3D Maker Lab and video-recorded for ease of transcription.

4.6 Procedure

Given the larger research project within which this study was designed, developed, and conducted, several procedural items vary from those of an independent study. Table 4.5 provides an approximate timeline of events related to this study's completion.

Table 4.5

Study Procedures Timeline

Timing	Procedure
February 2016	Ethical approval awarded to parent study ("Discover, Design, Develop: Exploring Production Pedagogies in Teaching and Learning", detailed in 4.1 Overview) by Ontario Tech University Research Ethics Board (#13862).
November 2018	Submitted initial research proposal to supervisor.
December 2018	Submitted revised research proposal to supervisor.
January 2019	Began study recruitment through digital and physical advertising (detailed in 4.3 Participants).
January – March 2019	Obtained parental consent and campers' assent to participate in research-related activities during camp.
March 2019	Participants attended ChangeMakers March Break camp. Relevant research activities (see: 4.6.2 Data Collection) conducted.
April 2019	Parent study's REB file was amended to include me as a team member such that the data could be utilized for this thesis.

4.6.1 Ethics

Obtaining informed and voluntary consent is crucial in respecting participants' autonomy and demonstrating respect for persons in research (Allmark, 2002; Canadian Institutes of Health Research et al., 2018). During the camp registration process, parents and/or guardians (hereafter referred to as registrants) were advised that the ChangeMakers March Break Camp had an associated voluntary research component. A copy of the information letter (Appendix C) was embedded into the online registration form, with the following text bolded for emphasis: "Participation in the research component of this camp is entirely optional and students will not be penalized in any way if they do not participate." In this letter, registrants were informed of the purpose of the study, methods of data collection, potential risks of participation, data confidentiality procedures, and the option for their child to withdraw at any point. Following this section of the registration form, registrants were asked to indicate whether they wished for their child to participate in the research project. If they selected the affirmative option, they were directed to save a PDF version of the information letter and to complete the attached consent form (Appendix C) with their child. On both the online registration form and the PDF consent form, registrants were invited to ask questions by phone or email to ensure informed consent. Completed consent forms were accepted via mail, drop-off, or scanned and returned through email, after which they were secured in a locked filing cabinet in the STEAM-3D Maker Lab office. Consent was freely given for all 17 registered campers.

Over the five-day camp, assent was reaffirmed on an ongoing basis out of respect for campers' personal autonomy. Although the six overhead cameras recorded the entirety of each camp day, participants were directed to "blind spots" in the STEAM-3D Maker Lab or accompanied to alternative workspaces in the hallway or a nearby classroom if they did not wish to be recorded. Furthermore, any focused audio/video recordings or photographs captured by camp facilitators were immediately preceded by requests for permission from all involved campers.

Research with human participants, particularly those from vulnerable populations (e.g., children), benefits from the use of care, compassion, and empathy in the study design process. Having completed the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (Canadian Institutes of Health Research et al., 2018) *Course on Research Ethics* (TCPS 2: CORE, Appendix I), I prioritized the three fundamental principles of respect for persons, concern for welfare, and justice in all aspects of the research design. In addition to my ethical responsibilities as a researcher, as an educator and fellow human being, I also prioritized participants' experience of the ChangeMakers camp. As this study took place within the context of a recreational March Break camp, not only was I concerned with conducting sound, ethical research, I also wanted participants to enjoy their break from school. Both of these priorities were addressed through the integration of reciprocity. Lather (1986) defined reciprocity in research as "a give-and-take, a mutual negotiation of meaning and power" (p.263). While the questions driving the study were my own, the only constraints I imposed were those necessary to explore the core research concepts (e.g., the selection of construction kits to facilitate engagement with IoT) and preserve participants' well-being (e.g., safety procedures for working with electronics, rules for respectful conduct). In some cases, this worked to the detriment of the research (see: 6.5.2 Limitations of Camp Design), but I was determined that participants would have the opportunity to pursue their own interests and construct their own meanings during the study.

Among her recommendations for conducting reciprocal research, Lather (1986) emphasized interactivity and flexibility in the research design, dialogic and reflexive interviewing, and negotiating the meaning of data with participants. In this exploratory study, I was most interested in participants' perspectives and experiences of the research foci, so conversations and negotiations regarding the camp's format and activities were a regular occurrence. I solicited participants' feedback through reflective journaling, group discussions, and one-on-one conversations, and they were welcome to share as much information as they felt comfortable. In an attempt to mitigate the inherent imbalance of authority between teachers and students in educational contexts, I engaged in self-disclosure through the expression of my own perspectives and positions about IoT, social justice, and the research while asking for and emphasizing the validity of participants' perspectives. Furthermore, while a series of predefined questions guided the post-study interviews (see: Section 4.5.6), they too were approached as a conversation, taking whichever direction participants chose. Finally, due to delays in data analysis and reporting, I was unable to maintain contact with participants and their families to renegotiate my interpretation of their experiences, however this practice is in line with my research philosophy and would have further legitimized the research presented in this thesis. As Lather (1986) explains, "researchers are not so much owners of data as they are 'majority shareholders' who must justify decisions and give participants a public forum for critique" (p.264). However, I prioritized accuracy in analyzing participants' experiences (Creswell, 2013), identifying both positive and negative outcomes in both the case studies and cross-case analysis.

4.6.2 Data Collection

Described in this section are the data collection procedures conducted over the course of the five-day study. An overview of these procedures can be viewed in Table 4.6.

Table 4.6

Overview of Camp Activities & Data Collected

Camp Day	Research Activities	Data Collected
1	Introduction to communities and civilizations Introduction to coding Guided reflections	Pre-study questionnaire Participant observations Artifacts
2	Introduction to IoT Introduction to and exploration of IoT-capable maker technologies Guided reflections	Audio/video recordings Artifacts
3	Introduction to citizenship and social justice Designing IoT passion projects Supported work on IoT passion projects Guided reflections	Audio/video recordings Participant observations Artifacts
4	Supported work on IoT passion projects Guided reflections	Audio/video recordings Artifacts
5	Introduction to IoT security and privacy Supported work on IoT passion projects Showcasing completed and in-progress IoT passion projects	Post-study interviews Artifacts

The pre-study questionnaire (Appendix D) was administered on the morning of the first day. In preparation, Apple MacBook Pro laptops had been pre-loaded with a digital copy of Version A or Version B of the questionnaire and placed in front of alternate chairs on the STEAM-3D Maker Lab's tables. After campers were signed in by their parent and/or designated guardian, they were invited to choose a seat in front of a laptop. Following a brief introduction from the camp facilitators, campers were reminded of the confidentiality of their responses and asked to complete the questionnaire in as much detail as possible. Although they were asked not to collaborate or share answers, they were invited to seek clarification or ask for help from camp facilitators. Campers were given an unlimited amount of time to complete the pre-study questionnaire, but most were submitted within 20 minutes. Upon finishing, campers engaged in quiet recreational activities using the Lab's iPads while the remaining questionnaires were completed.

In addition to leading camp activities and providing just-in-time support, the three primary facilitators also engaged in participant-observation. Large-group activities and discussions were typically facilitated by one of the three core team members, during which the other two would document free-form field notes using a note-taking application on their mobile devices or excuse themselves to an adjacent room to record voice memos using a speech-to-text application. A similar procedure was followed during camper-directed passion project work periods to record observations of phenomena related to the research questions. These notes were later consolidated onto the secure hard drive on which the study's electronic data were being stored and erased from the original device. However, the administrative and facilitative duties associated with running the camp were more time-intensive than we anticipated, resulting in only eight observations being recorded across the five days.

As described in 4.5.5 Artifact Collection, digital design journal entries and other process documents (including photographs) were collected as artifacts over the course of the study. Thirty minutes at the end of each day were reserved for campers' reflection, during which multimodal responses to provided reflection prompts (Appendix B) were recorded using *Seesaw Class* (n.d.). These, in addition to any spontaneous entries that campers wished to make, were automatically stored in the STEAM-3D Maker Lab teacher account and downloaded from the app onto the secure hard drive following each day of camp. As campers were free to edit their digital design journal entries at will, downloaded entries were compared against their locally stored counterparts upon the study's conclusion to discern whether changes had been made, at which point the new version would also be downloaded. Other artifacts were collected by taking a screenshot (e.g., campers' brainstorming mind maps), a photograph (e.g., finished IoT passion projects), or retaining a physical copy (e.g., design plans drawn on paper).

To capture audio/video data, each day one of the three primary facilitators was tasked with launching the AXIS (Axis Communications AB, n.d.) software, digitally repositioning the six overhead cameras if needed, and beginning to record shortly before 9:00am. To reduce file size, recordings were paused over campers' one-hour lunch break and stopped shortly after the conclusion of formal camp activities at 3:00pm. During occasions on which additional audio/video recording was needed (e.g., on day two, when another classroom was used to explore IoT technologies), I determined an appropriate location for a traditional camcorder such that the greatest possible number of participants were visible but the flow of traffic through the space remained unobstructed. These recordings were supplemented with focused audio/video recordings (see: 4.5.3 Participant-Observation) and videos captured on a series of iPads when a technical complication prevented the overhead cameras from being used on the fifth day of the study. At the end of each day, the recordings from each camera were transferred to the secure external hard drive and erased from the AXIS Camera Station (Axis Communications AB, n.d.), camcorder memory card, or iPad storage, as applicable.

On the fifth and final day, semi-structured post-study interviews were conducted as campers worked to finalize their IoT passion projects. All 17 campers were invited to participate – individually or with their partner (if applicable) – and a concerted effort was made to extend the invitation during periods of observed downtime (e.g., waiting for a component to be 3D printed or for a facilitator to become available for extra support). However, given the range of complexity in campers' passion projects, time was a valuable resource and only 10 campers were willing to disengage from their work when asked. Interviews were conducted in a closed office adjacent to the main working space of the STEAM-3D Maker Lab for privacy and to reduce ambient noise. Nine interviewees provided their assent for the interview to be video-recorded and one asked to be audio-recorded only. An interview schedule consisting of eight open-ended questions (Appendix E) guided the conversations, however departures from these questions were considered indicative of participant's learning and adequately explored. In total, eight interviews were conducted with ten participants at an average length of just over nine minutes per interview.

4.7 Data Analysis

Following the conclusion of the ChangeMakers March Break camp, all audiovisual data (i.e., overhead cameras, focused video recordings, video reflections, and interviews) were transcribed and analyzed alongside other textual data (i.e., pre-study questionnaires, participant artifacts) using thematic analysis procedures (Braun & Clarke, 2006). This analytic approach was deemed appropriate given the study's objectives to explore participants' experiences learning and making with IoT, as well as their engagement with concepts related to citizenship and social justice. Thematic analysis facilitates a comprehensive understanding of exploratory research phenomena through the provision of rich, descriptive detail (Braun & Clarke, 2006; Neuendorf, 2019), and is suitable for use within a range of interpretive frameworks (Braun & Clarke, 2006; Creswell, 2013). As such, data for this study were analyzed in accordance with Braun and Clarke's (2006) six-phase process for conducting thematic analysis.

First, I familiarized myself with the data by actively reading and transcribing audiovisual data in full (including gestures, changes in vocal tone, etc.) into digital spreadsheets organized by day and method of data collection. This initial system of organization enabled me to first analyze the data *in situ*, revealing patterns of learning and engagement that were influenced by interactions with the context, other campers, and camp facilitators. Next, I generated an initial set of codes by working "systematically through the entire data set, giving full and equal attention to each data item, and identify[ing] interesting aspects … that may form the basis of repeated patterns (themes) across the data set" (Braun & Clarke, 2006, p. 89). Key concepts from the study's research questions (i.e., making, IoT, social justice, and citizenship) were used as a framework to guide data analysis, ensuring the coded data were relevant. For example, campers' conversations about social issues in their community or the role of various sensors in their passion projects were marked for further analysis, while their friendly banter about each other's Bloxels (Pixel Press Technology, n.d.) creations was not. However, the descriptive codes for each relevant datum were developed inductively (Braun & Clarke, 2006; Creswell, 2013; Neuendorf, 2019). As coding progressed, operational definitions were devised for each code to ensure consistency across the data set (Miles et al., 2020). A full list of the operationalized codes is available in Appendix F, Appendix G, and Appendix H. A second cycle of coding (Miles et al., 2020) was conducted in parallel with Braun and Clarke's (2006) third phase of identifying themes within the data. Codes were re-evaluated, modified, and condensed as necessary, illuminating several themes and subthemes evident within the coded data. These included (a) the content of participants' IoT learning, with subthemes of IoT concepts and components, perceived issues, applications, and personal evaluations of the technology; (b) participants' engagement with social consciousness, with subthemes of awareness, orientation toward issues, personal perceptions, and applications of technology; and (c) the role of making, with subthemes of engagement in reflective design, orientation toward challenges, critical making, and collaboration. In phase four, these themes were reviewed against the coded data and overall data set to ensure they were an accurate representation of the study's findings prior to conducting further analysis of the data under each theme (phase five; Braun & Clarke, 2006).

Finally, data excerpts and analytic insights were organized for presentation in this thesis to address the research questions as stated in Section 2.6.

Multimodal content analysis (Jewitt, 2008; Miles et al., 2020; Neuendorf, 2019) was employed to examine participants' digital design journal entries and collected artifacts using the codes developed during thematic analysis. In line with Jewitt's (2008) assertion that "all modes in a communicative event or text contribute to meaning" (p. 247), the inclusion of these multimodal data for analysis was considered important for developing a full understanding of the research questions. Despite representing only a small portion of the data, "the interpretive work of students is reshaped through their engagement with a range of modes, image, animation, hypertext, and layered multimodal texts" (Jewitt, 2008, p. 259), so they could not reasonably be excluded. These texts were analyzed for evidence of participants' IoT learning, engagement with ideas related to citizenship and/or social justice, and the influence of making on each of these concept areas.

As with any qualitative data analysis, these procedures were conducted recursively (Braun & Clarke, 2006). True to Creswell's (2013) description, I

> engage[d] in the process of moving in analytic circles rather than using a fixed linear approach. One enters with data of text or images … and exits with an account or narrative. In between, the researcher touches on several facets of analysis and circles around and around. (p. 182)

This was particularly true in the context of conducting multiple case study research, which is a cyclical exercise in "interpretive *synthesis*" (Miles et al., 2020, p. 97, emphasis in original). Developing a cohesive analysis of the data in this study entailed continuously revisiting individual cases and the data set as a whole to ensure that participants' experiences were being accurately represented and that no significant insights or contributions were inadvertently excluded.

While qualitative inquiry denounces notions of objectivity and generalizability, it remains the responsibility of the researcher to ensure their findings are credible and trustworthy (Creswell, 2013; Lincoln & Guba, 1985; M. N. Marshall, 1996; Patton, 2015). To this end, I sought critical feedback from my research advisor throughout the process of designing and conducting the study, analyzing the data, and reporting the findings in this thesis. I endeavoured to explore possible alternative explanations (Lincoln & Guba, 1985; Patton, 2015) for phenomena during the analysis process and to present them in the body of this work where applicable. Furthermore, I engaged in the deliberate, conscientious design of research procedures (Lincoln & Guba, 1985; Patton, 2015) as well as the structure of the ChangeMakers March Break camp, although the latter was subject to variability as with any naturalistic environment. I also sought to include rich, comprehensive detail throughout this manuscript to enable the reader to make judgments about its transferability to similar educational contexts (Lincoln & Guba, 1985; Patton, 2015). Finally, data were triangulated using multiple sources, as "no single method ever adequately solves the problem of rival explanations. Because each method reveals different aspects of empirical reality and social perception, multiple methods of data collection and analysis provide more grist for the analytical mill" (Patton, 2015, p. 661). Identifying evidence for the study's findings across multiple data sources was intended to lend additional credibility to the assertions proposed herein. Triangulation was also sought within and across cases (Stake, 2006), so as not to misrepresent solitary findings as significant themes.

5 Findings

5.1 Overview

This study was designed to explore how making with and learning about IoT might contribute to global citizenship and social justice education at the elementary school level. Two research questions were developed to guide this study:

- How do students' understandings & perceptions of the Internet of Things evolve over the course of a week-long maker passion project?
- How might being immersed in an IoT-oriented passion project facilitate engagement with citizenship and/or a social justice mindset?

The results have been organized by research question, first exploring the development in participants' understandings and perceptions of IoT followed by an examination of the ways in which they demonstrated engagement with citizenship and social justice over the five-day camp. Each section begins with an overview of the major findings informed by the cross-case analysis of data from participant pool A, followed by a comprehensive analysis of three cases from participant pool B. Different cases have been presented for each research question given the variability in the quantity and strength of data collected from participants. Preference was given to cases with data that could be triangulated across multiple sources; as participants' voluntary engagement with the concepts under study varied outside of the pre-study questionnaire and post-study interviews, it was not possible to ensure uniform data collection from each participant. Consequently, the cases selected to illustrate each research question were those deemed the most methodologically complete and therefore most appropriate for inclusion.

5.2 Learning About the Internet of Things through Making

The first objective of this study was to explore how participants' understandings and perceptions of IoT evolved over the course of a week-long maker passion project. In general, the ChangeMakers March Break camp appeared to have a positive impact on participants' understandings of IoT. At the beginning of camp, most participants were unfamiliar or expressed only a rudimentary understanding of IoT or smart devices. In response to the pre-study questionnaire item that asked participants to indicate whether they had heard of IoT or smart homes and devices, two of the ten participants said "yes", seven said "maybe", and only one said "no". However, when asked to describe their understanding of these concepts, only three of the participants' answers reflected some level of comprehension or familiarity. The remaining seven responses were either incorrect (two) or a variation of "I don't know" (five). A summary of participants' pre-study descriptions of IoT have been presented in Table 5.1. As the camp progressed, participants began to demonstrate a developing understanding of the functionality and applications of IoT, including the role of sensors in networks of connected things, the ability of IoT to improve our quality of life through the monitoring and automation of daily tasks, and numerous examples of IoT systems. Participants also began to recognize IoT in their personal contexts, such as when Aileen shared an example from her home: "You could use Google [Assistant] and say, 'okay Google, turn the lights off.'"

Additional understanding emerged as participants engaged with the IoT-maker technology kits. For example, as Anisha followed a coding tutorial to create a light-level detection system with her micro:bit, she was able to explain that "it's going to read the light from the sensor." Despite the hesitance in her voice, she had begun to recognize the components at work in her rudimentary IoT creation: a sensor that detects the amount of light in a given area, a series of codes to convert this reading into a comprehensible result, and an LED screen to display the converted reading. After working with these technologies to construct their passion project prototypes, participants' understandings developed further. As Amalya initially conceptualized her texting-and-driving deterrent, she said, "I was [thinking] to use the micro:bit to sense it or something." However, as her prototype progressed, so too did her familiarity with IoT and the functionality of connected things, as indicated in a mid-week reflection: "Internet of Things are tools and technology that improves and helps us to make our lives much simpler with the help of the internet. The tool I am using for my project is a micro:bit. And the micro:bit is going to send an alarm to the phone through Bluetooth."

Table 5.1

Summary of Participants' Pre-Study Understandings of IoT

Heard of IoT?	Description of IoT
Yes	"Google."
	"I think it means that the internet is connected to every device."
Maybe	"I do not know."
	"I know nothing of it."
	"?????"
	"I don't know."
	"I never heard of 'Internet of Things'. I think a smart device means that it is an advanced piece of technology that can help you in your daily life. (Like Google Home or Amazon Echo)"
	"I think it means a web site that shows stuff for sale."
	"I know what smart phones and TVs are but I don't know what 'Internet of Things' are."
No	"I do not know."

Note. Responses coded as reflecting some degree of understanding or familiarity have been highlighted for visibility.

Similarly, while some of her ideated components were unavailable during the camp, Emily conceptualized a robot that could monitor the number and whereabouts of endangered species, integrating motion sensors to detect and track animal movement, a GPS system for location monitoring, and a camera with pattern recognition to accurately identify individual members of a species. Despite participants' growing familiarity with IoT components, their application of this knowledge was not always consistent. For example, while Emily was capable of identifying the components necessary for her passion project and articulating the ways in which they would work together as a network of things to inform "animal rangers", when asked to reflect on how her prototype utilized IoT, she wrote "can't be sure".

Following the five-day maker camp, eight of the ten participants had demonstrated some growth in their understanding of IoT from pre-study, and nine were able to provide real-world examples or articulate their perceptions of these technologies. A summary of participants' descriptions of IoT provided during their post-study interviews have been consolidated into Table 5.2. As participants' understandings developed, they also began to express their perceptions of IoT and its applications for society. The most common belief, communicated by six of the ten participants, was that IoT was useful for its ability to make our lives easier or more convenient. Amalya noted that IoT "helps us to do our everyday tasks easier" and is "helping everyone connect", while Derick expressed that IoT "will help the future". Despite its perceived utility, eight of the ten participants also expressed concerns associated with the security and privacy implications of IoT, including the possibility that hackers could expose personal data or damage entire networks of devices, which Isabelle explained could have dire consequences: "If, say, an assassin wanted a person dead that's in hospital attached to technology that's attached to the IoT, they could simply shut it down from anywhere and that person would die." Other identified drawbacks included the potential for IoT to make us lazy (Emily) and socially disconnected (Shaelyn), as well as economic barriers that prevent widespread use of the technology (Isabelle).

Table 5.2

Summary of Participants' Post-Study Understandings of IoT

Description of IoT	Improved from Pre-Study?
"You can make stuff that will help the future, but sometimes it won't. … sometimes it could hack your personal use."	Y
"I think [IoT] means that the internet has lots of things inside of it."	N
"… they're all connected. And different technologies are connected to homes, phones, computers, cars."	Y
"I understand [IoT] to be good for controlling. Closing doors and picking up groceries. … it would tell you what's out of stock in the fridge and what we need."	Y
"… smart home devices, like the smart home fridge that will notify you when you need to buy milk, eggs, etc."	Y
"I'm going to pass."	N
"My understanding is that it's many advanced technology devices that are connected to each other, to know you and help you."	Y
"It's pretty cool, because now … our home is basically being all controlled by our phone."	Y
"Technology that connects to the internet and makes our life easier. It helps us to do our everyday tasks easier … and improve our life, pretty much."	Y
"[It's] some device that… it's on your phone. That controls most of the things."	Y

5.2.1 Case Studies

The following three cases were selected to provide a holistic representation of the ways in which participants developed – or failed to develop – an understanding of IoT over the ChangeMakers March Break camp. Aaron and Luca demonstrated individual and collective growth in their understanding of IoT concepts and applications, despite their passion project prototype lacking these elements. Anisha and Derick's passion project was directly aligned with IoT, but their conceptual understandings rarely extended beyond the locus of their project. Finally, Arshad is presented as a negative case: his passion project was also directly aligned with IoT concepts, but he articulated little growth in understanding by the end of camp.

5.2.1.1 Aaron & Luca

> "It [works] with sensor waves and turns on automatically by itself. … let's pretend you left the fridge open. It actually has sensors and it puts it to your phone. That's the Internet of Things. It's all smart, it does it by itself. It's so cool."

Aaron and Luca each described themselves as frequent technology users, respectively identifying their favourite activities as coding and playing with the iPad. Of the several partnerships that were formed during the ChangeMakers March Break camp, Aaron and Luca were the sole pair without a pre-existing relationship. As each began to design their individual passion projects, camp facilitators discovered that both Aaron and Luca were incredibly passionate about soccer and were looking to prototype an invention to enhance soccer skills development. After a brief conversation, the pair were excited to combine their ideas and work collaboratively on a maker passion project designed to improve players' shots on goal through a soccer net augmented with shooting targets and automated ball return, as well as a robotic goalie that scaled to match the player's skill level.

Before the study began, neither Aaron nor Luca were familiar with IoT. Luca was the only participant to indicate that they were wholly unfamiliar with the concept, while Aaron thought that he may have heard of it before. However, when asked to describe IoT, Aaron wrote that "I think it means a web site that shows stuff for sale". This lack of understanding was also evident in their engagement with the IoT pre-learning activities and discussion on the second day of camp. One of the videos used to introduce IoT depicted a child sleeping through his alarm, after which his mother used an app on her phone to increase the alarm volume from another room in the house (Flanagan et al., 2014). As the child reluctantly leapt from his bed, most of the campers laughed, but Aaron looked around confused, asking "what's so funny?" While it is possible that his attention may have lapsed, he appeared to be engaged with the media up to that point and thus may not have understood the interconnectivity of the devices in the home that enabled the mother to disrupt her child's sleep. Towards the end of this pre-learning period, however, the pair began to demonstrate a developing understanding of the concepts underlying IoT. Contributing to a conversation about the role of sensors in IoT, Aaron made a connection to his personal experience, suggesting, "it's like when you walk in a room and then the lights turn on automatically." As the discussion concluded, Aaron sought to consolidate his understanding of the pre-learning activities, stating that "the Internet of Things is basically a smart house. It can predict everything you want before you even want it. And it makes your life better … it makes everything connected to your phone." This articulation of his developing understanding featured two of the most identified themes across participants: improved quality of life and the smartphone as a central control mechanism.

Collaboratively designing and constructing their maker passion project was another avenue through which Aaron and Luca became increasingly familiar with IoT. Following the third day of camp, Luca described the relation of their prototype to IoT:

> The robot could sense where the ball is going to be, and it could give opinions on people's shots. If the robot could sense where the shots are going, it could block more shots. As the kid gets better, the robot gets better too. It's like learning.

Given limited access to technological components, Aaron and Luca's passion project featured two servo motors – one representing the player, the other representing the automated goalie – that each rotated a plastic arm along a 90-degree path at a regular interval (Figure 5.1).

Figure 5.1

Aaron and Luca's Soccer Passion Project Prototype

However, as Luca explains, their design as intended would enable the robotic goalie to sense various information about the player's shooting capability and use this data to modify its goaltending to provide sufficient challenge for the player. The player would gradually learn to be more unpredictable in their play to bypass the automated goalie, and eventually transfer these skills to games against human players. While this excerpt highlights only one element of Aaron and Luca's IoT prototype, the description of the goalie's sensors and use of AI suggest a developing understanding of the concepts underlying IoT.

As the maker camp concluded, both Aaron and Luca demonstrated growth in their understanding of IoT. Luca emphasized the connectivity between objects and end-user smartphone applications, saying that "Internet of Things is like … it's on your phone, that controls most of the things." Aaron elaborated, explaining that:

> [IoT] is pretty cool, because now … our home is basically being all controlled by our phone. … Everything is a smart device. For example, your fridge could literally tell you what you need for shopping. … If you want a thing, it literally tells you on the app. That's why they're called smart devices.

Despite not using industry terminology to describe the processes at play, Aaron adequately communicates his understanding of objects being smart because they are capable of sensing information (e.g., what is in the fridge), acting on that information (e.g., comparing the fridge's current contents against a list of preferred groceries), and interfacing with end-user software (e.g., sending a notification to the user to purchase missing items).

In addition to their developing understanding of IoT's functionality, Aaron and Luca also demonstrated their thinking about potential security and privacy implications of networked things. During a discussion about data vulnerabilities resulting from IoT's use of cloud services, Aaron speculated,

> I was just thinking that when you put that [data] into the cloud, you could have some kind of little forcefield – like a shield – around it. Like a firewall around it while you're going into the cloud so no one can just hack it while it's in the air, free.

Although this discussion was prompted by a video on IoT security considerations (National Institute of Standards and Technology, 2018), the specific kind of intervention Aaron identifies was a product of his own critical engagement with the topic. The video and resulting discussion primarily focused on protecting IoT devices from infiltration, while Aaron proposed an additional need to protect the data being transmitted. Despite the technical inaccuracies in his suggestion (e.g., the role of a firewall, or the time data spend "in the air"), he had clearly begun to reconcile his understanding of IoT to the point of critical engagement and problem-solving. The theme of security considerations resurfaced in Aaron and Luca's post-study interview, where they each identified concerns related to hacking data and devices through the IoT: Luca mentioned smart cars and the ability for wireless unlocking and ignition signals to be interrupted, and Aaron suggested that an abundance of our personal data transmitted over IoT could be obtained by hacking our smartphones.

Apart from privacy concerns they described as "scary", Aaron and Luca expressed positive perceptions about IoT technology. Both participants felt it was "cool" and reflected on its ability to help us in our everyday lives. They also identified numerous applications for the technology, including securing your home from afar, maintaining a smart garden, reducing electricity consumption, driverless vehicles, and minimizing human casualties during international conflict. Although their passion project was one of the least integrated with IoT, opportunities to engage with IoT concepts through facilitated discussions and the maker technology kits appeared to facilitate an introductory understanding of its functionality, applications, and potential areas of concern.

5.2.1.2 Anisha & Derick

> "The Internet of Things is good because it helps the future, and it saves others' lives. … and it helps you with your house."

Anisha and Derick were cousins, opting to collaborate on their maker passion project given similar interests and pre-existing levels of comfort and rapport. Collectively, they brainstormed three potential project ideas before deciding upon a home security and alarm system with facial recognition. Derick explained that "it could help a lot of people that need a lot of security around their house", and Anisha identified issues with guns, violence, and the political climate as further inspiration. Despite their detailed concept and passion for the subject, Anisha and Derick were unable to complete their prototype as the technical complexity of their project required components, knowledge, and dedicated support that were unavailable during the ChangeMakers March Break camp.

The pair's pre-study questionnaire responses indicated little experience with IoT prior to beginning camp. Anisha said that she had "maybe" heard of it, but when asked to describe her understanding, simply wrote "I don't know." Derick responded "yes" to having heard of IoT, but defined it as "Google", suggesting that he, like Aaron, had erroneously interpreted the phrase as synonymous with the world wide web. Following the IoT pre-learning activities during the second day of camp, they each expressed a personal connection to smart technologies, identifying the presence of digital personal assistants (e.g., Google Assistant) and other smart devices in their homes. These initial understandings were further documented in their digital design journals, with Anisha explaining that "the Internet of Things … is like a smart house or a smart phone."

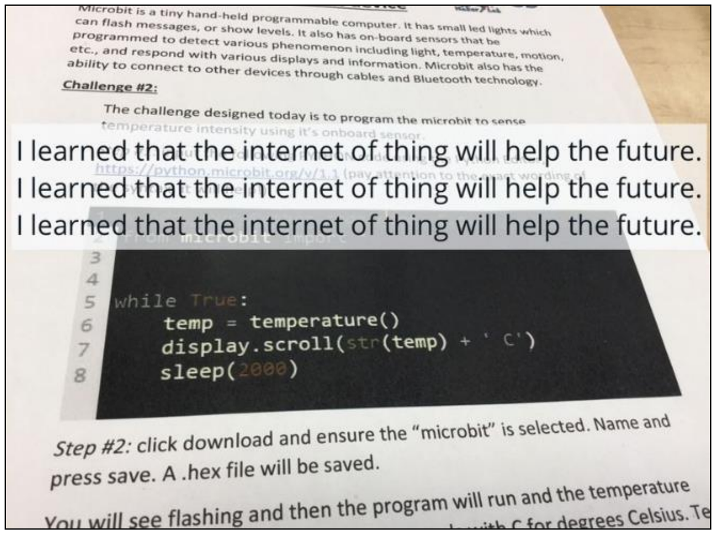
Although their contributions to camp discussions and entries in their digital design journal suggested a relatively limited understanding of IoT, Anisha and Derick each appeared to concretize their learning through engagement with the maker technology kits to produce their passion project. As they began to work through the design process, they identified three areas of interest and a potential solution for each. Two of their three proposed projects detailed concepts related to IoT, including motion and proximity sensors, location tracking, camera integration, and triggered alarm systems. For example, Anisha described their IoT prison security concept:

> To keep the prisoners from escaping jail, all of the prisoners can have a bracelet detector so when the prisoners are escaping, the police can find where the prisoners are, and it will set off an alarm when the prisoners pass the wall.

Their cognitive engagement with IoT concepts and components continued after making the final decision to design a home security system reliant on facial recognition technology. Reflecting on their final design, Anisha wrote "you take a picture of the people that will be in your house and then after [the system] will recognize their face. When the camera doesn't recognize a face, it'll take a picture and set off an alarm." Despite lacking the technical terminology, Anisha and Derick's passion project design reflected an understanding of how numerous IoT components could be integrated: a motion sensor that triggers a camera, a software application with AI to compare photos against an approved database, and an alarm system. The pair navigated multiple challenges over the week, including scaling down their prototype to match available technology and overcoming frustrations related to unstable Bluetooth connectivity in the micro:bit app, but they persisted through the development process with their project goals in mind.

Figure 5.2

Influence of Maker Technologies in IoT Learning



Note. Derick's digital design journal entry from day two repeats the phrase, "I learned that the internet of thing will help the future" over a photograph he took of the micro:bit coding instructions.

Upon the completion of the ChangeMakers camp, Anisha and Derick's post-study interview responses signified growth in different areas of IoT learning. Anisha expressed, "I learned what the Internet of Things is … and I learned how micro:bits could be used for music and plants and lights, and lots of other things." However, when asked to expand on what she learned about IoT, she encouraged her cousin Derick to respond first and eventually declined to answer. Anisha's choice to abstain was consistent with her behaviour throughout camp; she was often reluctant to contribute to group discussions unless she was completely confident in her response. This, in combination with her avoidant body language during the interview and surface-level understanding of IoT evident across camp activities and digital design journal entries implies a limited understanding of concepts underlying IoT. However, her identification of the micro:bit in relation to IoT reinforces the notion that making with the provided technology kits imparted a concrete understanding of the ways in which networked devices interact for both her and Derick (see: Figure 5.2).

Continuing Anisha's line of thought, Derick described his understanding of IoT as "you can make stuff that will help the future, but sometimes it won't." Like his cousin, Derick's understanding of IoT reflects a degree of agency: IoT is something you create – not just consume – to benefit your life. The second half of his response forefronts the security and privacy implications of IoT, another domain that Derick resonated with during camp. He goes on to explain that IoT, while good, can be "scary … because people could hack into your things … and they can hack into your security." Using their passion project as an example, he continues, "if you have the thing that's our project, if they can hack into your computer then they'll try to put their face on the recognition [system], and then it'll know it and it'll let them in." In this excerpt, Derick went beyond simply recalling the discussions and pre-learning activities on IoT's security vulnerabilities, applying this knowledge to analyze the ways in which their proposed home security system could be infiltrated. Reiterating his concerns, Derick expressed that, given the opportunity to continue working on their passion project, he "would put some firewalls. … To help its security. To make it secure from hackers." Over the course of the ChangeMakers camp, Derick and Anisha mainly spoke about IoT in generalities, using phrases like "smart", "cool", and "future" in their descriptions. However, in discussions or reflections about their maker passion project, they were able to identify specific IoT components, articulate their functionality, and integrate concepts from the pre-learning activities and discussions, highlighting the influential role of the design and making process in their IoT engagement and learning.

Apart from these security and privacy concerns, Anisha and Derick both thought that IoT could be useful. Derick explained that it can "help you know when something's happening in your house, or it can sense your emotions and automatically [do] what you want, before you know you want it." While IoT may not be able to sense your thoughts and emotions per se, Derick may have been referring to the introductory videos (Flanagan et al., 2014; Fw:Thinking, 2013) in which smart home systems responded to environmental data and programmed routines to modify the home's lighting, temperature, ambient music, and other devices in ways that appeared to anticipate the user's needs. Citing more specific examples, Anisha thought that IoT was cool because "it can do lots of cool stuff, like turn off the lights or remind me to close the fridge." Despite these concrete examples and their self-declared exposure to smart devices in their own homes, both Derick and Anisha frequently referred to IoT as being relevant for the future.

5.2.1.3 Arshad

> "I'm very interested in what would happen to us and the Earth after a few million years. Humans will need a new home because Earth will be going through a new ice age, and volcanoes will erupt … and asteroids will hit Earth. … humans will need a new home and the first two planets are very hot, Mercury and Venus. Mars is just beside Earth, and it has ice water. It has water, but it's frozen, so scientists think humans could live on Mars."

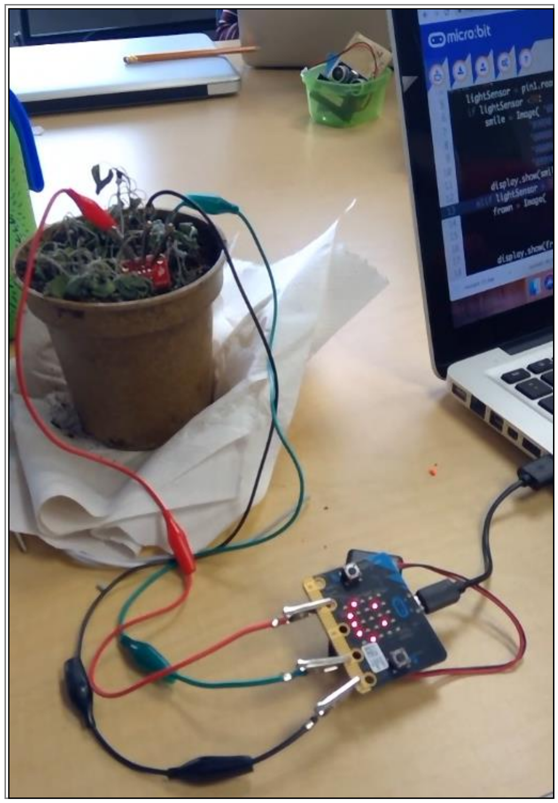
Arshad was ten years old and used technology – primarily mobile apps – only occasionally in his spare time. Although he was accompanied to the ChangeMakers March Break camp by his seven-year-old brother, he opted to pursue an independent maker passion project: a smart garden system to support eventual human life on Mars. His final prototype included a micro:bit with an external moisture sensor that he coded in Python, and a 3D-printed scale model of his proposed garden housing. Arshad was selected for inclusion in this study's findings as a negative case; despite his passion project being an archetypal representation of smart technology and his personal comfort navigating novel maker technologies, he appeared to internalize very little about IoT by the end of camp.

Based on his responses to the pre-study questionnaire, Arshad was one of the few participants who entered the camp with some understanding of IoT. He indicated that he had heard of it before and explained that he thought “it means that the internet is connected to every device.” While not entirely accurate, he appeared to understand concepts related to interconnectivity and having ubiquitous access to objects and devices by means of the internet. However, unlike most of the other participants, Arshad’s responses did not develop in complexity as camp progressed, and in some cases reflected a regression in understanding from pre-study. Following the second day, during which IoT concepts were formally introduced through informative videos, group discussions, and exploring the IoT maker technology kits, participants were asked to describe what they learned. Rather than recounting the smart technologies evident in the videos, reflecting on his experiences making with the IoT technology kits, or recalling any of the conversations surrounding IoT, Arshad simply said, “I discovered about the Internet of Things that it’s useful and fun for kids and grown-ups.” While his conceptual understanding cannot be evaluated from this excerpt, subsequent reflections and post-study interview responses highlight Arshad’s lack of connection with IoT. Halfway through camp, it became evident that he had conflated IoT with the internet more broadly, explaining that “I think the Internet of Things is good and bad, because some things on the internet, they can ask like, ‘what’s your name’, ‘what’s your phone number’.” Despite his astute observations about internet privacy, Arshad’s responses were not relevant to IoT, suggesting that perhaps he was not as familiar as his pre-study responses implied. This conflation continued through the end of camp when he explained, “I think [IoT] means that the internet has lots of things inside of it.” He also described IoT as useful, because “you can play educational games on it,” further signposting his erroneous homogenization of the two concepts.

Although Arshad was unable to conceptualize IoT throughout most of the ChangeMakers camp, he did identify with the various components as he worked on his smart garden passion project. As he tested his Python-coded micro:bit with a freshly watered plant (pictured in Figure 5.3), he explained the functionality of his passion project: “when you put this sensor into [the soil], it senses how much water is inside the plant.”

Figure 5.3

Arshad’s Smart Garden for Mars Passion Project Protype



Continuing, he described how the sensor communicated with the user via the micro:bit, displaying a smiling face when the soil’s water level is acceptable, and a frowning face when the plant needs watering. While Arshad’s use of IoT vocabulary was limited to sensors, he appeared to understand how the components work together in his passion project, and how they would benefit humanity in the event of a planetary relocation. The explanations offered in relation to his passion project imply a modicum of IoT knowledge mediated by the design and making process; however, his inability to provide a definition or examples of IoT beyond this context suggests that the overall program may have been ineffective for Arshad's development of conceptual understanding.

5.3 Engaging in Citizenship & Social Justice

This study also sought to explore how participants engaged in citizenship and socially conscious activity through passion-based making with IoT. To inspire critical thinking and engagement with social issues, the ChangeMaker motif was embedded throughout the five-day camp, emphasizing themes of empathy, community, collaboration, citizenship, and agency across the community-building exercises, pre-learning activities, spontaneous conversations, and reflective digital design journal entries. All of the participants identified with social issues of varying magnitude, ranging from concerns with a personal or community locus to broader issues affecting substantial proportions of society. Over the course of the camp, eight of the ten participants demonstrated a connection with global issues, such as those outlined in the *2030 Agenda for Sustainable Development* (United Nations, 2015). Specific concerns included safety and security, accessibility, protection of endangered species, health and medicine, animal welfare, agriculture, and access to food and water. However, there were three issues that arose consistently during conversations about being a ChangeMaker: bullying, climate change, and poverty. All ten participants engaged with at least one of these topics over the five days, from voicing concerns to proposing novel solutions. Bullying struck a personal note for half of the participants who had either experienced it themselves or witnessed a friend or classmate being bullied. Aileen even reflected on her experiences as the victim of bullying partially inspiring her smart mood bracelet passion project, while Aaron cited the Pink Shirt Day initiative (CKNW Kids' Fund, n.d.) as evidence that relatively minor actions can have a significant impact on widespread social issues. Climate change and sustainability efforts were identified by over two-thirds of the participants, many of whom expressed a desire to affect change in this area. Anisha reflected broadly on the potential for IoT to be used in addressing climate issues, while Aileen questioned the environmental impact of the maker technologies employed during camp, especially the filament in the Maker Lab's handheld and tabletop 3D printers. Isabelle repeatedly emphasized the importance of sustainability initiatives, declaring several times over camp that "the Earth is dying"; however, Arshad felt that the Earth would eventually become uninhabitable regardless of our efforts and designed his passion project around supporting our existence on another planet. Finally, while poverty was addressed by only two of the participants, they identified that it was both a local and global issue, and Aileen suggested that technology could be leveraged to support underserved communities: "Robots and stuff that could make houses for homeless people. We could make more gardens and farms for food and coats. … We need more food and coats for people who don't have [them]." The prominence of these three issues is unsurprising: anti-bullying initiatives are common in elementary schools, climate change is widely discussed throughout society, and the geographical area in which the camp was conducted was known for high levels of poverty.

Despite their understanding of concerns related to citizenship and social justice, most of the participants were unable to identify with these terms at either the pre- or post-study condition. In response to the pre-study questionnaire item that asked whether participants were familiar with the terms "social justice" or "citizenship", only two of the ten said "yes", five said "maybe", and three said "no". However, only Shaelyn was able to produce an appropriate albeit broad definition, explaining that "I think these terms might mean being a proper citizen that helps society and your community." Participants' pre-study responses have been summarized in Table 5.3 below. During the post-study interviews, participants were asked to describe their understanding of social justice following their engagement with various social issues over the course of the camp. Having offered insightful definitions at pre-study, it came as no surprise that both Shaelyn and Isabelle demonstrated an understanding of the term, with Isabelle explaining that "social justice, to me, means people from the community – not that it's their job – may bring peace or stop some sort of fighting among themselves." The remaining eight participants were evenly divided between uncertainty or simply providing an inaccurate description.

Table 5.3

Summary of Participants' Pre-Study Understandings of Social Justice and Citizenship

Heard of Concepts?	Participant	Description of Social Justice and/or Citizenship
Yes	Aileen	"People."
	Shaelyn	"I think these terms might mean being a proper citizen that helps society and your community."
Maybe	Aaron	"A type of science."
	Amalya	"I think social justice means social rights."
	Derick	"I do not know."
	Emily	"I don't know?"
	Isabelle	"Justice that is caused by normal people."
No	Anisha	"I think social justice means helping someone with technology."
	Arshad	"I think the term 'global justice' means the world has justice for everyone and I think 'global citizenship' means that all the world has citizenship."
	Luca	"I do not know."

Note. Responses coded as reflecting some degree of understanding or familiarity have been highlighted for visibility.

However, when these participants were asked what it meant to be a ChangeMaker, all but one expressed an understanding in line with the ideals of social justice. Themes of changing the world, helping others, and innovation for good were evident in participants' responses, such as Derick who explained "we're going to create stuff for the future and we're setting a better [standard] for the Earth." While the ChangeMakers phrase was used to refer to campers throughout the week, it was contextualized by one of the facilitators during the social justice pre-learning activities on day three:

> The reason that we chose ChangeMakers as our theme this year is because … you guys are the ones that can make this change. If you recognize these problems in society and start to learn different ways to solve the problems. Our generation, we've tried to think of things … we don't know what else to do. So you guys are the ones that are coming up and you can really make a change.

While most participants may not have identified with the "social justice" terminology, their contributions to camp activities and discussions, as well as their resonation with the "ChangeMaker" phrase, highlight the ways in which they engaged in socially conscious activity during camp.

In addition to exploring issues related to social justice and citizenship through both directed and spontaneous group discussions, participants were also motivated to apply a socially conscious lens to their maker passion projects. Five of the ten participants entered camp with a positive sense of self-efficacy regarding their ability to create something that would improve others' lives, and four were neutral. One participant (Isabelle) abstained from answering this question at pre-study but was also the only one to answer "no" in response to being asked whether she felt she could make something that would improve her own life. However, her self-doubt appeared to stem not from a lack of motivation to help others but a lack of experience with maker technologies. She explained, "I can only design on Tinkercad," and suggested that she could only create something to benefit someone else "if it's a keychain, then yes." Interestingly, participants' self-efficacy around making for good appeared to be independent from any prior experience: only two of the ten participants indicated that they had created something in the past with the intention of benefiting someone other than themselves, while four were unsure and the remaining four had not. As camp progressed, most of the participants continued to position themselves as agents of producing change for social good through their IoT maker passion projects. Amalya, while beginning to design and construct her project prototype, spontaneously uttered “I’m just going to help change the world somehow” to her tablemates. Others described more specifically how their passion projects would benefit others, like Anisha and Derick who described how their home security project could enhance personal safety:

> When someone comes into your house and robs something, or when they try to do something bad, the home security thing that we made will help stop that. … our creation will help civilization because no bad people or robbers will break into your house.

Similarly, while Aileen’s motivation for her project was primarily personal, she also felt that it could help others communicate:

> It can be hard to tell people what you’re feeling so it’s easier to just show it to them. … other people could use [my bracelet] to say their mood, like if they get sick and they start losing their voice. … I think it would help people.

Participants also began to identify social justice and citizenship applications for IoT during their explorations of the provided maker technology kits, particularly for monitoring energy consumption, promoting conservation, and to enhance personal safety and security measures.

5.3.1 Case Studies

The three cases presented in this section are illustrative of the diverse ways in which participants engaged with concepts related to social justice and citizenship throughout the ChangeMakers March Break camp. Amalya repeatedly expressed her desire to have a positive impact on the world, designing her project around the endemic problem of texting and driving which she had been passionate about since it was introduced through a school project. Shaelyn demonstrated a conscious understanding of social justice and citizenship issues, but ultimately pursued a narrower passion project aimed at reducing the negative impacts of technology. Finally, Emily was inspired by a love of animals that she shared with family and friends and sought to protect endangered species with a robot that could track and monitor the health of threatened animal populations.

5.3.1.1 Amalya

> "If I was able to design my own civilization, I would include the major basic needs that help us to be happy and healthy in our everyday life. … I will also invent new and helpful technologies that will make our everyday life easier."

Amalya was one of the camp's eldest participants, aged 13 years. She described herself as an avid technology user, accessing her phone, personal computer, and television every single day. Coming into the camp, Amalya believed that she was capable of using these skills to improve her life and the lives of others, writing "I believe that I can create something with technology that could contribute to a better/easier/more fun life because everything we do now is with the help of technology. Technology [has] impacted on our life so much." The pervasiveness of technology became the inspiration behind her maker passion project: a texting-and-driving deterrent made with a micro:bit and custom 3D-printed holder.

As camp began, Amalya was one of a few campers to demonstrate some familiarity with the term social justice. On her pre-study questionnaire, she explained, "I think social justice means social rights." While her response was incomplete, she did appear to understand that social justice and citizenship were related to rights and opportunities but did not yet understand the specifics of that relationship. Like most participants, however, her understanding of the phrase did not improve following the five-day camp; however, she did explain that she thought being a ChangeMaker meant that "we're the future of this population. ChangeMakers. And we can actually change stuff coming up."

Despite lacking familiarity with the terms, Amalya was aware of and evidently concerned about a range of social justice and citizenship issues. Following the second day of camp, she recorded the following in her digital design journal:

> There is a lot of bad stuff happening to our Earth. For example climate change, global warming, pollution and etc. We live in this Earth, we should learn, understand, and take care of our Earth. We should try to prevent or help make this Earth a better place.

In addition to environmental sustainability, she also reflected on issues of public health, access to food and water, and applications of technology that could make everyday tasks easier to complete. Thinking broadly about the impact she could have on the world, Amalya's passion project was inspired by a school art assignment in which she depicted the compelling nature of technology, particularly smartphones. She highlighted the disruptive effect that personal devices can have on education, as well as the staggering impact smartphones have had on road safety. Explaining the motivation behind her IoT maker passion project, Amalya said that "statistics show that more people die from texting and driving than drinking and driving. And for me, that was so crazy!" Positioning herself in relation to this issue, she reflected, "I want to prevent texting and driving because people who text and drive are not only putting their lives in danger, but also putting other people's lives in danger on the road." While distracted driving may not be considered a global issue worthy of inclusion in the SDGs (United Nations, 2015), its implications for personal health and safety have rendered it a major North American concern (Canadian Automobile Association, n.d.). Amalya's dedication to this issue represented her orientation towards local citizenship, namely her active participation in investigating pertinent issues and demonstrating innovative problem solving (Ontario Ministry of Education, 2018).

Beyond mere identification with related values and ideals, Amalya embodied the ChangeMaker ethos through work on her maker passion project. As she developed the design of her texting-and-driving deterrent on the third day of camp, she appeared to be happy with her progress, smiling and saying aloud, "I want to change the world, let's go!" Surprised by her unprompted utterance, one of the facilitators asked if she had said that, and she laughed and repeated, "yeah, I'm just going to help change the world somehow." In contrast with several participants, she continued to position herself – rather than the technology – as the active agent in making societal change through her project. Phrases such as "I decided to make something that will prevent people from texting or checking their phone while driving", "I will use the micro:bit to sense it", and "I want to prevent texting and driving" were pervasive throughout her end-of-day reflections. Furthermore, she appeared to be cognizant of the potential impact she could have on the world, stating, "I believe that my creation could help improve other people's lives" and "my project can prevent road accidents". All of these statements originate from Amalya as the agent of change: she decided to pursue the project, she leveraged the technology to suit her purpose, and her creation would benefit the world by reducing accidents related to distracted driving. She punctuated her ChangeMaker orientation during the interview, where she explained, "that's why I wanted to help change the world, somehow. To help change, or save, lives. I always like to help people, so I was trying to find out: how can my actions help other people?" While Amalya might have had an altruistic perspective prior to camp, the opportunity to design and make something to benefit society not only helped her to realize that position, but also to reinforce her sense of self-efficacy as a ChangeMaker.

5.3.1.2 Shaelyn

> "My project … could help everyone who uses technology on a daily basis, but I think it would help kids the most. Since tech is becoming more common amongst children, more and more children strain their eyes from staring at a screen for too long. My project could prevent that and make the latest common thing safe."

Shaelyn was 12 years old with a passion for technology. While not an everyday user, she made frequent use of technology – particularly her laptop – for a variety of purposes. Despite her interest and experience, Shaelyn was initially undecided about her ability to create technological artifacts that could improve others' lives. However, she explained that, with her entrepreneurial disposition, she probably could: "I think I can because I like trying to think of different fun products and I think one day I can make a product that can help others." Like Amalya, Shaelyn's passion project was designed to offset some of the negative impact of our reliance on technology by reminding users to protect their vision from prolonged screen use. She designed an Arduino-based alarm and reminder system that would integrate with personal devices and alert the user to practice good visual hygiene.

On her pre-study questionnaire, Shaelyn expressed the most complete understanding of social justice and citizenship concepts out of all participants. She wrote, "I think these terms might mean … being a proper citizen that helps society and your community." She exemplified this understanding in her day one reflection that asked her to design a hypothetical civilization, in which she wrote about universal access to food and water, diverse options for education, plentiful health care with innovative tools for illness detection and monitoring, autonomous and eco-friendly alternatives for transportation, virtual reality solutions to promote active living, and ample recreation services "so people can have fun too."

Figure 5.4

Shaelyn's Ideal Civilization Design Reflection

If I wanted to create a civilization, I would want to add easy access to basic necessities like food and water. There would be access to nutritious foods so everyone can live a healthy happy life. I would also add many buildings for entertainment(like malls, cafes amusement parks, etc.) so people can have fun too. There would also be many hospitals, doctor clinics, and more so everyone can get well when they are ill. Obviously education is important, so i would add online school so you can learn at the comfort of your home. There would be a VR attachment that would simulate a gym or the outdoors so you can get exercise and reminders to get off the online system to socialize and get fresh air.

For technology, I would want to add transportation that runs on greenhouse gases, so it is Eco-friendly and produces less pollution. Hovering self-driving cars would be cool, hoverboards that actually hover, an Eco-friendly jet pack to fly with, and teleportation would be the things I add to make transportation easier. I would also want a scanner that can instantly heal you if you have a severe illness so everyone can live a good life. Overall, that's what I would want to add.

Her full response, pictured in Figure 5.4, includes numerous aspects related to both local and global citizenship, as well as social justice. Shaelyn continued to demonstrate her awareness of these issues and their significance throughout camp, including during her interview where she expressed a desire to have focused her passion project on a more impactful societal problem:

> It's not really a big project that could help society, it's just like a notification. But I think in that situation, where I had all the money, all the resources, I'd do something else to help the world … pollution and climate change, and global warming. If I had infinite coding and infinite technology, I could do something that could not take our problems away but reduce the amount of greenhouse gases in the atmosphere and use that to produce something useful. … Take a problem and make it useful.

Despite positioning her vision protection prototype as beneficial for society given the prevalence of technology across all sectors of our lives, she recognized that not only does humanity face more significant threats to its safety and security, but also that she was capable of creating something that could have an even more substantial impact on the world. Given her comparatively developed understanding of social justice and citizenship at pre-study, Shaelyn's articulated definitions of these concepts reflected little change upon the camp's conclusion. After the week of hands-on engagement with various social issues, she explained, "I think social justice means … doing something right or doing something for the good of it. … Doing the right things and bringing out justice in society." Extending her understanding from before the beginning of camp, Shaelyn highlights social justice as an active process in which citizens take matters into their own hands to create just conditions for the benefit of all.

Although her definitions of social justice and citizenship reflected only marginal development, Shaelyn engaged with issues of local and global significance from the perspective of a ChangeMaker. In her second day reflection, she positioned herself in relation to the social issues that were discussed that day: "these problems are important to me because many people in the world experience these problems, and even people close to me. … Making these inventions could help many people in the world." Reflecting on some of the ideas she and her fellow campers had shared for using IoT and other advanced technologies to resolve social justice concerns, she identified the personal relevance of these issues and positioned herself as capable of making an impact. Shaelyn maintained this perspective through the development of her passion project, creating a technological solution designed to compel users into complying with established guidelines for reducing digital eye strain (Nall, 2018). After troubleshooting her design with a facilitator, she decided that a timed notification would be too easily ignored; instead, she said, "I want it to be really annoying. Not really annoying, but something that'll make you [look away]. So Arduino, possibly the bright white lightbulbs, telling them to get off." Working through the design process to evaluate and subsequently iterate on her maker project enabled Shaelyn to integrate her understanding of the Arduino components into a prototype that she felt would be most effective, taking an active role in targeting the growing eye strain problem she had identified. As the week progressed, Shaelyn continued to situate her project work as influential and meaningful. After the third day, she explained, "I think my project can improve other people's lives because more people in the modern world use devices or technology … my invention will remind people to take a break from staring at the screen for so long." The following day, she identified her project as being particularly influential for children, reducing the impact of extended screen time on their developing vision. In each of these excerpts, Shaelyn positioned herself and her efforts as having a substantial impact on this issue, embodying the role of ChangeMaker as she actively applied her efforts to the resolution of an identified concern.

Shaelyn also channeled both her passion for technology and her desire to innovate into identifying novel applications of technology for resolving issues of citizenship and social justice. Following participants' introduction to IoT and the related maker technology kits, she reflected on several opportunities that were raised during the day's discussion, including cameras with motion detection or facial recognition to improve home safety and gardens with automated monitoring and watering systems to make food more readily available. She also offered a variety of original applications, such as food and water monitoring systems for developing nations and technological simulations for navigating difficult scenarios, like bullying. Shaelyn's passion project was also anchored in technology; as she explained, "I chose my project because I am very passionate about programming and technology. A project that involves programming a device that can improve the experience of using technology would be perfect to work on." Given the current demand for digital literacies, global competencies, and social-emotional skills in education (CASEL, 2013; Ontario Ministry of Education, 2016), Shaelyn's experiences in the ChangeMakers March Break camp suggest that opportunities for critical making with advanced technologies could contribute to the development of citizens who demonstrate proficiency in all three domains.

5.3.1.3 Emily

> "My brother likes animals, and same with me. I wanted to ask him what is his least favourite animal, and he says, 'I don't have one, I love all animals.' And I thought about it, and that is true even though I hate spiders. And I was like, 'why don't I make a thing for endangered animals?' because some of them are going to be extinct. … I wanted to know how to help them, and not let them go extinct."

Emily was nine years old and brought her passion for technology to the ChangeMakers March Break camp. Her father was an engineer and shared with Emily a sense of curiosity and desire to understand how things work. In contrast with the previous cases, she was reserved with her self-efficacious beliefs regarding her ability to make something that would improve her life or the lives of others, answering only "maybe" without further elaboration on the pre-study questionnaire. Emily derived inspiration for her IoT maker passion project from a love of animals that she shared with her brother and a close friend. Recognizing the plight of endangered species and the challenges inherent to monitoring their population, she designed an autonomous robot intended to collect and share data with local conservation officials.

Like most participants, Emily demonstrated little understanding of social justice or citizenship prior to camp. When asked on the pre-study questionnaire if she had heard of either concept, she indicated “maybe”, but when invited to describe her understanding, simply wrote “I don’t know?” Despite her contributions to camp discussions and engagement with various social issues over the week, she was still unable to ascribe a definition to the term “social justice” at post-study. However, when asked what it meant to be a ChangeMaker, Emily offered, “we might change the world, or maybe change a thing in someone’s life … in some people’s life.” Emily went on to indicate that she thought being a ChangeMaker was important “to help [people], not make things worse. Unless you fail, because failure is okay, but you need to learn from your mistakes.” She had experienced numerous setbacks in the development of her passion project prototype over the week which translated into an ongoing exercise in perseverance, a common theme in maker cultures and mindsets. After multiple iterations of her tiger model failed to 3D print, one of the camp facilitators urged her to celebrate the attempts and analyze what might have failed so that she could try again. This idea, borrowed from design (Psenka et al., 2017; R. C. Smith et al., 2015) and making (Blikstein, 2013; J. A. Marshall & Harron, 2018; Martin, 2015), became integrated into her understanding of being a ChangeMaker; that your attempts to help other people might not always succeed, but you can learn from them and make another attempt.

Given Emily’s understanding of social justice from an agentic perspective, her positioning of self as a ChangeMaker through work on her endangered species passion project came as no surprise. In describing her creation, she emphasized her involvement and ownership of the project and its subsequent impact on her target issue:

> My tracker will tell me where the animal is and what it is doing, and my camera will take a picture of the animal we are wanting to know how many are there. You might think it will take the same picture over and over again, but my camera will be knowing if it had already taken a photo of it.

Not only does Emily speak to the integration of sophisticated technologies (e.g., AI) in her project, she also centralizes herself in their development, highlighting her role as a ChangeMaker through the design and construction of a prototype intended to address a significant global issue. This positioning is also evident in the opening quote for Emily's case, which she offered during her post-study interview. When asked about her motivations behind her passion project, she confidently explained that, because she, her brother, and her friend all liked animals, "I was like, 'why don't I make a thing for endangered animals, because some of them are going to go extinct.' … I wanted to know how to help them, and not let them go extinct." Although the issues underlying species endangerment and extinction are vast and complex, Emily was undeterred; she identified a problem that she was passionate about and simply set out to resolve it. While she sought feedback and assistance with the development of her project from camp facilitators and volunteers, the ideas and implementation were hers; she was a ChangeMaker.

Despite Emily's enthusiastic participation in camp activities and discussions surrounding issues of social justice and citizenship, her contributions were limited to a few choice issues, namely agriculture, autonomous vehicles, enhancing prosthetic limbs with smart technology, and bullying. Apart from these, she was most vocal about her love for animals and her desire to help prevent endangered species from extinction. Her passion for this global issue was inspired by a family connection, as she expressed to one of the camp volunteers: "I chose this theme because my brother likes animals, and there are lots of animals in danger." After designing the base robot using the micro:bit-powered k8 robotics kit (InkSmith, n.d.-a) as a foundation, she began to consider the impact her invention might have on the animals it was designed to track. She explains, "I know what k8 could carry. Since she has to follow animals, she has to wear some disguises like leaves, rocks…" These musings reflected deep engagement with her chosen issue; beyond designing the technical specifications of her passion project, Emily recognized that a bright purple robot might do more harm than good in a natural environment and integrated elements of camouflage so as not to interfere with the animals' natural behaviour. She also leveraged her passion for and understanding of technology to design components specifically for the issue of tracking endangered species. Facial recognition technology was discussed at length during camp for its relation to Anisha and Derick's home security passion project, as well as in IoT security systems more generally. While Emily was uninterested in recognizing faces, she identified an opportunity to modify this technology for pattern recognition:

> My GPS tracker would let us know where the animal is. … The second part is my camera. My camera's going to take pictures, and I also want it to … know how many are left. … It'll have pattern recognition. For example, like the tiger. … every tiger has a different pattern, like a slightly different little pattern, so that's how [it] will recognize them.

While several of the components included in her design were inaccessible during the ChangeMakers March Break camp, Emily continued to reference them and their role in her prototype. She demonstrated an awareness of both IoT and AI technology, and how they could be integrated to successfully monitor endangered animal populations, reflecting deep engagement not only with the technology, but with the issue itself.

5.4 Summary of Findings

This investigation into participants' engagement with citizenship and social justice through passion-based making with IoT revealed a number of common findings relevant to future research and educational applications. These have been organized into subsections based on research focus.

5.4.1 Learning About IoT through Making

1. Prior to the ChangeMakers March Break camp, most participants were unfamiliar with IoT.

2. By the end of camp, most participants had demonstrated some development in their understanding of IoT from pre-study, notably the interconnectivity of devices and the role of a central device or app for monitoring and control.

3. After participants were given the opportunity to explore the IoT maker kits and apply them to their passion projects, they demonstrated confidence and self-efficacy regarding their ability to create impactful projects with advanced technologies.

4. As participants' understandings of IoT developed, their most salient observation was that the technology was "cool" or "useful" because it could ease the burden of everyday tasks.

5. Most participants shared concerns related to privacy and the security of IoT systems, discussing the potential for devices to be hacked and the need to protect both the data being transmitted and the affected devices.

6. By the end of camp, nearly all participants could provide real-world examples of IoT, including numerous original applications that had not been discussed during the week.

5.4.2 Engagement with Citizenship & Social Justice

1. Most participants did not understand the terms "citizenship" and "social justice" at the outset of camp.

2. Despite being unfamiliar with the terms as provided, most participants demonstrated an awareness of significant issues related to social justice and citizenship, with climate change, sustainability, poverty, and bullying being the most commonly identified.

3. When given a choice in the design of their passion projects, participants were split in terms of the scope of their target issue: half elected to pursue a

personal or smaller-scale concern (e.g., soccer skills development, communication skills) while the other half targeted more traditional, large-scale issues (e.g., texting and driving, personal safety).

4. After participants explored the IoT maker technology kits, they began to identify applications of advanced technologies for producing societal change.

5. By the end of camp, most participants remained unable to define the terms "social justice" or "citizenship"; however, the majority developed an agentic understanding of these concepts encapsulated by the "ChangeMaker" label.

6. Throughout camp, most participants positioned themselves as ChangeMakers, articulating that they were capable of changing the world and identifying specific ways in which they could affect positive change in society.

6 Discussion

6.1 Overview

The purpose of this study was to explore how learning about and making with IoT might facilitate engagement with citizenship and social justice at the elementary school level. Recent emphasis on the development of digital literacies and social consciousness across K-12 education (Ontario Ministry of Education, 2016) necessitates the identification of effective teaching and learning practices to engage students in these domains. Given the need for tools that facilitate active engagement with citizenship and social justice (Hackman, 2005; Harshman & Augustine, 2013), as well as the emergent and influential role of IoT in society (Atzori et al., 2010; Rainie & Anderson, 2017), this research sought to investigate the impact of combining these foci into a singular educational experience mediated by passion-based making. The study was guided by the following research questions:

- How do students' understandings & perceptions of the Internet of Things evolve over the course of a week-long maker passion project?
- How might being immersed in an IoT-oriented passion project facilitate engagement with citizenship and/or a social justice mindset?

Analysis of the data revealed several promising findings. Most participants demonstrated positive, albeit modest, development in their understanding of IoT over the course of the ChangeMakers March Break camp. Furthermore, participants engaged with concerns related to citizenship and social justice during various camp activities, including the design and development of maker projects inspired by personally relevant issues. Complete study results are available in Chapter 5.

Naturally, the findings presented in this thesis are not intended to be generalized and applied broadly to elementary school populations. Constructivist research endeavours to illuminate the subjective and varied understandings individuals form about their experiences, which are heavily influenced by the context in which those experiences took place (Creswell, 2013; Harrison et al., 2017; Patton, 2015). The conditions of this study afforded substantial flexibility in comparison to the typical classroom and therefore cannot be considered analogous to formal education. Additional limitations of the research have been explored in Section 6.5, followed by recommendations for future research to enhance the applicability of similar findings to formal schooling (6.6). The bulk of this chapter analyzes the results in greater depth and situates them in relation to existing literature on making with and learning about IoT (6.2) and educational engagement with concepts related to citizenship and social justice (6.3). Finally, the educational implications of this research will be summarized in Section 6.4.

6.2 Making with & Learning about IoT

Among the numerous goals of formal schooling, from the compulsory levels (i.e., Kindergarten to Grade 12) through post-secondary education, is the directive to prepare graduates not only for the workforce, but also to participate meaningfully in society (Aldowah et al., 2017; Ontario Ministry of Education, 2016). In response to ongoing technological advancements and the pervasive integration of technology throughout all sectors of our lives, educational institutions have amended their curriculum documents to reflect the demand for digital literacies and competencies, such as the recent inclusion of coding into the Ontario mathematics curriculum for Grades 1 to 8 (Ontario Ministry of Education, 2020). More commonly, advanced technologies become integrated as tools with which to explore existing curricular objectives, as has been the case with augmented reality (AR; e.g., Yilmaz & Goktas, 2017), virtual reality (VR; e.g., Scoville et al., 2014), and 3D printing (e.g., Nemorin & Selwyn, 2017). Given the current prevalence of IoT throughout society (Freeman et al., 2017; Rainie & Anderson, 2017), as well as its predicted growth rate (Ronen et al., 2017), it is important for students to be granted the opportunity to explore the design, development, and societal impact of these networked systems (J. Chin & Callaghan, 2013; Kortuem et al., 2013; Selinger et al., 2013; Voas & Laplante, 2017).

While IoT has begun to see curricular integration at the post-secondary level (e.g., Akiyama et al., 2017; Ali, 2015; Babson College, n.d.; Koo, 2015; Kortuem et al., 2013; Raikar et al., 2016), similar offerings in elementary and secondary school are rare (e.g., Charlton & Avramides, 2016; Davis, 2017; Maia & Filho, 2018). However, previous literature has suggested that introducing students to IoT through multidisciplinary education – as opposed to being siloed in computer science and engineering faculties – can redefine the technology as participatory, empowering students to become producers, rather than just consumers, of sophisticated technologies (Akiyama et al., 2017; Burd et al., 2018). To explore what this might look like at the elementary school level, this study's first research objective was to investigate how students' understandings of IoT were influenced by their engagement in a week-long maker passion project using the technology. Three major themes emerged in the findings: (a) development in their general understandings and perceptions of IoT from pre- to post-study; (b) the effects of making with IoT on their developing understandings; and (c) concerns regarding the security and privacy implications of IoT.

6.2.1 Development in Understanding of IoT

To satisfy the growing demand for graduates capable of working with new and emerging technologies like IoT (Aldowah et al., 2017), students must develop not only a technical skillset (J. Chin & Callaghan, 2013; Kortuem et al., 2013), but also a conceptual understanding of the fundamental components and their role in society (Selinger et al., 2013). These learning outcomes have been increasingly integrated into post-secondary engineering and computer science curricula (Burd et al., 2018), but reports on similar offerings in elementary and secondary school are scarce. In the present study, campers were introduced to IoT through a range of activities, including brief illustrative videos, group discussions, real-world examples, and maker technology kits that enabled the development of IoT projects. Further engagement was elicited through campers' reflective digital design journal entries (Appendix B) and persistent work on their maker passion projects. Due to time constraints and the eventful camp program (see: Section 4.2.2), IoT concepts were presented at an introductory level, focusing primarily on basic components (e.g., sensors, actuators, monitoring), functionality, and real-world applications. Given campers' lack of familiarity with IoT indicated through their pre-study questionnaires, this foundational approach was doubly appropriate.

The research findings suggest that participation in the ChangeMakers March Break camp had a positive impact on participants' understandings of IoT. Prior to camp, most participants were either unfamiliar with the technology or simply recognized the "smart" label associated with popular consumer electronics. Over the course of the camp, however, participants began to formulate a basic understanding of IoT technology. They described the ubiquitous interconnectivity of networked things (Abdel-Basset et al., 2018; Atzori et al., 2010), illustrated during Aileen's post-study interview: "I learned about the Internet of Things, that they're all connected. And different technologies are connected to homes, phones, cars." They began to identify and communicate the role of various IoT components, including sensors to collect data (Voas & Laplante, 2017), actuators that respond to the data (Akiyama et al., 2017), and smartphone applications that enable data monitoring and device customization (Atzori et al., 2010). They observed the value in convenience and time saved through IoT's automation processes (J. Chin & Callaghan, 2013; McRae et al., 2018), exemplified by Amalya's comment that IoT "helps us to do our everyday tasks easier" and Derick's broad assertion that IoT "will help the future". Finally, they provided numerous examples of IoT applications, both recalled and imagined, as well as made connections to IoT systems in their personal contexts. Although a standardized definition of IoT is yet to be developed, Abdel-Basset et al. (2018) identified universal connectivity, heterogeneity of networks and devices, and things-related services as its three core features. By the end of the week, participants demonstrated a developing understanding of at least two of these three characteristics in addition to other granular details, suggesting that the

ChangeMakers camp was generally effective in facilitating an introductory understanding of fundamental IoT concepts.

The socially conscious orientation of the ChangeMakers camp also appeared to influence participants' thinking about IoT. In addition to common consumer applications like smart home appliances, security systems, and autonomous vehicles, campers identified opportunities for IoT to benefit disadvantaged populations. For example, Emily suggested the development of smart prosthetics, an idea supported by McRae et al. (2018) who asserted that IoT could be applied to enhance accessibility for individuals with disabilities. Similarly, multiple participants discussed the potential of smart gardens to offset food insecurity, which has been studied with positive results across various countries and degrees of financial need (Maia & Filho, 2018; Valpreda & Zonda, 2016). Meanwhile, both Isabelle and Aileen questioned whether it was possible for IoT to be of benefit to those most in need given the prohibitive cost of smartphones and a lack of infrastructure in developing countries. Their concerns were consistent with literature indicating that less than half of the world's population has access to the internet (Rainie & Anderson, 2017), let alone expensive consumer electronics. These examples indicate that as participants became increasingly familiar with IoT, they were capable of critical engagement with the technology, challenging social conditions that prevented its widespread use and proposing applications in service of social good.

The depth of understanding attained by participants in this study is consistent with Manches et al. (2015), whose participants successfully engaged with IoT technologies and proposed applications to other contexts after a short 90-minute session. In the present study, two learning periods totaling approximately 75 minutes focused exclusively on IoT concepts, with an additional 150 minutes spent exploring the maker technology kits, during which IoT connections were reinforced by camp facilitators. Throughout the rest of the week, campers were encouraged to reflect on the role of IoT in their passion projects, but these reflections were often independent and therefore failed to benefit from collective funds of IoT knowledge that may have developed through collaborative social engagement (Charlton & Avramides, 2016). Despite the observable development in campers' understandings of IoT, there were exceptions and caveats to note. One of the participants, Arshad, was successful in utilizing IoT concepts for his maker passion project, but his application of the technologies failed to translate into a consolidated understanding of IoT at post-study. He also had difficulty communicating about IoT in his daily reflections, inaccurately interpreting the phrase as equivalent to the colloquial use of the term "internet". It is possible that allocating additional time to engage with IoT concepts, both in isolation and as they related to participants' passion projects, may have strengthened their understandings of IoT, however this was beyond the scope of the present study and future research is recommended to investigate alternative instructional designs. Participants also failed to develop the technical vocabulary necessary to communicate a complete understanding of IoT. While they spoke confidently about sensors and other components in the maker technology kits, terminology related to cloud storage and computing, processing, and other sophisticated interactions (Akiyama et al., 2017; Atzori et al., 2010; Voas & Laplante, 2017) were absent from their descriptions. Additionally, while participants gradually became familiar with the phrase "Internet of Things", describing the technology as "smart" was observed far more abundantly. While these terms are used interchangeably in consumer applications, it is possible that "smart" was simply a more concrete term that, for participants, accurately represented the technology. This may also have benefitted from further integration of IoT foundations throughout the week; however, a lack of industry vocabulary did not preclude campers from understanding and communicating IoT concepts at an introductory level.

6.2.2 Making with Advanced Technologies

The degree to which makerspaces and production pedagogies have become increasingly visible throughout formal education (Freeman et al., 2017) calls for empirical evaluation of the benefits and affordances for learning demonstrated in out-of-school contexts (Halverson & Sheridan, 2014; Hughes et al., 2019). Through a student-centered, inquiry-based approach, maker pedagogies are thought to promote authentic, interdisciplinary learning (Hughes et al., 2017; Papavlasopoulou et al., 2017; Sheridan et al., 2014) that leverages students' prior experience as a foundation from which to construct new knowledge and competencies (Thumlert et al., 2015). As opposed to traditional instructionist models of education, making espouses a multidirectional learning process between students and their teachers, peers, tools and technologies, self-reflections, and other agents (Artut, 2018; Hughes et al., 2017; W. Smith & Smith, 2016; Stager, 2013). The integration of maker technologies can also facilitate a critical cultural shift, enabling students to conceive of themselves as producers, not just consumers, of powerful technological artifacts (Artut, 2018; Halverson & Sheridan, 2014; Marsh et al., 2018; Nascimento & Pólvora, 2018). Although IoT is not yet designated a maker technology in the same way as 3D printing and robotics, previous research has positioned IoT as a tool with which learners can critically examine and engage with their world (Kortuem et al., 2013), develop coveted digital competencies (Akiyama et al., 2017), and redefine computing as an active, participatory pursuit (Burd et al., 2018). Making with IoT can unravel its conceptual complexity, facilitating accessible engagement and understanding (Maia & Filho, 2018) in an interdisciplinary context that emphasizes project work over computer science or engineering principles (Charlton & Avramides, 2016).

In the present study, making with IoT design kits served to reinforce participants' understandings of introductory IoT concepts as well as elicit critical and active engagement with the technology. Existing literature suggests that well-designed maker technology kits can scaffold students' exploration of new and unfamiliar technologies by promoting excitement, self-efficacy (Psenka et al., 2017), and multiple points of entry (Resnick & Silverman, 2005; Sheridan et al., 2014). This was observed to be the case during the ChangeMakers March Break camp. Although the tutorials designed to support participants' initial exploration of the IoT maker technology kits emphasized the development of technological capacity over conceptual knowledge, they appeared to concretize what had been learned about IoT earlier that day. For example, working through the micro:bit coding tutorials enabled Anisha to both understand and communicate the roles of various IoT components in a rudimentary light level monitoring system. Similarly, Luca recognized that the maker kits could facilitate the development of IoT projects, such as a reminder system to reduce electricity consumption. These hands-on tutorials also extended participants' understandings of IoT and inspired the integration of complex interactions into their passion projects. As Amalya conceptualized the first draft of her texting-and-driving deterrent, sensors played a prominent role in what was originally a stand-alone system. However, as she learned more about the technology and its ability to interface with other devices, she developed a more sophisticated concept combining sensors and Bluetooth technology to communicate with the user's smartphone or vehicle. Engaging participants in the exploration of low-floor design challenges using maker technology kits enabled them to "think with objects" (W. Smith & Smith, 2016, p. 32), reinforce their developing understanding of sophisticated IoT concepts (Sheridan et al., 2014), and evoke technological fluency through iterative design, construction, and testing (Divitini et al., 2017).

The sustained passion project work that followed the introductory learning activities and maker technology tutorials also contributed to a deeper understanding of IoT. As participants applied their newly developed skills and knowledge to the design of a project representative of their personal interests, they were able to engage with a smaller subset of IoT concepts, deepening their understanding (Papert & Harel, 1991; Ratto, 2011) through inquiry, experimentation, and iteration (Buchanan et al., 2016). Participants progressed from communicating vague ideas and examples of IoT to articulating the role of specific components in their passion project design. Emily, for example, was able to conceptualize the integration of multiple sophisticated technologies in her endangered species tracker, including a GPS, motion sensors, camera, and pattern recognition software. Several participants also noted the significance of artificial intelligence and data processing in their designs, like Aaron and Luca whose soccer skills development robot was designed to offer feedback and responsively scale its challenge rating to match the user's skill level. While the introductory activities appeared to have a positive impact on participants' initial understandings of IoT, the subsequent opportunities to tangibly engage with IoT through the design and construction of their passion project prototypes afforded the agency (Blumenfeld et al., 1991; Robertson, 2013) and motivation (J. S. Brown & Adler, 2008) to explore in greater depth. Through "creating things, especially things that are meaningful to them or others around them" (Resnick & Silverman, 2005, p. 1), participants had an authentic purpose for making with and learning about IoT (Davis, 2017). Furthermore, participants came to understand IoT as something you create rather than consume, exemplified by Derick's explanation of IoT as "you can make stuff that will help the future." Situating campers' exploration of IoT within hands-on activities that emphasized experimentation, tinkering, and invention redefined the complex technology as participatory and accessible (Artut, 2018; Halverson & Sheridan, 2014; Marsh et al., 2018). That campers' inquiry-driven, passion-based making was scaffolded first with directed learning and discussion followed by guided maker activities further supported their IoT learning. Contrary to common misconceptions of the inquiry model, direct teaching is important (Vossoughi et al., 2016), particularly for learning fundamental skills and concepts (Bevan et al., 2014). With this foundation, participants were empowered to apply critical thinking and problem-solving skills through inquiry-based engagement (Gallup, 2019) on their maker passion projects.

Though the maker movement has been commended for its ability to concretize abstract concepts through their application to personally relevant projects (Kynigos, 2015; Noss & Clayson, 2015), the findings of the present study highlight the need for ongoing theoretical and conceptual engagement. Participants' passion project work – including digital design journal entries and prototypes in various stages of completion – became tangible representations of their developing IoT knowledge (Blumenfeld et al., 1991; Cocciolo, 2011; Ratto, 2011). However, for two of the participants, this conceptual understanding could not be detached from their maker passion projects. Both Anisha and Arshad integrated sophisticated IoT components into their project designs and were capable discussing them in that context but were unable to provide a basic definition of IoT at post-study. Research, analysis, synthesis, and sharing are integral components of both maker pedagogies (Chounta et al., 2017; Hughes, 2017) and design-based learning (Carroll et al., 2010; Doppelt, 2009). Unfortunately, these processes were underprioritized during the ChangeMakers camp in order to provide the most time possible for participants' prototypes to be completed. This meant that Anisha, Arshad, and other participants were inadvertently prevented from meaningful cognitive engagement that may have strengthened their understanding of IoT at post-study.

6.2.3 Engagement with Security & Privacy Concerns

Beyond understanding the basic functionality of IoT, eight of the ten participants also expressed concerns about the security and privacy implications of interconnected devices, as well as the data they transmit and store remotely. This was a notable theme in the findings given that the average IoT user demonstrates little awareness of the ways in which their personal data are captured, used, stored, and shared with third-party organizations (Manches et al., 2015). Aligned with provincial recommendations to facilitate digital literacies and digital citizenship education (Ontario Ministry of Education, 2016), researchers have compelled educators to involve their students in critical conversations about the implications of pervasive technologies (Bekker et al., 2015; Vega & Robb, 2019), including issues of trust, identity, privacy, protection, safety, and security regarding IoT (Aldowah et al., 2017). Although the limited duration of the ChangeMakers camp precluded a thorough analysis of the vulnerabilities identified in IoT to date (e.g., Rainie &

Anderson, 2017; Ronen et al., 2017), a brief introduction and series of discussions were held on the final day to promote critical engagement with the technology. Participation was lively as campers reconciled the implications of what they previously considered a “cool” and “helpful” technology, as was evident in their contributions to the discussion and post-study interviews. Participants identified the potential for personal data to be intercepted and used with malicious intent, questioning the security of devices with ubiquitous interconnectivity. This concern has been raised in the literature, describing the numerous points at which data could be observed, interrupted, or duplicated during the wireless transmission process in the absence of adequate security measures (Atzori et al., 2010; McRae et al., 2018; Rainie & Anderson, 2017). Campers also raised the issue of devices – or entire networks – being damaged or otherwise interfered with. Isabelle, for example, speculated that hackers could target healthcare systems to disable networks of life-sustaining equipment, similar to ransomware attacks that have been on the rise in hospitals (Weiner, 2021) with devastating financial and health ramifications. Other participants took this a step further to analyze possible implications of their own passion projects being hacked, like Derick, who observed that his home security prototype could be tampered with to falsely grant home access to unapproved individuals. These concerns have also been validated in the literature, from the potential for unattended devices to be physically modified (Atzori et al., 2010) to hackers gaining remote access to devices through insecure networks (Rainie & Anderson, 2017; Ronen et al., 2017). Finally, while the pre-learning activities and discussions served to highlight the security implications associated with IoT, some participants drew on their prior experiences with technology to propose the use of firewalls and other defenses to protect devices and data from infiltration. These suggestions were largely unprompted, representing participants’ voluntary engagement in critical thinking and problem solving in response to the various concerns.

Given the pervasive integration of IoT throughout society, these kinds of threats to privacy and security are described as having "the ability to directly affect the physical world. What used to be attacks against data and information have become attacks against flesh, steel, and concrete" (Schneier, 2016, para. 5). Though the scheduling of these activities in proximity to participants' post-study interviews may have affected the salience of the topic in their minds, the degree to which campers both raised and attempted to solve issues related to IoT security and privacy highlights the capacity of younger learners to engage with complex issues. As these technologies become increasingly prominent in spaces inhabited by elementary-aged students, it is important for them to not only understand IoT's functionality, but also to be critical of the ways in which data is collected, transmitted, and stored. This study's results are promising but require extensive validation by future research (see: Section 6.6) to address the various limitations (6.5) present in the current study.

6.3 Engagement with Citizenship & Social Justice

Classrooms in North America have become increasingly diverse, filled with students connected to people, places, and knowledge from around the world (Guo, 2014). As these connections multiply, students' exposure to issues of global inequity and injustice grows in tandem. Participation in our globalized society calls for citizens to be capable of understanding and engaging with significant global challenges (Carlisle et al., 2006; Hackman, 2005; Luksha et al., 2018). In response, education stakeholders have identified citizenship and innovation as invaluable global competencies (Ontario Ministry of Education, 2016), developed frameworks for facilitating citizenship education (e.g., Ontario Ministry of Education, 2018), and called for the integration of social justice and citizenship across the curriculum (Bell, 2016). Although schools have been accused of "perpetuat[ing] the social injustices woven throughout our society" (Carlisle et al., 2006, p. 57), their prominent role in students' formative years grants the potential to affect significant social change by actively challenging systemic inequities and empowering critically-minded and socially-conscious learners (Luksha et al., 2018).

Effective citizenship education enables students to situate themselves as members of various local and global communities (Ontario Ministry of Education, 2016), learning to identify, analyze, and respond to challenges of varying magnitude (A. Chin & Jacobsson, 2016; DiCicco Cozzolino, 2016; Guo, 2014). Social justice education extends this perspective, emphasizing the analysis and deconstruction of systems that perpetuate oppression as well as encouraging social action towards achieving equity (Carlisle et al., 2006; Hackman, 2005). Transformative pedagogies that are action-oriented, inquiry-based, and interdisciplinary can facilitate students' meaningful engagement with citizenship and social justice (Bell, 2016; Dover, 2009; Garber, 2004). Making is one such pedagogy. Critical making invites active engagement with societal, cultural, ethical, and political issues (Hughes, 2017; Nascimento & Pólvora, 2018; Ratto, 2011), enabling students to exercise personal agency through the construction of responsive artifacts (Tan & Barton, 2018). The use of maker technologies in these contexts can illuminate opportunities for technology to be employed for societal good (Bekker et al., 2015), while sharing the processes and products of maker citizenship can promote critical conversations and socially-active communities (Marsh et al., 2018; Scott & White, 2013).

Educators have identified engagement with global issues as a priority for their classrooms (Green, 2020), but social justice and citizenship education have only recently become a mainstream curricular focus (Feinstein & Carlton, 2013; Luksha et al., 2018). To examine the affordances of maker pedagogies and technologies for social engagement, the second objective of the present study was to explore the ways in which students might be capable of using technologies that promote interconnectivity and convenience through automation to actively engage in citizenship and social justice. The findings revealed four themes that will guide the discussion of this objective: (a) observable development in participants' understanding of social justice and citizenship; (b) participants' engagement with social issues; (c) participants' self-positioning as a ChangeMaker; and (d) applications of technology for making social change.

6.3.1 Development in Understanding of Social Justice & Citizenship

Underlying the goal of education to promote foundational skills and knowledge across curricular subject areas is the motivation to prepare students for life beyond school. As societies have become increasingly interconnected through globalization, this preparedness must include the ability to understand and engage with issues of local and global concern for the benefit of humanity (DiCicco Cozzolino, 2016; Guo, 2014). To explore participants' orientations towards social justice and citizenship activity, all aspects of the camp were guided by the theme "making for social change". While elements of both social justice and citizenship were addressed over the week, the scope of the camp limited the extent to which core systemic factors of social issues could be examined. Furthermore, the introductory activities emphasized notions of community, equity, inclusiveness, empathy, collaboration, and global quality of life. As a result, participants' engagement in the camp leaned towards citizenship over social justice.

In contrast to the marked development in participants' understandings of IoT over the course of the camp, few gains were made with respect to the terms "citizenship" or "social justice". Analysis of pre- and post-study data in isolation might falsely suggest that campers were unreceptive to these concepts given the decline in accurate definitions provided during their post-study interviews. However, the triangulated data tell a more complete story. While most participants were unable to ascribe meaning to social justice or citizenship by name at either pre- or post-study, they engaged actively with social issues of local and global significance (see: Section 6.3.2), identifying areas of concern, expressing empathy and compassion for affected individuals, and seeking novel solutions. As the objective of this study was to explore how participants engaged with issues related to citizenship and social justice rather than the development in their conceptual understanding, these findings were of little surprise.

Despite campers' lack of identification with these terms, they did appear to resonate with social justice and citizenship concepts from the perspective of being a ChangeMaker. During their post-study interviews (see: Appendix E), they isolated themes of leadership, creating a better future, helping others, and changing the world as they described their understanding of the ChangeMaker label. Similarly, they embodied the ChangeMaker theme (see: Section 6.3.3) through their passion project work and participation in group discussions, approaching even global issues from a personal locus of inspiration and understanding. Among the numerous models of social justice education, Dover (2009) highlighted the importance of beginning from students' existing knowledge, interests, and experiences. Acknowledging and honouring students' perspectives on social justice issues enables them to reclaim their voice and recognize the value in challenging oppressive forces (Garber, 2004). Furthermore, citizenship is exemplified by individual accountability inspiring action towards local and global issues (Guo, 2014; Ontario Ministry of Education, 2016). By these accounts, participants' engagement with social justice and citizenship through the ChangeMaker lens was a productive step towards effective social consciousness. The findings also align with Piaget's (1964) theories on cognitive development. Most participants would be classified as inhabiting the concrete operational stage, during which their reliance on egocentric thought would gradually diminish, yet abstracting knowledge beyond tangible concepts remained a challenge (McLeod, 2018; Piaget, 1964). However, research highlights the importance of building on students' existing bases of knowledge (Dover, 2009; Garber, 2004) through critical examination of the systemic factors underlying social issues to avoid inadvertently reproducing oppressive power dynamics and superficial solutions (Andreotti, 2015). Beyond their own perspective, students must develop the knowledge and values needed to sustain social action (Guo, 2014), including an understanding of the lived experiences of those affected by social issues (Andreotti, 2015; Leydens et al., 2014; Warming & Fahnøe, 2017). Furthermore, they must be supported by teachers who recognize and appreciate the influence of culture on our values and experiences of the world (Garber, 2004), as well as an educational context committed to challenging inequities and dismantling systems of oppression (Carlisle et al., 2006; Luksha et al., 2018). This depth of engagement was beyond the scope of the ChangeMakers March Break camp, therefore additional research is recommended to explore the ways in which advanced technologies like IoT could facilitate elementary-aged students' engagement with critical social justice education.

6.3.2 Engagement with Social Issues

Although most participants were unable to define citizenship or social justice at any point during the ChangeMakers camp, they demonstrated varying levels of conceptual understanding through their engagement with social issues. Over the course of the camp, participants identified, analyzed, and proposed solutions for concerns with local (e.g., bullying, homelessness, recreation) and global (e.g., poverty, climate change and sustainability, health, animal endangerment) origins. Their IoT maker passion projects facilitated a greater depth of engagement with one issue of personal relevance, challenging participants to consider multiple dimensions of the problem and how they might be addressed with technology based on a foundation of interconnectivity. Previous literature emphasized the importance of students learning to recognize and understand a range of social issues to meet the needs of our increasingly globalized society (Guo, 2014). The communities to which we belong are no longer restricted to our immediate geographical location; current and future students will find themselves members of numerous diverse and disparate communities spanning the globe (Ontario Ministry of Education, 2016). As such, they must be prepared to engage productively with complex social issues, including the ability to analyze contextual factors and respond appropriately (DiCicco Cozzolino, 2016; Guo, 2014). In the current study participants had minimal time to research the various social issues that were raised, but their collaborative contributions to group discussions and table conversations lent nuance to their collective understanding. This was evident during a discussion about the impacts of poverty and food insecurity, during which campers offered insights on gratuitous food waste, school breakfast programs, homelessness, and mental health concerns prevalent in underserved populations. While cultural and systemic considerations were largely absent from the conversation, participants leveraged their diverse backgrounds and experiences to shift from a general understanding of poverty being harmful to an appreciation for the specific barriers and measures currently in place. Camp facilitators raised questions to challenge participants' perspectives and encouraged them to engage in deep and critical thought, actively working to extend their understanding of and immersion in social consciousness (Garber, 2004; Guo, 2014). These activities served to reinforce campers' relationship with the global community (DiCicco Cozzolino, 2016; Ontario Ministry of Education, 2018), and encourage taking ownership and responsibility for contributing to effective resolutions (A. Chin & Jacobsson, 2016; Harshman & Augustine, 2013).

Hackman (2005) expressed a need for tools that enable critical analysis, participation in social change, and personal reflection to facilitate social justice and citizenship education. The passion project design challenge put forth during the ChangeMakers camp could be considered one such tool. Design, as a framework for making, scaffolds students' engagement with open-ended problems (Razzouk & Shute, 2012; R. C. Smith et al., 2015), promotes action (Carroll et al., 2010), and can facilitate students' application of technology towards societal concerns (Bekker et al., 2015). As learners make, their conceptual understandings are represented in their constructed artifact (Blumenfeld et al., 1991; Cocciolo, 2011; Ratto, 2011), and the very act of creating something meaningful stimulates complex engagement and learning (Bieraugel & Neill, 2017; Freeman et al., 2017). Furthermore, designing for social justice can promote empathy (Leydens et al., 2014), critical thinking (Razzouk & Shute, 2012), and reflection on the subject, process, and product of making (Bekker et al., 2015; Doppelt, 2009; R. C. Smith et al., 2015). These qualities were all evident during participants' passion project work and reflected their engagement with the issue they chose to pursue. For example, as Shaelyn designed her eye strain prevention device, she: (a) expressed empathy for technology users who experienced adverse health effects; (b) was excited to leverage technology to address the problem of screen-induced eye strain; (c) reflected on her project and its role in society; and (d) thought critically about both the problem and the value of her invention. Although campers cognitively engaged with numerous social concerns over the week, their IoT maker passion projects challenged them to explore a singular issue in greater depth. In doing so, they exercised personal agency (A. Chin & Jacobsson, 2016; Hughes et al., 2019), and reinforced skills and cognitive orientations towards social action (Lyles, 2018) that could scaffold future civic engagement.

6.3.3 Positioning of Self as ChangeMaker

Effective citizenship and social justice education empowers learners to take an active role in facilitating societal change (A. Chin & Jacobsson, 2016; Harshman & Augustine, 2013). Transformative pedagogies that forefront inquiry-based, interdisciplinary, student-driven learning (Bell, 2016), supplemented with tools designed to spark and sustain social action (Hackman, 2005), can empower students to engage with complex citizenship and social justice concerns. In the present study, most participants expressed a desire to have a positive impact on the world prior to beginning camp, but over the five days, campers actively positioned themselves as ChangeMakers during group discussions, individual reflections, and through work on their maker passion projects. Following the first day, campers began to identify and engage with social issues of varying magnitudes, but their self-positioning as agents capable of effecting societal change emerged after their exploration of the IoT maker technology kits. They expressed feelings of ownership (e.g., Amalya, "we should learn, understand, and take care of our Earth. We should try to prevent or help make this Earth a better place") and situated themselves in relation to various social issues (e.g., Shaelyn, "these problems are important to me because many people in the world experience these problems … making these inventions could help many people in the world"). Making has been described as facilitating intrinsically motivated learning (Artut, 2018; Stager, 2013), problem solving (Hughes et al., 2017; W. Smith & Smith, 2016), and an agentic response to social concerns (Marsh et al., 2018; Tan & Barton, 2018), which may explain the shift in participants' social consciousness as camp progressed.

Their embodiment of the ChangeMaker epithet became increasingly evident as they worked on the design and development of their passion project prototypes. Campers positioned themselves as: (a) inherently capable; (b) having meaningful impact; (c) solving important problems; and (d) aspiring to create change in the future. They communicated their capability as ChangeMakers through casual declarations of intent, such as Emily's, "I was like, 'why don't I make a thing for endangered animals?'" They reflected positively on the impact of their passion projects for affected populations, like Shaelyn's observation that her eye strain prevention device could make technology safer for the general population, but especially for children with developing eyesight. Amalya exemplified the ways in which campers framed their passion project work as addressing important societal problems, writing "I want to prevent texting and driving because people who text and drive are not only putting their lives in danger, but also putting other people's lives in danger." Finally, participants expressed aspirations to effect change in the future, such as Arshad's positioning of his smart garden project as supporting humanity's transition to another planet, and Shaelyn's reflection on her capacity to direct her passion and skills to solving some of society's most pressing environmental concerns. Although participants were encouraged to be ambitious with their passion projects, with the understanding that they would work towards the development of an early-stage prototype, their anecdotes reflected confidence and self-efficacy that could be expected from senior designers with access to vast industry resources. Many of their projects remained incomplete upon the camp's conclusion, yet they spoke of themselves and their work as though their invention was ready for deployment. Moreover, campers never expressed feeling overwhelmed by the scope of the challenge they were trying to solve; they simply designed, constructed, and iterated as if fully equipped to do so. Over the course of the camp, they positioned themselves as ChangeMakers: identifying a problem, designing a solution, and working with the technology to benefit society. While participants' personal characteristics may have had an impact on their ability to embrace the agency inherent in being a ChangeMaker, the design process is intended to scaffold makers' engagement with complex issues (R. C. Smith et al., 2015). Furthermore, the constraints established by their chosen problem and the available technology may have sustained campers' motivation and perseverance (Marsh et al., 2018).

The structure and design of the ChangeMakers camp afforded little time for research, yet participants' passion project work could still be classified as critical making. Through facilitated discussions and prompts provided by the camp facilitators, they engaged in critical analysis and discourse with their peers, daily reflections on their progress, and combined processes of artful making and critical thinking as they designed and produced their prototypes (Chounta et al., 2017; Ratto, 2011). The IoT maker technology kits were leveraged through their passion projects as tools to promote social action and change (Hughes, 2017; Nascimento & Pólvora, 2018; Orton-Johnson, 2014), enabling participants to respond creatively to societal issues of personal relevance (Kwon & Lee, 2017; Tan & Barton, 2018). Additionally, the self-selection of an orienting problem to inspire their maker passion project may have positively influenced their commitment to the design challenge (Blumenfeld et al., 1991; Psenka et al., 2017; Robertson, 2013; Sheridan et al., 2014). Collectively, these structures promoted active engagement with citizenship and social justice (Guo, 2014; Harshman & Augustine, 2013), enabling campers to position themselves as ChangeMakers.

The ChangeMaker characteristics observed in the present study closely resemble Marsh et al.'s (2018) depiction of maker citizenship. Through the conceptualization, design, and development of their maker passion projects, participants were empowered to challenge a range of social concerns (Nascimento & Pólvora, 2018), supported by their newly-developed technological competencies and subsequent motivation to leverage IoT for socially productive means (Bekker et al., 2015). While their projects varied in terms of social significance, nearly all of their designs addressed concerns related to what Marsh et al. (2018) described as "the three key elements of citizenship: rights, belonging, and/or participation" (p. 7). Even projects with a seemingly narrow focus – such as Aaron and Luca's soccer skills development robot – aimed to elevate users' sense of belonging to a particular community by developing intellectual and/or experiential capital and enhancing their enjoyment of shared activities. Campers sought to improve the human experience with innovative IoT projects that minimized barriers and created equitable conditions for societal participation (Leydens et al., 2014; Scott & White, 2013). They exercised individual and collective agency towards facilitating positive societal change (Tan & Barton, 2018), and positioned themselves as ChangeMakers with not only the skills, but desire, to positively affect their communities (Marsh et al., 2018; Ontario Ministry of Education, 2018).

It is pertinent to note that this group of participants may have been predisposed to socially active behaviours and mindsets, and that the findings reported herein may not be replicable in other contexts. The ChangeMakers March Break camp was advertised (see: Appendix A) as helping participants to "explore emerging technologies … to design and prototype an invention that could improve their lives (or the lives of others)!" While the STEAM-3D Maker Lab is known for hosting innovative technology camps, the wording of the advertisement may have enticed registrants with an inclination towards social action. Campers' pre-study questionnaires support this likelihood, given that most expressed a positive or neutral sense of self-efficacy regarding their ability to improve others' lives with technology despite lacking a history of doing so. As such, additional research is recommended to explore diverse populations' engagement with maker citizenship and the degree to which they position themselves relative to the ChangeMaker role.

6.3.4 Role of Technology in Making Change

Economic demands for graduates who are capable of innovating with emerging technologies have altered the educational landscape, necessitating the development of digital literacies and skills (Kortuem et al., 2013; Selinger et al., 2013), as well as transferable competencies to facilitate student success across evolving sectors (Ontario Ministry of Education, 2016). The rate at which technologies advance and exert influence on society has been meteoric for the last half-century, and while physical computing components have little room left for improvement, developments in algorithms, software, and hardware architecture will continue to drive the next generations of technology (Leiserson et al., 2020). Students must be equipped with the knowledge and skills necessary to navigate this continued technological growth (Blikstein, 2013), including the ability to adapt and learn on an ongoing basis (J. S. Brown & Adler, 2008; Carroll et al., 2010). However, educational making must avoid prioritizing skills and practices based on their economic viability (Vossoughi et al., 2016); in addition to learning valuable technological skills, making can promote critical engagement with timely social issues (A. Chin & Jacobsson, 2016; Kwon & Lee, 2017; R. C. Smith et al., 2015) as well as personal and social empowerment (J. A. Marshall & Harron, 2018; Simionescu, 2017; Vossoughi et al., 2016).

Since its widespread adoption beginning just over ten years ago, IoT has begun to transform not only economic infrastructure, but also individual quality of life (Rainie & Anderson, 2017). With a foundation of ubiquitous interconnectivity, automation, and communication, IoT could be applied to have a substantial impact on current global challenges (Abdel-Basset et al., 2018). However, apart from Babson College's IoT for Good Lab (n.d.), it remains relatively unexplored in the literature on making for social change. In the present study, participants used IoT-capable maker technology kits to design and construct passion project prototypes intended to solve a problem. Through that process, they began to recognize potential applications of IoT and other advanced technologies for confronting pressing social issues. Following their introduction to the maker technology kits, campers identified numerous potential projects using the littleBits, micro:bit, and Arduino that would have an observable impact on current societal challenges. In addition to their passion projects, they proposed the creation of motion-sensing cameras, gardens with automatic watering, and systems to monitor electricity consumption. Although these implementations already exist as consumer products, working with the maker technology kits enabled campers with little understanding of IoT to grasp its basic functionality and cognitively engage with its potential role in society (Maia & Filho, 2018; Psenka et al., 2017; Sheridan et al., 2014).

As they became increasingly comfortable with the technology over the five-day period, their ideas about leveraging IoT for social change developed in novelty and complexity. Participants extended their ideas about electricity conservation to comment on the resultant environmental impact, predicted the development of pilotless airplanes and other military applications to minimize casualties of war, and imagined special headsets that protected against bullying with a combination of IoT, AR, and VR. Several campers also expressed an understanding of technology as not only useful, but necessary to improve social conditions, like Isabelle's description of ChangeMakers "making a change, a change in the world, by learning about robotics … and technology." Scholars in the field of social justice and citizenship education have highlighted a need for practices that actively engage students with issues of local and global concern (Harshman & Augustine, 2013) and tools intended to support socially active behaviours and mindsets (Hackman, 2005). While neither IoT nor the maker technology kits used in this study were necessarily designed for this purpose, the findings suggest that their integration, in combination with critical making and human-oriented design, might facilitate students' engagement with social consciousness (Bekker et al., 2015; R. C. Smith et al., 2015). Moreover, the evolution in participants' conceptualization of the ways in which IoT and similarly sophisticated technologies might be applied to address social concerns reflect their relationship with the tools as active and participatory (Akiyama et al., 2017; Burd et al., 2018); from their perspective, technology can and should be used to create artifacts that benefit society, rather than something we simply consume. Participants also considered the existing economic and infrastructural barriers preventing the deployment of these technologies in socioeconomically disadvantaged regions, further highlighting their critical engagement with IoT, social justice, and citizenship (Hackman, 2005; Kortuem et al., 2013; R. C. Smith et al., 2015). Given the current emphasis on innovation, digital literacies, and citizenship in schools (Freeman et al., 2017; Ontario Ministry of Education, 2016), the findings of the present study suggest that interdisciplinary maker experiences with advanced technologies might cultivate valuable skills and mindsets related to technology and social action.

6.4 Educational Implications

In our increasingly interconnected world, schools are tasked with preparing students to be adaptive, innovative, digitally literate, and socially conscious (Freeman et al., 2017; Green, 2020; Ontario Ministry of Education, 2016). These learning objectives have been documented by the Canadian province of Ontario in various educator publications, including the *21st Century Competencies: Foundation Document for Discussion* (Ontario Ministry of Education, 2016), *Ready, Set, Green!* (Ontario Ministry of Education, 2007), and core curriculum documents (e.g., Ontario Ministry of Education, 2018, 2020), among others. While these qualities could be developed in isolation, research highlights the impact of interdisciplinary learning on solving open-ended, complex problems approximating those of the real world (Blumenfeld et al., 1991; J. S. Brown et al., 1989). The limitations of the present study (see: Section 6.5) prevent generalization of its findings, however the results suggest that curricula developed around student-driven, passion-based making with low-floor IoT construction kits could facilitate students' engagement with social justice and citizenship, sophisticated technological concepts, and global competencies.

Although the educational affordances of making and makerspaces have been extensively documented in the literature, many of these reports originate from community spaces with fewer constraints on time, materials, and personnel. The ChangeMakers March Break camp also benefited from a level of flexibility unavailable in the standard classroom, including a lack of mandated assessment and a reduced teacher-student ratio. However, with its fixed timetable, designated learning objectives, and facilitators variably experienced with the maker technologies, the ChangeMakers camp functioned as a liminal space between school and community contexts with valuable implications for formal education. This study corroborates previous research indicating that student-driven passion projects (J. S. Brown & Adler, 2008; Sheridan et al., 2014) leveraging the interdisciplinary nature of making (W. Smith & Smith, 2016) can facilitate learning in traditional educational environments. Not only do students desire opportunities to exercise agency over their learning (Gallup, 2019), personally-meaningful projects provide motivation and incentive for students to engage with curricular concepts (J. S. Brown & Adler, 2008; Hung et al., 2008; Robertson, 2013). Design challenges offer valuable constraints for students' engagement (Blumenfeld et al., 1991; Marsh et al., 2018; R. C. Smith et al., 2015) and promote authentic learning, encouraging students to integrate skills and knowledge from diverse disciplines into their solutions (Psenka et al., 2017; Razzouk & Shute, 2012; R. C. Smith et al., 2015). The design and creation of their passion projects evokes critical thinking (Hughes, 2017), creativity (Chounta et al., 2017), and other higher-order thinking processes (Bieraugel & Neill, 2017), ultimately resulting in a tangible representation of students' learning (Blumenfeld et al., 1991; Ratto, 2011). Though technology is not essential to making, the integration of coding, robotics, and emerging technologies like IoT can facilitate students' understanding of complex technological concepts (Bekker et al., 2015; Divitini et al., 2017; Psenka et al., 2017), and shift their perceptions of technology as something to create rather than consume (Artut, 2018; Nascimento & Pólvora, 2018). In doing so, students develop valuable digital literacies and competencies that will facilitate their participation in our technological society (Freeman et al., 2017; Hughes et al., 2017). However, the current study also highlighted the role of teachers in supporting students' inquiry-driven making. Left to their own devices, students' confidence and self-efficacy can fade, particularly over long-term projects (Vongkulluksn et al., 2018). Supports in the form of "constraints for creativity" (Marsh et al., 2018), scaffolded progression through a structured design process (R. C. Smith et al., 2015), and just-in-time learning interventions (Sheridan et al., 2014; W. Smith & Smith, 2016) are necessary to facilitate students' learning through making. Educators also play a pivotal part in facilitating critical discussions and analysis (Vossoughi et al., 2016), not only of social issues and their contributing factors, but regarding the role technology may or may not play in addressing them.

This study also offers meaningful implications for learning with and about IoT, particularly at the elementary school level. To date, IoT's integration into education has been primarily functional, for example: tracking student attendance (Freeman et al., 2017); improving security by monitoring the movement of staff and students through the building (Aldowah et al., 2017; Meola, 2020); conserving electricity through responsive lighting, heating, and cooling systems (Freeman et al., 2017); automating assessment (Meola, 2020); and facilitating personalized learning (Cajide, 2015; Selinger et al., 2013). Curricular programming has only recently begun to include IoT (Burd et al., 2018), and the majority of these programs have been limited to post-secondary education (e.g., Akiyama et al., 2017; Ali, 2015; Babson College, n.d.; Koo, 2015; Kortuem et al., 2013; Raikar et al., 2016). The present study suggests that not only are elementary-aged students capable of learning about IoT, they can also use the technology to design and create artifacts with personal and societal relevance. This is noteworthy for the promotion of digital fluency in education; beyond technological skills, students must also develop an understanding of digital architecture, including the ways in which devices interact with each other and their surrounding environments (Freeman et al., 2017). As IoT becomes increasingly prevalent in society, its inclusion in the classroom beyond the fulfillment of administrative duties can enhance the relevance and authenticity of students' learning (Selinger et al., 2013). Current emphases on STEM and STEAM education are natural points of integration for IoT. A multidisciplinary approach is necessary for students to understand and engage with IoT systems, given the variability in the function of each component (Charlton & Avramides, 2016; Simionescu, 2017). Additionally, programs utilizing educational technologies that capture data (e.g., programmable robots, electronics) can be amended to include IoT (Aldowah et al., 2017) with tools like the maker construction kits employed in this study. Integrating IoT at the elementary school level not only prepares students to be creative and innovative with technology (Bieraugel & Neill, 2017; Carroll et al., 2010), it also facilitates earlier access to the skills, mindsets, and technologies relevant to students' future participation in society (Blikstein, 2013; Divitini et al., 2017; Simionescu, 2017).

Finally, this study contributed to existing understandings of learners' participation in social justice and citizenship education and offered unique insights into the ways in which making with IoT could facilitate critical engagement with societal issues. The growing interconnection of society through globalization and rapid technological advancements requires students to be capable of understanding and responding to significant social concerns (Aldowah et al., 2017; Guo, 2014; Ontario Ministry of Education, 2016). The current study illustrates that elementary-aged students recognize a range of issues related to both citizenship and social justice, and that engagement in active practices such as discussion and reflection can deepen their understanding (Carlisle et al., 2006; Hackman, 2005). While ethnocentric perspectives of global issues can be problematic (Andreotti, 2015), this study also highlighted important developmental considerations for facilitating students' comprehension of social justice and citizenship. Particularly in elementary (K-3) and junior (4-6) grades, these concepts may be too abstract to use as a foundation for learning (McLeod, 2018; Piaget, 1964). Instead, beginning from a personally oriented “ChangeMaker” position leverages students’ existing knowledge, interests, and experiences (Dover, 2009), and encourages individual accountability with respect to local and global issues (Guo, 2014; Ontario Ministry of Education, 2016). However, following meaningful engagement at this level, students must be supported in expanding their understanding to accommodate diverse perspectives (Dover, 2009; Garber, 2004), including the lived experiences of those affected by social issues (Leydens et al., 2014; Warming & Fahnøe, 2017) and the systemic factors that perpetuate them (Andreotti, 2015).

Beyond conceptual understanding, this study highlighted the value of passion-based making with IoT for students’ engagement in social consciousness. Previous research has illustrated the roles of creativity, innovation, and critical thinking in resolving global problems (Abamu, 2017; Feinstein & Carlton, 2013). Critical making (Ratto, 2011) and maker citizenship (Marsh et al., 2018) enable learners to explore complex social issues through the design, production, and sharing of transformative cultural artifacts (Marsh et al., 2018; Nascimento & Pólvora, 2018; Orton-Johnson, 2014). Orienting students’ critical making around an issue of personal relevance empowers them to exercise their agency and creativity (Tan & Barton, 2018) while promoting deep engagement (J. S. Brown & Adler, 2008; Psenka et al., 2017). To this point, IoT has been underutilized for broad explorations of social justice and citizenship issues in an educational context (exception: Babson College, n.d.). However, the present study illustrates that elementary-aged students were capable of grappling with significant challenges through critical making with IoT construction kits. The maker kits scaffolded students’ engagement with IoT’s technological complexity (Maia & Filho, 2018; Psenka et al., 2017; Resnick & Silverman, 2005), enabling them to leverage its capacity for data collection, communication, and automation for the benefit of society (Bekker et al., 2015; Psenka et al., 2017). Given recent surveys that indicate teachers’ expectations to leverage technology for the purposes of engaging students in citizenship and social justice education (Green, 2020), existing calls for tools and practices to support active social engagement (Hackman, 2005; Harshman & Augustine, 2013) have never been more relevant. From this study, IoT presents itself as an attractive tool with which to facilitate global competencies, promote early development of sophisticated technological skills and knowledge, and explore issues related to citizenship and social consciousness.

6.5 Study Limitations

As an exploratory study, the goal of this thesis was to contribute to an understanding of the ways in which elementary-aged students might be capable of learning about sophisticated technologies and applying them in pursuit of social consciousness through critical making. Despite best efforts to produce valid and insightful research, this study contained several limitations that restrict its scope. The results of this short-term project, while optimistic, cannot make claims about any lasting impact on students' understandings of IoT or their active engagement with citizenship and social justice. The main limitations affected the study participants, camp design, and research design, and have been presented accordingly.

6.5.1 Participants

From the initial stages of planning the ChangeMakers March Break camp, the participant pool posed a substantial limitation. As with all recent STEAM-3D Maker Lab camps, recruitment took place primarily (a) online, and (b) through channels associated with Ontario Tech University. In-person recruitment was attempted through the posting of physical advertisements (Appendix A) around the Faculty of Education building and several community locations, as well as distribution to local partner schools; however, many of the responses were associated with the digital advertising. This recruitment strategy may have favoured families adjacent to the university or otherwise inclined towards technology. Participants' pre-study questionnaires and early camp participation hint at this being the case, illustrating their comfort and familiarity with a range of technologies. With an existing base of technological skills and knowledge, campers may have been more receptive to learning with and about advanced technologies like IoT, inadvertently biasing the results of the first research question.

Similarly, the limited sample from which the results were reported may not have been representative of the full camp roster, much less the greater population of elementary-aged students. Given the objective to explore changes in participants' understandings of IoT, social justice, and citizenship over the course of the camp, data were excluded from participants who did not consent to a post-study interview. Reasons for their lack of participation varied, but most could be attributed to a desire for more time to finalize their maker passion projects. This raises several unanswered questions about the study sample: did they have a better grasp of the technology, enabling them to finish their prototypes faster? Were their projects simpler, with less IoT integration? Were they less interested in IoT or social consciousness, translating to reduced effort or investment in their projects? Unfortunately, differences between the sample and campers whose data were excluded – and potential resultant impacts on the study – cannot be discerned, limiting the scope of the findings.

6.5.2 Camp Design

That the study was situated in the context of a recreational March Break camp also posed a limitation in terms of participants' engagement. Some campers objected to the structure and constraints imposed by the research goals and would temporarily disengage from directed activities. Considering the influence of environment on students' emotional engagement and self-efficacy during maker tasks (Vongkulluksn et al., 2018), their intermittent disconnection over the course of the camp may have had an impact on the study results. In a classroom or other formal educational context where learning is the expectation, students may be less likely to reject tasks that resemble work more than play.

Another consideration inherent to the maker orientation of the camp was its student-centered, inquiry-driven approach. Counterbalancing the benefits of this pedagogical style is the amount of time required to complete learning activities. As participants were unfamiliar with both IoT and the provided maker technology kits, the five-day camp duration limited the depth of possible engagement. Facilitators hoped that participants would finish camp with a completed passion project, therefore the bulk of the operating hours were dedicated to designing and making over the reinforcement of concepts related to IoT and social consciousness. Similarly, the infinite variations possible in students' inquiry-directed work, further compounded by the technological novelty, affected the quantity and quality of in-the-moment data able to be captured by camp facilitators. Even with a relatively small ratio of five to six campers per facilitator, participants required near-constant support to progress with their IoT maker passion projects. While the overhead cameras likely offset some of these data losses, the limited number of observational notes, photographs, and focused video recordings may have resulted in the loss of notable research insights.

As the ChangeMakers camp coincided with a week-long break in undergraduate classes at the Faculty of Education, campers were afforded the ability to work in spaces other than the STEAM-3D Maker Lab that reflected their desired noise level, congestion, and working area. This flexibility, while responsive to participants' productivity needs, posed a limitation regarding data collection. Unlike the overhead camera coverage in the Maker Lab, these alternative spaces lacked dedicated recording hardware and were dependent on portable camcorders which frequently malfunctioned. As a result, limited data were available for some campers, including the entire group that elected to use the Arduino electronics kit, which is arguably the closest to consumer-grade electronics of the three provided maker technologies. All but one of these campers were excluded from the participant sample due to their lack of participation in a post-study interview, however, their data may have had an observable impact on the study results given the complexity of the technology they engaged with over the week.

Finally, inadequate deployment of design principles and process guidelines may have worked to campers' detriment over the production of their passion projects, affecting their engagement with the concepts under study. Design offers a useful framework for making activities (Hughes et al., 2019; Martin, 2015; R. C. Smith et al., 2015), but students must be supported in developing designerly thinking (Bekker et al., 2015; R. C. Smith et al., 2015; Spencer & Juliani, 2016). Although campers were provided with a copy of The Works Museum's (2015) *Engineering Design Process* in their digital design journals and references to design principles were made throughout the camp, time constraints precluded a formal introduction to the stages of design. In line with R. C. Smith et al.'s (2015) observations, campers had difficulty developing their designs, progressing independently, and resolving problems, resulting in frustration and time lost waiting for assistance. These barriers may have redirected campers' effort and attention away from the ChangeMakers design challenge, limiting the degree to which they engaged with concepts related to IoT, social justice, or citizenship.

6.5.3 Research Design

Qualitative research designs innately contain several limitations that preclude the generalization of their results to the population at large. First, qualitative inquiry is generally conducted in naturalistic settings as opposed to controlled environments (Miles et al., 2020). Context therefore becomes an inextricable part of the data; how participants behave in one context will not necessarily translate to another (Patton, 2015). Secondly, the nature of the data demands interpretation by the researcher (Creswell, 2013; Harrison et al., 2017). While I have prioritized reflexivity through the process of conducting and reporting this study (see: 4.2.2.3 Situating Myself in the Research), my interpretation of the data was inevitably informed by my individual biases and subjectivities (Creswell, 2013; Patton, 2015). In light of these limitations, I would remind readers that the study's findings are not intended to be generalized; it would be more appropriate to consider their potential transferability to other settings. The data, context, and procedures have been described in as much detail as possible to aid comparisons to other environments and groups of learners (Creswell, 2013; Lincoln & Guba, 1985). Multiple cases, in combination with cross-case analysis, offer nuanced insight into participants' experiences and possible contributing factors (Miles et al., 2020). Furthermore, triangulation within and across cases (Stake, 2006) lends validity to the findings as they occurred within this context. However, widespread generalization remains impossible and future research must be conducted to examine younger students' engagement with IoT in pursuit of social action.

The study also suffered limitations with respect to data collection instruments. Due to the multiple disparate research foci of the ChangeMakers camp, the pre-study questionnaire was of excessive length (see: 4.5.2 Pre-Study Questionnaire; Appendix D). Two versions were created to account for potential survey fatigue (Galesic & Bosnjak, 2009), however this may not have been sufficient to offset the impact of a lengthy questionnaire. The observation criteria were also poorly designed which, in combination with the demands of camp facilitation, resulted in minimal in-the-moment data being recorded by the participant-observers. *Seesaw Class* (n.d.) was an effective tool to consolidate campers' designs, multimodal reflections, and progress work, but it was new to both myself and the participants. Campers received little training on its use, and as such, they may not have been able to leverage the software's multimodal capabilities to their full extent to adequately capture their thinking and making. Finally, while the variety of data sources (see: 4.5 Data Collection Tools) facilitated triangulation of the study's findings, the use of different formats at pre- and post-study made comparisons challenging. During their post-study interviews, participants were capable of elaborating and directing the conversation in ways that the pre-study questionnaire did not allow. However, the success of the interview format was dependent to some extent on the rapport established with participants over the week. In future iterations, care should be taken to minimize the differences between pre- and post-study data collection using validated instruments.

Lastly, as the camp was limited by the duration of students' mid-winter break from school, the short timeframe of the study precluded any insight into the long-term effects of camp participation, such as participants' retention of IoT learning or transfer of social consciousness. Every aspect of the research, from participants' cognitive engagement with the concepts under study to the design and construction of their passion project prototypes, was condensed such that the full impact of the study could not be realized. Given a longer duration, participants could explore IoT in greater depth, establish meaningful connections with significant global issues, investigate the systemic factors underlying social justice concerns, and spend more time bringing their IoT maker projects to fruition.

6.6 Future Research

Given the integration of sophisticated technologies into education (Freeman et al., 2017) and a growing emphasis on promoting engagement with citizenship and social justice, there is little reason to believe that elementary-aged students would be incapable of learning about IoT and using the technology to create socially impactful projects. However, since participatory engagement with IoT has only begun to factor into education at the post-secondary level, further research is necessary to substantiate this exploratory study.

This study was designed and conducted on a foundation of constructionist principles. While a breadth of research from informal makerspaces has suggested promising implications for making in formal educational contexts, these approaches still require validation (Freeman et al., 2017; Halverson & Sheridan, 2014; Hughes et al., 2019). Future research should examine the affordances of maker pedagogies on students' engagement with sophisticated concepts like IoT and social consciousness within the constraints of a classroom, as well as their impact on long-term retention and transfer to out-of-school environments. Similarly, critical making has been shown to facilitate meaningful involvement with social justice initiatives in community makerspaces (e.g., Chounta et al., 2017; Orton-Johnson, 2014; Ratto, 2011), but research in education is limited. Considering the demand for active engagement with citizenship and social justice in schools (Hackman, 2005; Harshman & Augustine, 2013; Ontario Ministry of Education, 2018), critical making should be explored as a method through which students can respond to societal issues through the production and sharing of evocative cultural artifacts.

Students are expected to be innovative and adaptable upon graduation in order to engage with a range of advanced technologies, including those that have yet to be developed. This study suggested that revolutionary technologies like IoT need not be delayed to students' post-secondary careers, but additional research is needed to determine the optimal time for integration and the fit with existing technological curricula. Higher education courses, particularly those designed for students outside of computer science and engineering disciplines (e.g., Akiyama et al., 2017), could be adapted for use with existing IoT construction kits (e.g., Arduino, n.d.; Micro:bit Educational Foundation, n.d.; Sphero Inc., n.d.-c) and unplugged tools for designing IoT (e.g., Mora et al., n.d.). Given the impact of the ChangeMakers camp on participants' understandings of IoT, future research should also investigate the impact of its various program elements – such as design, making, collaborative discussion, and reflection – to evaluate efficacy.

The limitations associated with this study's sample call for mixed methods research to evaluate the impact of moderating variables on participants' IoT learning and engagement with social justice and citizenship. While the findings of the present study appear promising, it is likely that participants were predisposed to both technology and social consciousness, on account of the recruitment procedures. Understanding the role of students' prior experiences with technology and social action could enable teachers to more effectively design learning activities and environments to accommodate them.

Finally, while the focus of this study was on students' learning and engagement, future research should explore educators' experiences teaching with and about IoT. Technology factors heavily into modern classrooms (Vega & Robb, 2019), and is expected to become more prevalent over the next ten years (Green, 2020). However, teachers' confidence and self-efficacy can affect their willingness to integrate sophisticated technologies into the classroom (Blackley et al., 2017; Hira et al., 2014; Stevenson et al., 2019), as well as the resultant impact of those technologies on students' learning (Vega & Robb, 2019). As mentioned in Section 4.2.2.2, none of the camp facilitators or teacher candidate volunteers in the present study had any prior experience making or teaching with IoT, though they did benefit from a wealth of experience with various educational technologies. If the expectation is that students will learn with and about advanced technologies like IoT, it is crucial to explore educators' experiences and perceptions to develop professional learning experiences that facilitate their technological confidence and self-efficacy.

7 Conclusions

If education aspires to prepare students for participation in the world beyond, digital literacies and social consciousness must continue to be prioritized. Technology has and will continue to reshape our interactions with society (Banica et al., 2017), therefore students must develop not only technological skills (Blikstein, 2013; Garcia & Cano, 2014), but also global competencies like creativity and innovation to support their engagement with emerging technologies and dynamic social contexts (J. S. Brown & Adler, 2008; Carroll et al., 2010; Ontario Ministry of Education, 2016). Globalization has all but eliminated the impact of international borders on our exposure to world issues, requiring that students also become capable of analyzing and responding to pervasive social challenges (DiCicco Cozzolino, 2016; Dover, 2009; Luksha et al., 2018; Ontario Ministry of Education, 2016). Among the numerous frameworks for social justice (e.g., Carlisle et al., 2006; Dover, 2009) and citizenship education (e.g., Ontario Ministry of Education, 2018; United Nations, n.d.), participatory engagement is highlighted as an integral component. Schools are encouraged to develop curricula that integrate opportunities for critical analysis (Andreotti, 2015; Hackman, 2005; Warming & Fahnøe, 2017) and tools that promote active engagement with local and global challenges (Hackman, 2005; Harshman & Augustine, 2013). These recommendations include leveraging the creative potential of technology through action-oriented, transformative pedagogies (Bell, 2016), as well as empowering students to create technological artifacts that benefit their local and global communities (Nascimento & Pólvora, 2018; Scott & White, 2013), engage in critical maker citizenship (Marsh et al., 2018; Ratto, 2011), and identify applications of technology to facilitate social change (Bekker et al., 2015).

Through its ability to improve our quality of life and the efficiency of our daily operations, IoT has rapidly developed a pervasive presence in society (Banica et al., 2017; Gómez et al., 2013; Rainie & Anderson, 2017) and is beginning to transform education (Freeman et al., 2017; Meola, 2020; Selinger et al., 2013). However, its integration into elementary and secondary schools has thus far been limited to upgrading administrative operations (Aldowah et al., 2017). IoT is a powerful technology with the ability to connect people, data, things, and services all over the world (Rainie & Anderson, 2017). It has already had a beneficial impact on various global challenges, including sustainability, agriculture, health care, and more (Atzori et al., 2010). Supporting students to become leaders in innovation and active global citizens means providing opportunities to engage with influential technologies like IoT. At present, formal curricular programming around IoT has only occurred at the tertiary level (e.g., Akiyama et al., 2017; Ali, 2015; Koo, 2015; Kortuem et al., 2013; Raikar et al., 2016), and Babson College (n.d.) is one of the few institutions that has explicitly explored its impact on social justice and citizenship. Several isolated projects have been reported with K-12 students (e.g., Charlton & Avramides, 2016; Davis, 2017; Maia & Filho, 2018; Manches et al., 2015), highlighting their capacity to understand and engage with sophisticated technologies like IoT.

Inspired by educational directives to facilitate digital literacies, global competencies, and social consciousness, in combination with the current deployment of IoT in education, the present study was designed to explore how making with and learning about IoT might facilitate engagement with citizenship and social justice at the elementary school level. Participants in the ChangeMakers March Break camp were introduced to IoT through short-form videos, group discussions, and hands-on experience with three low-floor IoT maker kits: littleBits (Sphero Inc., n.d.-c), micro:bit (Micro:bit Educational Foundation, n.d.), and Arduino (n.d.). Over the remaining days of camp, participants designed and constructed maker passion projects using IoT to solve a problem of personal relevance and make a positive change in the world. Despite the camp's limited duration and many participants' prototypes only partially completed, the findings suggest that working through their passion projects contributed to an understanding of IoT and facilitated their engagement with social justice and citizenship over the week.

Compared to an almost complete lack of familiarity with the technology at pre-study, participants demonstrated a basic understanding of the concept of ubiquitous interconnectivity, components of an IoT system, affordances and limitations of IoT in society, as well as a range of possible applications. They also demonstrated critical engagement with the technology, expressing concerns about the security and privacy implications of IoT as well as potential barriers to its integration in developing countries. Working with IoT on their maker passion projects, participants engaged with a range of social justice and citizenship issues, as well as problems with a more limited scope. They did not develop a nuanced understanding of the terms "citizenship" and "social justice", but they did relate the underlying principle of improving social conditions to the ChangeMaker label, which they positioned themselves alongside. In doing so, they adopted an active orientation towards social consciousness, identified in the literature as an essential component of citizenship and social justice education (Hackman, 2005; Lyles, 2018; Ontario Ministry of Education, 2016). Their experiences developing an IoT passion project also provided unique insight into the role of IoT and other advanced technologies in facilitating social change.

The limitations of this exploratory study preclude generalization of its results to other educational contexts and groups of learners, but its design, findings, and underlying theoretical framework could be used to inform future research. Through a constructionist lens (Papert, 1980; Papert & Harel, 1991), making has been identified as having numerous affordances for learning (Abdi, 2014; Halverson & Sheridan, 2014; Psenka et al., 2017) including a shift towards participatory and productive engagement with technology (Artut, 2018; Nascimento & Pólvora, 2018; Thumlert et al., 2015). Critical making in particular combines creative production with critical thinking (Ratto, 2011), enabling learners to grapple with complex social issues through the construction of culturally relevant artifacts (Hughes, 2017; W. Smith & Smith, 2016; Tan & Barton, 2018). Design thinking adds a layer of scaffolding to students' maker projects (Psenka et al., 2017; R. C. Smith et al., 2015), providing a framework for risk taking, problem solving, and creativity (Spencer & Juliani, 2016). It can also illuminate the human experience of societal challenges (Gobble, 2014), facilitating a sense of empathy and agency to develop equity-oriented solutions (Carroll et al., 2010; Leydens et al., 2014; Razzouk & Shute, 2012). Student-directed design work leverages intrinsic motivation and inquiry (Buchanan et al., 2016; Gallup, 2019) towards solving personally-meaningful problems (Doppelt, 2009). Moreover, passion-based learning invites students' curiosity into the classroom, equipping them with the skills and desire to continue self-directed inquiry outside of formal education (J. S. Brown & Adler, 2008; Robertson, 2013). In combination with principles of design and passion-based learning, maker pedagogies could therefore be leveraged to facilitate learning with and about advanced technologies like IoT (Charlton & Avramides, 2016; Freeman et al., 2017; Hughes et al., 2017), as was observed in this study. Furthermore, maker passion projects that integrate these technologies could not only enhance students' digital literacies and competencies, but also offer a method through which learners can meaningfully investigate and respond to issues of personal and social relevance.

In light of increasing demand for schools to facilitate social consciousness, innovation, critical thinking, and technological competencies, a need for educational practices that amalgamate these qualities into authentically multidisciplinary activities has emerged. This study builds on previous research highlighting the capacity for passion-based making to support students' transition from education to our technology-driven economy (Freeman et al., 2017; Hughes et al., 2017), using design as a framework for social engagement (Bekker et al., 2015; Razzouk & Shute, 2012; R. C. Smith et al., 2015). IoT has already begun to transform the ways that we live, work, and play, and this study suggests that not only could it be applied to society's most challenging issues, but that elementary-aged students are more than capable of using the technology to ideate and create these innovative solutions. While educational stakeholders must be wary of assigning unwarranted value to any individual technology (McRae et al., 2018), passion-based making with IoT has the potential to facilitate critical digital skills and literacies, engagement with topical social concerns, and the development of valuable global competencies, all of which are essential for students' participation in society beyond education.

8 References

Abamu, J. (2017, March 19). *Students use the Internet of Things, big data and big ideas to build smarter cities*. EdSurge. https://www.edsurge.com/news/2017-03-19-students-use-the-internet-of-things-big-data-and-big-ideas-to-build-smarter-cities

Abdel-Basset, M., Manogaran, G., Mohamed, M., & Rushdy, E. (2018). Internet of Things in smart education environment: Supportive framework in the decision-making process. *Concurrency and Computation: Practice and Experience*, *31*(10), 1–12. https://doi.org/10.1002/cpe.4515

Abdi, A. (2014). The effect of inquiry-based learning method on students' academic achievement in science course. *Universal Journal of Educational Research*, *2*(1), 37–41.

Ackermann, E. (2001). Constructivisme et constructionisme: Quelle différence? [Piaget's constructivism, Papert's constructionism: What's the difference?]. In J.-J. Ducret (Ed.), *Constructivismes: Usages et perspectives en éducation* (Vol. 1, pp. 85–97). Service de la recherche en éducation. https://learning.media.mit.edu/content/publications/EA.Piaget%20_%20Papert.pdf

Akiyama, K., Ishihara, M., Ohe, N., & Inoue, M. (2017). An education curriculum of IoT prototype construction system. *Proceedings of the 2017 IEEE 6th Global Conference on Consumer Electronics (GCCE 2017)*, 1–5. https://doi.org/10.1109/GCCE.2017.8229221

Aldowah, H., Ul Rehman, S., Ghazal, S., & Umar, I. N. (2017). Internet of Things in higher education: A study on future learning. *Journal of Physics: Conference Series*, *892*, 1–10. https://doi.org/10.1088/1742-6596/892/1/012017

Ali, F. (2015). Teaching the Internet of Things concepts. In M. E. Grimheden (Ed.), *Proceedings of the WESE'15: Workshop on Embedded and Cyber-Physical Systems Education* (pp. 1–6, Article 10). Association for Computing Machinery. https://doi.org/10.1145/2832920.2832930

Allmark, P. (2002). The ethics of research with children. (Ethical issues in research). *Nurse Researcher*, *10*(2), 7–20.

Amazon.com Inc. (n.d.). *Alexa developer official site*. Amazon Alexa. Retrieved September 30, 2021, from https://developer.amazon.com/en-US/alexa.html

American Psychological Association. (2020). *Publication manual of the American Psychological Association* (7th ed.). American Psychological Association.

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., & Wittrock, M. C. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives* (Abridged edition). Longman.

Andreotti, V. (2015). Global citizenship education otherwise: Pedagogical and theoretical insights. In A. Abdi, L. Shultz, & T. Pillay (Eds.), *Decolonizing global citizenship education* (pp. 221–230). Sense Publishers.

Andriole, S. (2020, March 30). *It's time for an internet-for-all public utility (before Corona crashes it)*. Forbes. https://www.forbes.com/sites/steveandriole/2020/03/30/its-time-for-an-internet-for-all-public-utility-before-corona-crashes-it/#6e27f518af95

Anno, M. (1999). *Anno's magic seeds*. Penguin Putnam Books for Young Readers.

Apple Inc. (n.d.). *Control your home with Siri*. Apple Support. Retrieved September 30, 2021, from https://support.apple.com/en-ca/HT208280

Arduino. (n.d.). *Arduino*. Retrieved December 18, 2020, from https://www.arduino.cc/

Artut, S. (2018). Makerspace or maker(-): Making culture as an alternative society to mass consumption. *International Journal of Social and Economic Sciences*, *8*(2), 52–55.

Ashton, K. (2009, June 22). *That "Internet of Things" thing*. RFID Journal. https://www.rfidjournal.com/that-internet-of-things-thing

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, *54*(15), 2787–2805. https://doi.org/10.1016/j.comnet.2010.05.010

AWM. (n.d.). *Frictionless™*. AWM Smart Shelf. Retrieved September 30, 2021, from https://smartshelf.com/frictionless-shopping.html

Axis Communications AB. (n.d.). *AXIS camera station s2008 appliance*. Axis Communications. Retrieved October 8, 2021, from https://www.axis.com/en-tr/products/axis-s2008

Babson College. (n.d.). *IoT for Good Lab*. Retrieved July 20, 2020, from https://www.babson.edu/academics/centers-and-institutes/the-lewis-institute/action-tanks/iot-for-good/

Baker, L. M. (1999). Use of problem-based learning in a basic reference course. *Journal of Education for Library and Information Science*, *40*(1), 66–69. https://doi.org/10.2307/40324298

Banica, L., Burtescu, E., & Enescu, F. (2017). The impact of Internet-of-Things in higher education. *Scientific Bulletin - Economic Sciences*, *16*(1), 53–59.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, *13*(1), 1–14. https://doi.org/10.1207/s15327809jls1301_1

Bekker, T., Bakker, S., Douma, I., van der Poel, J., & Scheltenaar, K. (2015). Teaching children digital literacy through design-based learning with digital toolkits in schools. *International Journal of Child-Computer Interaction*, *5*, 29–38. https://doi.org/10.1016/j.ijcci.2015.12.001

Bell, D. V. J. (2016). Twenty-first century education: Transformative education for sustainability and responsible citizenship. *Journal of Teacher Education for Sustainability*, *18*(1), 48–56. https://doi.org/10.1515/jtes-2016-0004

Bevan, B., Petrich, M., & Wilkinson, K. (2014). Tinkering is serious play. *Educational Leadership*, *72*(4), 28–33.

Bieraugel, M., & Neill, S. (2017). Ascending Bloom's pyramid: Fostering student creativity and innovation in academic library spaces. *College & Research Libraries*, *78*(1), 35–52. https://doi.org/10.5860/crl.78.1.35

Biggs, J. (2015, January 12). Teddy the Guardian, the protective plushie, gets $400k in seed investment. *TechCrunch*. https://social.techcrunch.com/2015/01/12/teddy-the-guardian-the-protective-plushie-gets-400k-in-seed-investment/

Blackley, S., Sheffield, R., Maynard, N., Koul, R., & Walker, R. (2017). Makerspace and reflective practice: Advancing pre-service teachers in STEM education. *Australian Journal of Teacher Education*, *42*(3), 22–37.

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs: Of machines, makers and inventors* (pp. 1–21). Transcript Publishers. https://doi.org/10.14361/transcript.9783839423820.203

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *23*(3 & 4), 369–398.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brown, J. S., & Adler, R. P. (2008). Open education, the long tail, and learning 2.0. *Educause Review*, *43*(1), 17–32.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42. https://doi.org/10.3102/0013189X018001032

Brown, T. (2009). *Change by design: How design thinking transforms organizations and inspires innovation*. Harper Business.

Buchanan, S. M. C., Harlan, M. A., Bruce, C., & Edwards, S. (2016). Inquiry based learning models, information literacy, and student engagement: A literature review. *School Libraries Worldwide*, *22*(2), 23–39.

Buldu, M. (2010). Making learning visible in kindergarten classrooms: Pedagogical documentation as a formative assessment technique. *Teaching and Teacher Education*, *26*(7), 1439–1449. https://doi.org/10.1016/j.tate.2010.05.003

Burd, B., Barker, L., Divitini, M., Perez, F. A. F., Russell, I., Siever, B., & Tudor, L. (2018). Courses, content, and tools for Internet of Things in computer science education. *Proceedings of the 2017 ITiCSE Conference on Working Group Reports (ITiCSE-WGR '17)*, 125–139. https://doi.org/10.1145/3174781.3174788

Cahn, P. S., Bzowyckyj, A., Collins, L., Dow, A., Goodell, K., Johnson, A. F., Klocko, D., Knab, M., Parker, K., Reeves, S., & Zierler, B. K. (2016). A design thinking approach to evaluating interprofessional education. *Journal of Interprofessional Care*, *30*(3), 378–380. https://doi.org/10.3109/13561820.2015.1122582

Cajide, J. (2015). *The connected school: How IoT could impact education*. HuffPost. https://www.huffpost.com/entry/the-connected-school-how-_b_8521612

Canadian Automobile Association. (n.d.). *Distracted driving*. CAA National. Retrieved July 31, 2021, from https://www.caa.ca/driving-safely/distracted-driving/

Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, & Social Sciences and Humanities Research Council. (2018). *Tri-council policy statement: Ethical conduct for research involving humans*. http://publications.gc.ca/collections/collection_2019/irsc-cihr/RR4-2-2019-eng.pdf

Carlisle, L. R., Jackson, B. W., & George, A. (2006). Principles of social justice education: The Social Justice Education in Schools project. *Equity & Excellence in Education*, *39*(1), 55–64. https://doi.org/10.1080/10665680500478809

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination, and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education*, *29*(1), 37–53. https://doi.org/10.1111/j.1476-8070.2010.01632.x

CASEL. (2013). *Effective social and emotional learning programs: Preschool and elementary school edition*. Collaborative for Academic, Social, and Emotional Learning. https://casel.org/wp-content/uploads/2016/01/2013-casel-guide.pdf

Chachra, D. (2015, January 23). *Why I am not a maker*. The Atlantic. https://www.theatlantic.com/technology/archive/2015/01/why-i-am-not-a-maker/384767/

Charlton, P., & Avramides, K. (2016). Knowledge construction in computer science and engineering when learning through making. *IEEE Transactions on Learning Technologies*, *9*(4), 379–390. https://doi.org/10.1109/TLT.2016.2627567

Chin, A., & Jacobsson, T. (2016). TheGoals.org: Mobile global education on the Sustainable Development Goals. *Journal of Cleaner Production*, *123*, 227–229. https://doi.org/10.1016/j.jclepro.2015.08.061

Chin, J., & Callaghan, V. (2013). *Educational living labs: A novel Internet-of-Things based approach to teaching and research* [Paper presentation]. 9th International Conference on Intelligent Environments, 92–99. https://doi.org/10.1109/IE.2013.48

Chounta, I.-A., Manske, S., & Hoppe, H. U. (2017). "From making to learning": Introducing dev camps as an educational paradigm for re-inventing problem-based learning. *International Journal of Educational Technology in Higher Education*, *14*(21), 1–15. https://doi.org/10.1186/s41239-017-0061-2

CKNW Kids' Fund. (n.d.). *Pink Shirt Day*. Pink Shirt Day. Retrieved July 24, 2021, from https://www.pinkshirtday.ca

Cocciolo, A. (2011). Situating student learning in rich contexts: A constructionist approach to digital archives education. *Evidence Based Library and Information Practice*, *6*(3), 4–15. https://doi.org/10.18438/B8DP6N

Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches* (3rd ed.). SAGE Publications Ltd.

Davis, T. (2017). The Internet of Things for kids. *Science and Children*, *54*(9), 84–91.

de Graaff, E., & Kolmos, A. (2007). History of problem-based and project-based learning. In E. de Graaff & A. Kolmos (Eds.), *Management of change: Implementation of problem-based and project-based learning in engineering* (pp. 1–8). Sense Publishers. https://doi.org/10.1007/978-0-387-09829-6_13

Dexter Industries. (n.d.). *GrovePi Starter Kit*. Retrieved October 4, 2021, from https://www.dexterindustries.com/GrovePi/get-started-with-the-grovepi/grove-pi-starter-kit/

DiCicco Cozzolino, M. (2016). Global citizenship education within a context of accountability and 21st century skills: The case of Olympus High School. *Education Policy Analysis Archives*, *24*(57), 1–26. https://doi.org/10.14507/epaa.24.2364

Digital Dream Labs. (n.d.). *Vector: Alive and aware*. Digital Dream Labs. Retrieved December 18, 2020, from https://www.digitaldreamlabs.com/pages/aware

Divitini, M., Giannakos, M. N., Mora, S., Papavlasopoulou, S., & Iversen, O. S. (2017). Make2Learn with IoT: Engaging children into joyful design and making of interactive connected objects. *Proceedings of the 2017 Conference on Interaction Design and Children*, 757–760. https://doi.org/10.1145/3078072.3081312

Doppelt, Y. (2009). Assessing creative thinking in design-based learning. *International Journal of Technology and Design Education*, *19*(1), 55–65. https://doi.org/10.1007/s10798-006-9008-y

Dover, A. G. (2009). Teaching for social justice and K-12 student outcomes: A conceptual framework and research review. *Equity & Excellence in Education*, *42*(4), 506–524. https://doi.org/10.1080/10665680903196339

Feinstein, N. W., & Carlton, G. (2013). Education for sustainability in the K-12 educational system of the United States. In R. McKeown & V. Nolet (Eds.), *Schooling for Sustainable Development in Canada and the United States* (pp. 37–49). Springer Netherlands. https://doi.org/10.1007/978-94-007-4273-4_3

Flanagan, K., Windley, B., & Cook, J. R. (2014, January 14). *Life simplified with connected devices* [YouTube video]. https://youtu.be/NjYTzvAVozo

Freeman, A., Adams Becker, S., Cummins, M., Davis, A., & Hall Giesinger, C. (2017). *NMC/CoSN Horizon Report: 2017 K-12 Edition*. The New Media Consortium.

Freire, P. (2005). *Pedagogy of the oppressed* (M. B. Ramos, Trans.; 30th anniversary ed.). The Continuum International Publishing Group.

Fw:Thinking. (2013, March 1). *What is The Internet of Things?* [YouTube video]. https://youtu.be/LVlT4sX6uVs

Galesic, M., & Bosnjak, M. (2009). Effects of questionnaire length on participation and indicators of response quality in a web survey. *Public Opinion Quarterly*, *73*(2), 349–360. https://doi.org/10.1093/poq/nfp031

Gallup. (2019). *Creativity in learning*. Gallup Inc. https://www.gallup.com/education/267449/creativity-learning-transformative-technology-gallup-report-2019.aspx

Garber, E. (2004). Social justice and art education. *Visual Arts Research*, *30*(2), 4–22. JSTOR.

Garcia, I. A., & Cano, E. M. (2014). Designing and implementing a constructionist approach for improving the teaching-learning process in the embedded systems and wireless communications areas. *Computer Applications in Engineering Education*, *22*(3), 481–493. https://doi.org/10.1002/cae.20574

Gershenfeld, N. A. (1999). *When things start to think*. Henry Holt and Company.

Giroux, H. A. (1985). Critical pedagogy, cultural politics and the discourse of experience. *The Journal of Education*, *167*(2), 22–41.

Giroux, H. A. (2004). Critical pedagogy and the postmodern/modern divide: Towards a pedagogy of democratization. *Teacher Education Quarterly*, *31*(1), 31–47.

Gobble, M. M. (2014). Design thinking. *Research Technology Management*, *57*(3), 59–60.

Godhe, A.-L., Lilja, P., & Selwyn, N. (2019). Making sense of making: Critical issues in the integration of maker education into schools. *Technology, Pedagogy and Education*, *28*(3), 317–328. https://doi.org/10.1080/1475939X.2019.1610040

Gómez, J., Huete, J. F., Hoyos, O., Perez, L., & Grigori, D. (2013). Interaction system based on Internet of Things as support for education. *Procedia Computer Science*, *21*, 132–139. https://doi.org/10.1016/j.procs.2013.09.019

Google Nest. (n.d.). *Nest doorbell*. Google Store. Retrieved September 30, 2021, from https://store.google.com/ca/product/nest_hello_doorbell

Green, A. (2020). *Staff of 2030: Future-ready teaching*. The Economist Intelligence Unit. https://clouddamcdnprodep.azureedge.net/gdc/gdc0bLWb9/original?ocid=mkto_eml_168508

Guo, L. (2014). Preparing teachers to educate for 21st century global citizenship: Envisioning and enacting. *Journal of Global Citizenship & Equity Education*, *4*(1), 1–23.

Gutwill, J. P., Hido, N., & Sindorf, L. (2015). Research to practice: Observing learning in tinkering activities. *Curator: The Museum Journal*, *58*(2), 151–168. https://doi.org/10.1111/cura.12105

Hackman, H. W. (2005). Five essential components for social justice education. *Equity & Excellence in Education*, *38*(2), 103–109. https://doi.org/10.1080/10665680590935034

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review*, *84*(4), 495–504. https://doi.org/10.17763/haer.84.4.34j1g68140382063

Harrison, H., Birks, M., Franklin, R., & Mills, J. (2017). Case study research: Foundations and methodological orientations. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *18*(1), Article 19. https://doi.org/10.17169/fqs-18.1.2655

Harron, J. R., & Hughes, J. E. (2018). Spacemakers: A leadership perspective on curriculum and the purpose of K–12 educational makerspaces. *Journal of Research on Technology in Education*, *50*(3), 253–270. https://doi.org/10.1080/15391523.2018.1461038

Harshman, J. R., & Augustine, T. A. (2013). Fostering global citizenship education for teachers through online research. *The Educational Forum*, *77*(4), 450–463. https://doi.org/10.1080/00131725.2013.822040

Hira, A., Joslyn, C. H., & Hynes, M. M. (2014). Classroom makerspaces: Identifying the opportunities and challenges. *2014 IEEE Frontiers in Education (FIE) Conference Proceedings*, 1–5. https://doi.org/10.1109/FIE.2014.7044263

Hughes, J. (2017). *Meaningful making: Establishing a makerspace in your school or classroom*. What Works? Research Into Practice. http://www.edu.gov.on.ca/eng/literacynumeracy/inspire/research/meaningful_making.html

Hughes, J., Fridman, L., & Morrison, L. (2017). *Perspectives on making as a pedagogical approach* [Paper presentation]. International Council on Education for Teaching (ICET) 61st World Assembly, Masaryk University, Czech Republic.

Hughes, J. M., Morrison, L. J., Kajamaa, A., & Kumpulainen, K. (2019). Makerspaces promoting students' design thinking and collective knowledge creation: Examples from Canada and Finland. In A. L. Brooks, E. Brooks, & C. Sylla (Eds.), *Interactivity, Game Creation, Design, Learning, and Innovation* (pp. 343–352). Springer International Publishing. https://doi.org/10.1007/978-3-030-06134-0_38

Hughes, J., & Morrison, L. J. (2018). The use of e-textiles in Ontario education. *Canadian Journal of Education/Revue Canadienne de l'éducation*, *41*(1), 356–384.

Hughes, J., Thompson, S., & Morrison, L. (2018, April 15). *Science 3D: Discovery, design and development through makerspaces* [Paper presentation]. 2018 Annual Meeting of the American Educational Research Association (AERA), New York, NY. AERA Online Paper Repository

Hung, W., Jonassen, D. H., & Liu, R. (2008). Problem-based learning. In J. M. Spector, J. van Merriënboer, M. D. Merrill, & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 485–506). Routledge.

InkSmith. (n.d.-a). *K8 robotics kit*. InkSmith Education Technology. Retrieved August 4, 2021, from https://www.inksmith.ca/pages/k8-robotics-kit

InkSmith. (n.d.-b). *Land climate action kit*. Retrieved July 13, 2020, from https://inksmith.teachable.com/courses/630901

International Telecommunication Union. (2018, January 23). *UN broadband commission sets global broadband targets to bring online the world's 3.8 billion not connected to the Internet*. ITU. https://www.itu.int/en/mediacentre/Pages/2018-PR01.aspx

Internationella Stiftelsen Young Masters Programme. (2017). *TheGoals.org*. TheGoals.Org. http://www.thegoals.org/

Jewitt, C. (2008). Multimodality and literacy in school classrooms. *Review of Research in Education*, *32*, 241–267. https://doi.org/10.3102/0091732X07310586

Kafai, Y. B., & Burke, Q. (2017). Computational participation: Teaching kids to create and connect through code. In P. J. Rich & C. B. Hodges (Eds.), *Emerging research, practice, and policy on computational thinking* (pp. 393–405). Springer International Publishing. https://doi.org/10.1007/978-3-319-52691-1

Kafai, Y. B., & Burke, Q. (2013). The social turn in K-12 programming: Moving from computational thinking to computational participation. In R. McCauley, T. Camp, P. Tymann, J. D. Dougherty, & K. Nagel (Eds.), *Proceedings of the 44th ACM Technical Symposium on Computer Science Education (SIGCSE '13)*. Association for Computing Machinery. https://doi.org/10.1145/2445196.2445373

Kafai, Y. B., & Peppler, K. A. (2011). Youth, technology, and DIY: Developing participatory competencies in creative media production. *Review of Research in Education*, *35*(1), 89–119. https://doi.org/10.3102/0091732X10383211

Kennedy-Clark, S. (2013). Research by design: Design-based research and the higher degree research student. *Journal of Learning Design*, *6*(2), 26–32. https://doi.org/10.5204/jld.v6i2.128

Kincheloe, J. L., & McLaren, P. (2011). Rethinking critical theory and qualitative research. In K. Hayes, S. R. Steinberg, & K. Tobin (Eds.), *Key works in critical pedagogy* (Vol. 32, pp. 285–326). Sense Publishers.

Kincheloe, J. L., McLaren, P., Steinberg, S. R., & Monzó, L. D. (2017). Critical pedagogy and qualitative research: Advancing the bricolage. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (5th ed., pp. 235–260). SAGE Publications.

Koo, S. G. M. (2015). An integrated curriculum for Internet of Things: Experience and evaluation. *Proceedings of the 2015 IEEE Frontiers in Education Conference (FIE)*, 1–4. https://doi.org/10.1109/FIE.2015.7344347

Kortuem, G., Bandara, A. K., Smith, N., Richards, M., & Petre, M. (2013). Educating the Internet-of-Things generation. *Computer*, *46*(2), 53–61. https://doi.org/10.1109/MC.2012.390

Kupfer, M. (2016, December 21). *CRTC declares broadband internet access a basic service*. CBC News. https://www.cbc.ca/news/politics/crtc-internet-essential-service-1.3906664

Kurti, R. S., Kurti, D. L., & Fleming, L. (2014). The philosophy of educational makerspaces. *Teacher Librarian*, *41*(5), 8–11.

Kwon, B.-R., & Lee, J. (2017). What makes a maker: The motivation for the maker movement in ICT. *Information Technology for Development*, *23*(2), 318–335. https://doi.org/10.1080/02681102.2016.1238816

Kynigos, C. (2015). Constructionism: Theory of learning or theory of design? In S. J. Cho (Ed.), *Selected Regular Lectures from the 12th International Congress on Mathematical Education* (pp. 417–438). Springer International Publishing. https://doi.org/10.1007/978-3-319-17187-6_24

Lather, P. (1986). Research as praxis. *Harvard Educational Review*, *56*(3), 257–277.

Leiserson, C. E., Thompson, N. C., Emer, J. S., Kuszmaul, B. C., Lampson, B. W., Sanchez, D., & Schardl, T. B. (2020). There's plenty of room at the top: What will drive computer performance after Moore's law? *Science*, *368*(6495), eaam9744. https://doi.org/10.1126/science.aam9744

Leydens, J. A., Lucena, J. C., & Nieusma, D. (2014). What is design for social justice? *Proceedings of the 121st ASEE Annual Conference & Exposition*. https://peer.asee.org/23301

Lincoln, Y. S., & Guba, E. G. (1985). Establishing trustworthiness. In *Naturalistic inquiry* (pp. 289–327). SAGE Publications Ltd.

Lock, J., Gill, D., Kennedy, T., Piper, S., & Powell, A. (2020). Fostering learning through making: Perspectives from the International Maker Education Network. *International Journal of E-Learning & Distance Education*, *35*(1), 1–26.

Luksha, P., Cubista, J., Laszlo, A., Popovich, M., & Ninenko, I. (2018). *Global education futures report: Educational ecosystems for societal transformation*. Global Education Futures.

Lyles, A. (2018, May). *Taking a stand: Do civically active youth turn out any different from the rest?* Psychology Today. https://www.psychologytoday.com/us/articles/201805/taking-stand

Maia, R. F., & Filho, A. P. A. (2018). A proposal of an educational approach based on the application of Internet of Things and urban agriculture concepts to motivate and improve learning outcomes. *Proceedings of the 14th International Conference on Frontiers in Education: Computer Science and Computer Engineering (FECS '18)*, 235–239. https://doi.org/10.18356/8519891f-en

Manches, A., Duncan, P., Plowman, L., & Sabeti, S. (2015). Three questions about the Internet of things and children. *TechTrends*, *59*(1), 76–83. https://doi.org/10.1007/s11528-014-0824-8

Mann, S. (2014). Maktivism: Authentic making for technology in the service of humanity. In *DIY citizenship: Critical making and social media* (pp. 29–51). The MIT Press.

Marsh, J., Arnseth, H. C., & Kumpulainen, K. (2018). Maker literacies and maker citizenship in the MakEY (Makerspaces in the Early Years) project. *Multimodal Technologies and Interaction*, *2*(3), 50. https://doi.org/10.3390/mti2030050

Marsh, J., Wood, E., Chesworth, L., Nisha, B., Nutbrown, B., & Olney, B. (2019). Makerspaces in early childhood education: Principles of pedagogy and practice. *Mind, Culture, and Activity*, *26*(3), 221–233. https://doi.org/10.1080/10749039.2019.1655651

Marshall, J. A., & Harron, J. R. (2018). Making learners: A framework for evaluating making in STEM education. *Interdisciplinary Journal of Problem-Based Learning*, *12*(2). https://doi.org/10.7771/1541-5015.1749

Marshall, M. N. (1996). Sampling for qualitative research. *Family Practice*, *13*(6), 522–525.

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research*, *5*(1), 30–39. https://doi.org/10.7771/2157-9288.1099

Mas'ud, B., Fachruddin, A. T. C., & Syamsinar, S. (2019). Promoting passion-based learning as a solution of improving creativity in English classroom. *Inspiring: English Education Journal*, *2*(2), 165–179.

McLaughlin, N. (1999). Origin myths in the social sciences: Fromm, the Frankfurt school and the emergence of critical theory. *Canadian Journal of Sociology / Cahiers Canadiens de Sociologie*, *24*(1), 109–139. https://doi.org/10.2307/3341480

McLeod, S. A. (2018, January 14). *Concrete operational stage.* Simply Psychology. https://www.simplypsychology.org/concrete-operational.html

McRae, L., Ellis, K., & Kent, M. (2018). *Internet of Things (IoT): Education and technology: The relationship between education and technology for students with disabilities*. Curtin University.

Meola, A. (2020, March 12). *Applications of Internet of Things technology in the education sector*. Business Insider. https://www.businessinsider.com/iot-technology-education

Micro:bit Educational Foundation. (n.d.). *Micro:bit*. Retrieved December 18, 2020, from https://microbit.org/

Miles, M. B., Huberman, A. M., & Saldaña, J. (2020). *Qualitative data analysis: A methods sourcebook* (4th ed.). SAGE Publications Ltd.

Mora, S., Gianni, F., & Divitini, M. (n.d.). *Tiles IoT inventor toolkit*. Retrieved June 12, 2020, from https://www.tilestoolkit.io/

Nall, R. (2018, April 18). *Does the 20-20-20 rule prevent eye strain?* Medical News Today. https://www.medicalnewstoday.com/articles/321536

Nascimento, S., & Pólvora, A. (2018). Maker cultures and the prospects for technological action. *Science and Engineering Ethics*, *24*(3), 927–946. https://doi.org/10.1007/s11948-016-9796-8

National Institute of Standards and Technology. (2018, April 26). *What is the Internet of Things (IoT) and how can we secure it?* [YouTube video]. https://youtu.be/H_X6IP1-NDc

Nemorin, S., & Selwyn, N. (2017). Making the best of it? Exploring the realities of 3D printing in school. *Research Papers in Education*, *32*(5), 578–595. https://doi.org/10.1080/02671522.2016.1225802

Neuendorf, K. A. (2019). Content analysis and thematic analysis. In P. Brough (Ed.), *Advanced research methods for applied psychology: Design, analysis and reporting* (pp. 211–223). Routledge.

Noss, R., & Clayson, J. (2015). Reconstructing constructionism. *Constructivist Foundations*, *10*(3), 285–288.

Ontario Ministry of Education. (2007). *Ready, set, green!* Queen's Printer for Ontario.

Ontario Ministry of Education. (2016). *21st century competencies: Foundation document for discussion*. Queen's Printer for Ontario.

Ontario Ministry of Education. (2018). *The Ontario curriculum: Social studies (grades 1 to 6), history and geography (grades 7 and 8)*. Queen's Printer for Ontario.

Ontario Ministry of Education. (2020). *The Ontario curriculum: Mathematics (grades 1 to 8)*. Queen's Printer for Ontario.

Orton-Johnson, K. (2014). DIY citizenship, critical making, and community. In *DIY citizenship: Critical making and social media* (pp. 141–155). The MIT Press.

Papavlasopoulou, S., Giannakos, M. N., & Jaccheri, L. (2017). Empirical studies on the maker movement, a promising approach to learning: A literature review. *Entertainment Computing*, *18*, 57–78. https://doi.org/10.1016/j.entcom.2016.09.002

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books.

Papert, S., & Harel, I. (1991). Situating constructionism. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 1–11). Ablex Publishing. https://web.media.mit.edu/~calla/web_comunidad/Reading-En/situating_constructionism.pdf

Patton, M. Q. (2015). *Qualitative research & evaluation methods: Integrating theory and practice* (4th ed.). SAGE Publications Ltd.

Pei, X. L., Wang, X., Wang, Y. F., & Li, M. K. (2013). Internet of Things based education: Definition, benefits, and challenges. *Applied Mechanics and Materials*, *411–414*, 2947–2951. https://doi.org/10.4028/www.scientific.net/AMM.411-414.2947

Penzenstadler, B., Khakurel, J., Plojo, C. J., Sanchez, M., Marin, R., & Tran, L. (2018). Resilient smart gardens—Exploration of a blueprint. *Sustainability*, *10*(8), 2654. https://doi.org/10.3390/su10082654

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*, *31*, 31–43. https://doi.org/10.1016/j.tsc.2018.10.002

Piaget, J. (1952). *The origins of intelligence in children* (M. Cook, Trans.). International University Press.

Piaget, J. (1964). Part I: Cognitive development in children. *Journal of Research in Science Teaching*, *2*, 176–186.

Pixel Press Technology. (n.d.). *Bloxels EDU*. Retrieved December 18, 2020, from https://edu.bloxelsbuilder.com/

Popplet lite (Version 2.5.1). (n.d.). [Computer software]. Notion Inc. https://www.popplet.com/

Psenka, C. E., Kim, K.-Y., Okudan Kremer, G. E., Haapala, K. R., & Jackson, K. L. (2017). Translating constructionist learning to engineering design education. *Journal of Integrated Design and Process Science*, *21*(2), 3–20. https://doi.org/10.3233/jid-2017-0004

Putjorn, P., Siriaraya, P., Deravi, F., & Ang, C. S. (2018). Investigating the use of sensor-based IoET to facilitate learning for children in rural Thailand. *PLoS ONE*, *13*(8), e0201875. https://doi.org/10.1371/journal.pone.0201875

Raikar, M. M., Desai, P., & Naragund, J. G. (2016). Active learning explored in open elective course: Internet of Things (IoT). *Proceedings of the 2016 IEEE 8th International Conference on Technology for Education (T4E)*, 15–18. https://doi.org/10.1109/T4E.2016.012

Rainie, L., & Anderson, J. (2017, June 6). *The Internet of Things connectivity binge: What are the implications?* Pew Research Center: Internet & Technology. https://www.pewresearch.org/internet/2017/06/06/the-internet-of-things-connectivity-binge-what-are-the-implications/

Ratto, M. (2011). Critical making: Conceptual and material studies in technology and social life. *The Information Society*, *27*(4), 252–260. https://doi.org/10.1080/01972243.2011.583819

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research*, *82*(3), 330–348. https://doi.org/10.3102/0034654312457429

Resnick, M., & Rosenbaum, E. (2013). Designing for tinkerability. In M. Honey & D. E. Kanter (Eds.), *Design, make, play* (pp. 163–181). Routledge.

Resnick, M., & Silverman, B. (2005). Some reflections on designing construction kits for kids. *Proceeding of the 2005 Conference on Interaction Design and Children - IDC '05*, 117–122. https://doi.org/10.1145/1109540.1109556

Ring. (n.d.). *Home security systems | Smart home automation*. Ring. Retrieved September 30, 2021, from https://ring.com

Robertson, J. A. (2013). *Passion-based learning: The design and implementation of a new approach to project-based learning (PBL) for alternative education* [Dissertation]. Simon Fraser University.

Ronen, E., O'Flynn, C., Shamir, A., & Weingarten, A.-O. (2017). IoT goes nuclear: Creating a ZigBee chain reaction. *Proceedings of the 2017 IEEE Symposium on Security and Privacy*, 195–212. https://doi.org/10.1109/SP.2017.14

Schneier, B. (2016, July 25). *The Internet of Things will turn large-scale hacks into real world disasters*. Motherboard: Tech by Vice. https://www.vice.com/en_us/article/qkjzwp/the-internet-of-things-will-cause-the-first-ever-large-scale-internet-disaster

Scott, K. A., & White, M. A. (2013). COMPUGIRLS' standpoint: Culturally responsive computing and its effect on girls of color. *Urban Education*, *48*(5), 657–681. https://doi.org/10.1177/0042085913491219

Scoville, T., Pham, M., & Lartigue, J. (2014). Promoting K-8 learning using Oculus Rift: Employing virtual reality to increase learning outcomes in elementary biology. In T. Bastiaens (Ed.), *Proceedings of World Conference on E-Learning* (pp. 1100–1105). Association for the Advancement of Computing in Education (AACE). http://www.learntechlib.org/primary/p/148954/

Seesaw. (n.d.). *Seesaw class* (Version 7.2.5) [Computer software]. Seesaw Learning Inc. https://web.seesaw.me

Selinger, M., Sepulveda, A., & Buchan, J. (2013). *Education and the Internet of Everything: How ubiquitous connectedness can help transform pedagogy*. Cisco. https://www.cisco.com/c/dam/en_us/solutions/industries/docs/education/education_internet.pdf

Shapiro, L., & Levy, A. (2009, February 5). Resource: Community building activities. *Teachers for Social Justice*. http://www.teachersforjustice.org/2009/02/resource-community-building-activities.html

Sheridan, K., Halverson, E. R., Litts, B. K., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review*, *84*(4), 505–531. https://doi.org/10.17763/haer.84.4.brr34733723j648u

Sheridan, K. M., Konopasky, A. W., Williams, A., & Wingo, G. J. J. (2016). Resourceful and inclusive: Towards design principles for makerspaces. *Paper Presented at the 2016 Annual Meeting of the American Educational Research Association*, 1–27.

Simionescu, S. (2017). Reasons for and benefits of teaching Internet of Things basics in the eve of the 4th industrial revolution. *Proceedings of BCI '17*, 1–7. https://doi.org/10.1145/3136273.3136285

Sinha, S. (2021, September 22). State of IoT 2021: Number of connected IoT devices growing 9% to 12.3 billion globally, cellular IoT now surpassing 2 billion. *IoT Analytics: Market Insights for the Internet of Things*. https://iot-analytics.com/number-connected-iot-devices/

Sivaraj, R., Ellis, J. A., Wieselmann, J. R., & Roehrig, G. H. (2020). Computational participation and the learner-technology pairing in K-12 STEM education. *Human Behavior and Emerging Technologies*, *2*(4), 387–400. https://doi.org/10.1002/hbe2.220

Smith, R. C., Iversen, O. S., & Hjorth, M. (2015). Design thinking for digital fabrication in education. *International Journal of Child-Computer Interaction*, *5*, 20–28. https://doi.org/10.1016/j.ijcci.2015.10.002

Smith, W., & Smith, B. C. (2016). Bringing the maker movement to school. *Science and Children*, *54*(1), 30–37.

Spencer, J., & Juliani, A. J. (2016). *Launch: Using design thinking to boost creativity and bring out the maker in every student*. Dave Burgess Consulting, Inc.

Sphero Inc. (n.d.-a). *Getting started with your CloudBit*. LittleBits Classroom. Retrieved October 4, 2021, from https://auth.littlebits.com/cloudstart

Sphero Inc. (n.d.-b). *LittleBits Rule Your Room Kit*. Sphero LittleBits. Retrieved October 4, 2021, from https://sphero.com/products/rule-your-room-kit

Sphero Inc. (n.d.-c). *The littleBits classroom*. Retrieved December 18, 2020, from https://classroom.littlebits.com/welcome

Stager, G. S. (2013). Papert's prison fab lab: Implications for the maker movement and education design. *Proceedings of the 12th International Conference on Interaction Design and Children*, 487–490. https://doi.org/10.1145/2485760.2485811

Stake, R. E. (2006). *Multiple case study analysis*. The Guilford Press.

Stevenson, M., Bower, M., Falloon, G., Forbes, A., & Hatzigianni, M. (2019). By design: Professional learning ecologies to develop primary school teachers' makerspaces pedagogical capabilities. *British Journal of Educational Technology*, *50*(3), 1260–1274. https://doi.org/10.1111/bjet.12743

Tan, E., & Barton, A. C. (2018). Towards critical justice: Exploring intersectionality in community-based STEM-rich making with youth from non-dominant communities. *Equity & Excellence in Education*, *51*(1), 48–61. https://doi.org/10.1080/10665684.2018.1439786

Teicher, J. (2018, February 7). *The little-known story of the first IoT device*. IBM: Industrious. https://www.ibm.com/blogs/industries/little-known-story-first-iot-device/

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5–8. https://doi.org/10.3102/0013189X032001005

The Works Museum. (2015). *Engineering design process*. The Works Museum. https://theworks.org/educators-and-groups/elementary-engineering-resources/engineering-design-process/

Thumlert, K., de Castell, S., & Jenson, J. (2015). Short cuts and extended techniques: Rethinking relations between technology and educational theory. *Educational Philosophy and Theory*, *47*(8), 786–803. https://doi.org/10.1080/00131857.2014.901163

United Nations. (n.d.). *About the Sustainable Development Goals*. United Nations Sustainable Development. Retrieved June 3, 2020, from https://www.un.org/sustainabledevelopment/sustainable-development-goals/

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. United Nations Sustainable Development Goals Knowledge Platform. https://sustainabledevelopment.un.org/post2015/transformingourworld

Valpreda, F., & Zonda, I. (2016). Grüt: A gardening sensor kit for children. *Sensors*, *16*(2), 231. https://doi.org/10.3390/s16020231

Vega, V., & Robb, M. B. (2019). *The Common Sense census: Inside the 21st-century classroom*. Common Sense Media.

Voas, J. (2016). *Networks of "Things"* (NIST Special Publication No. 800–183; pp. 1–25). National Institute of Standards and Technology. http://doi.org/10.6028/NIST.SP.800-183

Voas, J., & Laplante, P. (2017). Curriculum considerations for the Internet of Things. *Computer*, *50*(1), 72–75. https://doi.org/10.1109/MC.2017.27

Vongkulluksn, V. W., Matewos, A. M., Sinatra, G. M., & Marsh, J. A. (2018). Motivational factors in makerspaces: A mixed methods study of elementary school students' situational interest, self-efficacy, and achievement emotions. *International Journal of STEM Education*, *5*(43), 1–19. https://doi.org/10.1186/s40594-018-0129-0

Vossoughi, S., & Bevan, B. (2014). *Making and tinkering: A review of the literature* (pp. 1–55). National Research Council Committee on Out of School Time STEM.

Vossoughi, S., Hooper, P. K., & Escudé, M. (2016). Making through the lens of culture and power: Toward transformative visions for educational equity. *Harvard Educational Review*, *86*(2), 206–232. https://doi.org/10.17763/0017-8055.86.2.206

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press.

Warming, H., & Fahnøe, K. (2017). Social work and lived citizenship. In H. Warming & K. Fahnøe (Eds.), *Lived citizenship on the edge of society: Rights, belonging, intimate life and spatiality*. Springer Nature. https://doi.org/10.1007/978-3-319-55068-8_1

Weiner, S. (2021, July 20). *The growing threat of ransomware attacks on hospitals*. Association of American Medical Colleges. https://www.aamc.org/news-insights/growing-threat-ransomware-attacks-hospitals

Yilmaz, R. M., & Goktas, Y. (2017). Using augmented reality technology in storytelling activities: Examining elementary students' narrative skill and creativity. *Virtual Reality*, *21*(2), 75–89. https://doi.org/10.1007/s10055-016-0300-1

Zimmerman, E. (2018, July 27). *The 4 C's of learning in a connected classroom*. EdTech. https://edtechmagazine.com/k12/article/2018/07/4-cs-learning-connected-classroom

Appendices

Appendix A – ChangeMakers Camp Advertising

CHANGEMAKERS MARCH BREAK CAMP

March 11th - March 15th, 2019

WHAT'S THE CAMP ABOUT?

We are pleased to announce the return of our STEAM-3D Maker Lab's March Break Maker Camp! This year, students involved in our **ChangeMakers March Break Camp** will explore emerging technologies [including the Internet of Things (IoT)] to design and prototype an invention that could improve their lives (or the lives of others)! Students will have access to a variety of technologies to help them complete their projects, including 3D printing, circuit -building (paper, fabric, or other), coding, and more!

This year's **featured tools** include littleBits, micro:bits, Arduino and Raspberry Pi!

TO REGISTER:

Email **uoitsteam3D@gmail.com**.

Or, visit **bit.ly/STEAM3D-MBC2019** for more information.

BROUGHT TO YOU BY:

STEAM-3D Maker Lab

Western

INKSMITH

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

WHO?

Students in **grades 4 - 9** are welcome to register!

WHERE?

Camp will be held at the University of Ontario Institute of Technology's **Faculty of Education** building in downtown Oshawa:

11 Simcoe Street N.
Oshawa, ON L1H 7L7

WHEN?

Camp will run from **Monday March 11th to Friday March 15th**.

Camp hours are **9am - 3pm.**

Before- and After-Care are being offered for one hour beyond regular camp hours (8am - 4pm) for an extra fee.

HOW MUCH?

The base cost of camp is **$150 + taxes** per child.

Before- and After-Care is available for an extra $50.

This year, campers will be provided with lunch and a tech kit **free of charge!**

Appendix B – Digital Design Journals: Reflection Prompts

Monday March 11, 2019: Reflections

- If you were able to design your own civilization, what would you include?
- What kinds of things would be needed so that everyone could be healthy and happy?
- What kinds of technology would it include?

Tuesday March 12, 2019: Let's Make Change!

Today, we talked about some problems that could be solved with our "Internet of Things" inventions – like using too much electricity and monitoring gardens to feed people without enough food.

What other problems can you think of that we might be able to solve through our inventions? These can be problems that happen at your school (bullying), or bigger problems in the world (people living in unsafe areas).

Why are these issues important to you?

Tuesday March 12, 2019: Reflections

- What did you discover about the Internet of Things (IoT) today?
- What tools did you most enjoy using?
- What kinds of things could we make with these tools that would benefit the civilizations we talked about yesterday?

Wednesday March 13, 2019: Reflections

- Why did you choose your project and/or goal for the week?
- How do you think your creation could help improve other people's lives? Or improve a civilization?
- Do you think the Internet of Things (IoT) is a good thing or a bad thing? Why?

- What are your “next steps” for your invention? Are there any other maker tools that would help?

Thursday March 14, 2019: Reflections

- How do you think your project could work with the Internet of Things? (Example: Could you connect it to other stuff? Could you use the information your project collects?)

- Where would your project fit into a civilization? What kinds of people could it help?

- What do you need to finish up tomorrow?

Appendix C – Letter of Information & Consent Forms

ChangeMakers March Break Camp 2019
Request for Consent:

Our faculty is committed to engaging in ongoing research related to education. To that end, we are asking for both your consent and that of your child to participate in research connected to the activities in this March Break Camp. With the approval of the UOIT Research Ethics Board (REB #15-094), our goal is to evaluate the impact of production pedagogies (described below) and emerging technologies such as the Internet of Things (IoT) on students' perceptions of and involvement with civic engagement and social justice. Participation in the research component of this camp is entirely optional and students will not be penalized in any way if they do not participate.

Production pedagogies are student-centred approaches to teaching and learning, drawing on constructivism, constructionism, project- and problem-based learning to create an environment in which important questions, big-picture projects, and *making* drive the learning process. In contrast to the 'transmission' model of the traditional classroom (emphasizing a unidirectional flow of knowledge from teacher to student), makerspaces enable students -- or 'makers' -- to construct knowledge by working on projects and creating with physical and digital tools.

In these spaces, civic engagement and social justice can be explored through *critical making*. Beyond simply creating objects for the sake of doing so, critical making emphasizes the exploration and critique of social phenomena through the process of creating tangible or virtual artifacts, enabling students to draw their own conclusions through their engagement with multiple media.

Data will be collected from students at various times during the week. All activities will be a part of the regular camp program; however, only data collected from students who have consent from parents/guardians and who have consented themselves to participate in the research study will be used in the analysis and reporting of findings.

Participation in this research would involve the following commitments for your child:

1. **Presurveys:** At the beginning of camp, participants will be asked to complete a brief online questionnaire, which should take no longer than 15-20 minutes to complete. Questions will be related to their past experiences with making, digital technologies, as well as their perceptions of and experiences with civic engagement and social justice.

2. **Focus groups or open-ended interviews:** In small focus groups of 3-4 students or one-on-one informal interviews, participants will be asked to reflect on their experiences and learning during the camp.

3. In addition to using the above as data in our study, the research team will observe camp activities and interactions and collect data using observation notes, audio recordings, and video recordings of selected session proceedings. These recordings will be transcribed and students will be assigned a pseudonym; they will not be identified by name or using any other identifiable information. Copies of digital texts (videos, infographics, participant journals/reflections) and tangible products (3D printing, littleBits/Arduino projects, other constructed items) will also be collected as data and anonymized.

There are limited risks to participating in this study. However, we have outlined below the potential risks for yours and your child's consideration:

- First, there are some physical risks. Participants will be working with electrical components and other craft materials. They may also be standing or sitting for extended periods of time. To mitigate these risks, we will show the participants how to safely use all equipment (providing additional safety equipment where necessary) and will integrate physical activity breaks into the camp's schedule to ease sitting or standing for extended periods.

- Second, there are some psychological risks, such as participants being embarrassed or anxious if their digital/tangible products do not work or if they are not aesthetically pleasing. To mitigate this, we will ensure the participants understand that they have a right to pass and to not share their work if they do not wish to.

Please understand that this is a voluntary project aimed at improving students' academic achievement and skills. Your decision to allow your child to participate or not participate in this research has no effect on their ability to participate in any part of the program, nor will they be penalized in any way if they do not have consent to participate.

Your child may withdraw from the research without penalty, prejudice, or explanation at any time by informing one of the investigators, or by closing the survey on their browser (during the presurvey). The information your child provides will be accessible to the research team only. Pseudonyms will be assigned to each participant once the data has been collected and any images or video where participants are visible will be altered to obscure faces. Further, any names that are present on participant work will be removed before publication.

Data collected from interviews, questionnaires, and student work will be stored securely at UOIT under the lead researcher's supervision. Hard copies of transcripts will be kept in locked filing cabinets in the researchers' offices. We may engage in secondary use of data, which means we may use the information originally collected for this study in other ways (i.e., in other research/data analysis/publications). By consenting to participate, the participant does not waive any normal legal rights or recourse.

Dissemination of research results will be through standard academic means such as journal articles, conference presentations, and books. No participants will be identified by name.

Your signature and your child's signature on the following consent form indicates that you and they have read this letter together, understand/discussed its contents, and agree to participation in this research project. Any questions or concerns about the research can be directed to Dr. Janette Hughes (janette.hughes@uoit.ca; 905-721-8668, ext. 2875). You may also contact the Ethics and Compliance Officer (compliance@uoit.ca; 905-721-8668, ext. 3693).

Thank you for your voluntary participation this important research initiative.

Sincerely,
Dr. Janette Hughes
Professor and Canada Research Chair, Technology & Pedagogy
UOIT Faculty of Education

ChangeMakers March Break Camp 2019
Parent/Guardian & Student Consent to Participate in Research

Participant Concerns and Reporting:
If you or your child have any questions concerning the research or experience any discomfort related to the study, please contact the lead researcher (Dr. Janette Hughes) at 905-721-8668, ext. 2875 or janette.hughes@uoit.ca.

Any questions regarding your rights as a participant, complaints, or adverse events may be directed to the Research Ethics Board through the Ethics and Compliance Officer (compliance@uoit.ca; 905-721-8668, ext. 3693).

This study has been approved by the UOIT Research Ethics Board (REB #15-094).

Parent/Guardian & Student Consent:
By checking the boxes and signing below, my child and I indicate that we understand the risks, benefits, and procedures of this study and give consent for my child's participation. We understand that participation is voluntary and that my child is free to withdraw at any time without consequence. We also understand that my child's data will be kept confidential until such time as the ID key is destroyed, and that my child's data will then become anonymous and part of a larger set of data analysis for scholarly purposes, including but not limited to the creation of research articles and conference presentations. Finally, we understand that neither I nor my child is waiving any legal rights by signing this form.

	Parent/ Guardian	Student
I give consent for the results from the presurvey to be used anonymously in the research project.	☐	☐
I give consent for the results from any interviews to be used anonymously in the research project.	☐	☐
I give consent for the use of any (anonymized) photos, videos, or observations for the purpose of the research project.	☐	☐
I give consent for the use of any (anonymized) physical or digital artifacts created at camp for the purpose of the research project.	☐	☐

Parent/Guardian Name: ***(block capitals)***	
Parent/Guardian Signature:	
Date:	
Parent/Guardian Email Address:	

Student Name: ***(block capitals)***	
Student Signature:	
Date:	

Appendix D – Pre-Study Questionnaire

As described in Section 4.5.2, this questionnaire was developed in collaboration with another graduate student conducting research on an unrelated project during the ChangeMakers March Break camp. Two versions of the questionnaire were administered, each with a different question order.

For ease of comprehension, the questions considered for analysis in this thesis have been **bolded** in each version.

Version A

1. **What is your full name?**
2. **How old are you?**
3. **How do you describe yourself?**
   __ Female __ Male __ Prefer not to say __ Other: ______________________
4. **How often do you use technology at home?**
   __ Never __ Occasionally __ Sometimes __ Often __ Everyday
5. **What kind of technology do you enjoy using?**
6. What is your favourite school subject? Why?
7. What does a scientist or mathematician look like, to you?
8. Do you feel a difference in ability when surrounded by kids or students of another gender, versus a setting where it's only your gender? Please explain.
9. Have you had a female teach you STEM education? How many times (roughly)?
10. Do you envision yourself pursuing a job in a STEM-focused area (i.e., engineer, scientist, mathematician)? What kind of job would you like to do when you're older?
11. Who has had the greatest impact on your choice for a career path? Why do you think that?

12. Do you feel like boys are better than girls at science? Technology? Computing? Math?

13. What kinds of words would you use to describe your abilities in science?

14. What kinds of words would you use to describe your abilities in math?

15. **Have you ever heard of the "Internet of Things"? Or "Smart" homes / devices?**
    __ Yes __ No __ Maybe

    a. **What do you know about it? What do you think it means?**

16. **Do you believe you could use IoT to make your life better / easier / more exciting? Why / why not?**

17. **Do you believe you can create something with technology that could contribute to a better / easier / more fun life? Why / why not?**

18. **Do you believe you can create something with technology that could contribute to a better / easier life for someone else? Why / why not?**

19. **Have you ever heard of the terms "social justice" or "global citizenship"?**
    __ Yes __ No __ Maybe

    a. **What do you think these terms might mean?**

20. **Have you ever done or created something to improve someone else's life, either on your own or in school?**
    __ Yes __ No __ Maybe

    a. **If "yes", what did you do or create?**

Version B

1. **What is your full name?**

2. **How old are you?**

3. **How do you describe yourself?**
   __ Female __ Male __ Prefer not to say __ Other: ______________________

4. **How often do you use technology at home?**
   __ Never   __ Occasionally   __ Sometimes   __ Often   __ Everyday

5. **What kind of technology do you enjoy using?**

6. **Have you ever heard of the "Internet of Things"? Or "Smart" homes / devices?**
   __ Yes   __ No   __ Maybe

   a. **What do you know about it? What do you think it means?**

7. **Do you believe you could use IoT to make your life better / easier / more exciting? Why / why not?**

8. **Do you believe you can create something with technology that could contribute to a better / easier / more fun life? Why / why not?**

9. **Do you believe you can create something with technology that could contribute to a better / easier life for someone else? Why / why not?**

10. **Have you ever heard of the terms "social justice" or "global citizenship"?**
    __ Yes   __ No   __ Maybe

    a. **What do you think these terms might mean?**

11. **Have you ever done or created something to improve someone else's life, either on your own or in school?**
    __ Yes   __ No   __ Maybe

    a. **If "yes", what did you do or create?**

12. What is your favourite school subject? Why?

13. What does a scientist or mathematician look like, to you?

14. Do you feel a difference in ability when surrounded by kids or students of another gender, versus a setting where it's only your gender? Please explain.

15. Have you had a female teach you STEM education? How many times (roughly)?

16. Do you envision yourself pursuing a job in a STEM-focused area (i.e., engineer, scientist, mathematician)? What kind of job would you like to do when you're older?

17. Who has had the greatest impact on your choice for a career path? Why do you think that?

18. Do you feel like boys are better than girls at science? Technology? Computing? Math?

19. What kinds of words would you use to describe your abilities in science?

20. What kinds of words would you use to describe your abilities in math?

Appendix E – Post-Study Interview Questions

1. Could you state your first name and age for me?

2. What kinds of things did you learn about this week?

3. What does "social justice" mean to you?
   Follow-up prompt: What does it mean to be a ChangeMaker?
   Elaboration prompts: Do you think social justice is important? Why / why not?

4. What is your understanding of the Internet of Things (IoT)?
   Elaboration prompts: Where might you see it being used? What do you think about it? Why do you think that?

5. Do you think that IoT could be used to help other people?
   Elaboration prompt: How / why not?

6. What motivated you to choose your project this week?

7. If you were to keep working on your project, what kinds of things would you want to add to it?
   Elaboration prompt: Could anything from IoT help you?[3]

8. Do you have anything else you'd like to add about your experience with the tools or ideas this week?

---

[3] Due to time and technology constraints, the IoT component of many participants' prototypes was incomplete. This prompt was added to elicit their understanding of how IoT could be applied to complete or extend their passion projects.

Appendix F – Coding Scheme for IoT

Codes Related to Participants' IoT Engagement

Code	Description	Example
Applications	Examples of how IoT might be applied to everyday problems.	"I think, like, if it gets foggy in the shower, when [the Arduino] detects moisture, it could turn the fan on."
Evaluation	Value statements regarding participants' opinions of IoT.	Aaron reflects on IoT, saying that, "The Internet of Things is cool, but at the same time, it's kind of scary, because…" Luca finishes his thought, adding, "yeah, but people can hack you. And people can see, like, whatever you're doing at home."
Interest & Engagement	Being interested in engaging with IoT devices.	"I want [Vector] to recognize my face."
Making with IoT	Denotes participants' engagement with IoT in relation to maker technologies or their maker passion projects.	"I learned about the Internet of Things and I learned how micro:bits could be used for music and plants and stuff, and lights, and lots of other things."
Personal Connection	Recognizing IoT concepts in their lives.	"I have these cameras at my house, where if they detect motion in that spot, it will send a notification."
Security & Privacy	Evidence of participants' thinking about issues of security or privacy related to IoT.	"I was just thinking that when you put that [data] into the cloud, you could have some kind of little forcefield – like a shield – around it. Like a firewall around it while you're going into the cloud so no one can just hack it while it's in the air, free."

Sensors	Noticing or describing sensors, one of the basic components of an IoT system.	Describing her potential horse groomer passion project, Isabelle explains "it needs sensors so that it can sense where the horse is and where the comb should be so it doesn't comb its eyeballs."
Understanding – N/A Understanding – Developing Understanding – Moderate Understanding - Proficient	Participants' engagement with IoT was coded on a continuum of understanding. On the lower end, "N/A" represented comments that were incorrect or otherwise suggested they had not yet formed an understanding. "Proficient" was considered the upper end, and would include the use of proper terminology, accurate descriptions of IoT systems and interactions, etc. Note: Zero excerpts were coded as "proficient".	"[IoT means] being connected to the internet." (N/A) "A lot of things were connected to one another, like to the phone, sending notifications." (Developing) "If you have the thing that's our project, if they can hack into your computer then they'll try to put their face on the recognition [system], and then it'll know it and it'll let them in. … Unless it has a firewall." (Moderate)
Values (Global)	Comments regarding IoT's impact on society, or the world at large.	"I discovered just how much it could change the world and 'reality itself' if IoT existed for everyone."
Values (Personal)	Comments regarding IoT's impact on your personal life.	"I learned about the Internet of Things … and smart gardens, which are gardens that are controlled and water themselves for you, which gives you a lot of free time, if you did not know."

Appendix G – Coding Scheme for Social Justice & Citizenship

Codes Related to Participants' Social Justice & Citizenship Engagement

Code	Description	Example
Antithetical	Expressions that stand in contrast to goals of social justice & citizenship.	Discussing their passion project, Aaron suggests "we could do where you make it like, if you want to try, you have to give me one dollar." Luca agrees, "okay, we could do that. We'd be rich!"
Applications	Examples of how social justice and/or citizenship concepts might be addressed.	"I would want to have transportation that runs on greenhouse gases, so it is eco-friendly and produces less pollution."
Applications – IoT	Examples of how social justice and/or citizenship concepts might be addressed using IoT or the provided maker technologies.	"Soon, people are going to learn how to get other stuff for helping. For example, airplanes that can fly themselves and shoot things … so let's say war on the other side, in other countries. If they shoot the airplanes, people won't die."
Awareness	Identifying social justice / citizenship issues.	"A problem in society is probably world hunger … a lot of people who actually need food aren't getting enough food because there are people who are lucky enough to have food, shelter, and all that [who] are just wasting the food that they have."

Awareness (Safety)	Related to issues of personal safety and security as a common issue.	“Statistics show that more people die from texting and driving than drinking and driving. That’s insane.”
Awareness (Sustainability)	Related to environmental sustainability as a common issue.	“The Earth is dying.”
Evaluation	Value statements representing participants’ opinions of social justice and/or citizenship.	“Social justice, I think, is good because we’re kind of helping each other, and helping social life become more comfortable and happy.”
Interest & Engagement	Demonstrating interest or excitement about addressing issues related to social justice and/or citizenship.	“I want to change the world, let’s go!”
Local Focus	Campers did not universally identify with “big” issues. Some of the concerns they identified were related to “smaller” local and/or personal problems.	“I chose this project because I like soccer … I wanted to get better at soccer. I think my project could help other people. The robot could give people a challenge so they could try to score on the robot goalie’s net.”
Personal Connection	Statements that highlight personal significance of a particular issue.	Describing the inspiration behind her passion project, Amalya explained, “recently I did an art project where I had to make a printmaking, so my print was a hand holding a phone and the phone says, ‘don’t put me down’, to say that your phone is controlling you and not you controlling your phone.”

Understanding – N/A Understanding – Developing Understanding – Moderate Understanding – Proficient	Participants' ability to explain social justice or citizenship was coded on a continuum. On the lower end, "N/A" represented an inability to correctly articulate their understanding. On the higher end, excerpts coded as "Proficient" would have expressed an accurate definition including examples, systemic factors, etc. Note: Zero excerpts were coded as "Proficient".	"I don't know what social justice is. … oh wait, you help people with your words?" (N/A) "Ohhh! Social justice could mean, like, changemakers in the world. Helpers, engineers, some type of leader of workers." (Developing) "Social justice, to me, means people from the community – not that it's their job – may bring peace or stop some sort of fighting among themselves." (Moderate)
Values (Global)	Demonstrating awareness of either a) far-reaching impact of a particular social issue, or b) potential widespread value of their passion project.	"I want to prevent texting and driving because people who text and drive are not only putting their lives in danger, but also putting other people's lives in danger on the road. I believe that my creation could help improve other people's lives."
Values (Personal)	Demonstrating awareness of either a) local or personal impact of a particular social issue, or b) potential local or personal value of their passion project.	"I chose this theme [for my passion project] because my brother likes animals, and there are lots of animals endangered."

Appendix H – Coding Scheme for Making

Codes Related to Participants' Making

Code	Description	Example
Agency	Evidence of participants' self-efficacious beliefs related to making.	After learning basic micro:bit coding, Derick says, "okay, I'm going to make it do some math!"
Challenges	Evidence of participants' encountering difficulty during making.	"How did they do this? k8 is very stubborn. k8 and her body parts are very stubborn."
Collaboration	Evidence of participants working together on a maker project.	After Aaron is unsuccessful getting his Arduino circuit to work, he asks another camper for help.
Design	Evidence of participants' design considerations related to their making.	"I'm going to use a tube attached to the Arduino thing, and then the Arduino will attach to the arm."
Disempowerment	Feelings of dejection, discouragement related to making.	After trying several times to get their code to work, participant slumps in their seat and says "I can't do anything…"
Empowerment	Evidence of participants being proud, excited, or motivated to make.	After successfully getting their LED to blink with the Arduino, Isabelle says "there we go! We did a good job" and high-fives her partner. "I can't believe the micro:bit gets to be coded. Coding is fun!"

Failure Tolerance	Denotes occasions where participants expressed a growth mindset or a constructive response to making gone wrong.	Trying to assemble the k8 robot, one participant says "every time I try, I fail". His partner responds, "yeah, you just keep on trying!"
Inquiry	Thinking, questioning, or searching for answers about their making.	"When I have a blue [LED] in, and then put another blue one in, it works, but when I put this red one in, the light stops…" After creating a basic indoor light sensor, Aileen asks, "what if you brought this outside?"
Interest & Engagement	Demonstrated intrigue or being interested in making.	After assembling littleBits components and observing them work, Aaron exclaims, "what?! Okay, now I'm interested."
Iteration	Evidence of participants' testing and making changes to maker artifacts.	Aaron and Luca test their "soccer goalie". After a few practice shots, they decide they need to add a more substantial cardboard body to add challenge for the player.
Reflection	Evidence of participants' thinking about their maker activity.	"I just realized the factor of ignoring. For example, someone could probably ignore a bright white bulb. Okay…"
Sharing	Evidence of participants wanting to communicate with others about their making.	After successfully wiring four LEDs together using the Arduino breadboard, a participant says aloud, "hey guys, I can do this. Who wants to see a trick? A different trick?"

Appendix I – TCPS 2: CORE Certificate

PANEL ON
RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

Jennifer Robb

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

Date of Issue: **10 November, 2020**