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Abstract

Break it till you Make it explores the democratization of digital project-based learning with children ages 7-11. Using elementary schools and community centers in Toronto as a case study, this project looks at how we can dramatically lower the cost of digital project-based learning when classes sizes of 30 are common place.

The research investigated the current trends in digital education, and how digital project-based education fosters the 4 Cs: creativity, critical thinking, communication and collaboration.

Finally, the research documented the process of building a low-cost mobile makerspace, the cost-effective workshops and participant feedback. The result showed the dramatic reduction of cost per child for digital learning and the scalability of the workshops.

The overarching methodology used was action-based and incorporated mixed methods to design the workshops. Staff and volunteers participated as facilitators and co-participants. Lastly the project provides a new lens by which to look at digital making, by using accessible materials and crafting tools.

Keywords:

digital making, low-cost makerspaces, workshop design, computational thinking, digital fabrication, interactive play.

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For My Family: Sharon, Andre and Emil

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Prologue

The graduate study path was one of introspection, study and in my case many hours of isolation in my basement away from my family. As there was no part-time option and taking time off work to pursue a master's was not an option. I had to balance full-time work, education and a family. I got an immense amount of support from my family but I wanted a way to bring them into the fold of this journey I was on. I did not conscientiously do this but most of my projects through all the terms had me designing projects that incorporated ideas from my children. They were my inspiration, and also validated many of the ideas I was working on. During this time, I introduced my 10yrs old son to coding and had him program my entire game prototype. My daughter designed characters for the very first zombie game in *Creation'n'Computation* and for the final thesis, they playtested all my prototypes. This helped me stay connected to them despite having long stretches of isolation when engaged in assignments and work.

The title " Break it! till you Make it!" also came from this journey of self-discovery, I was breaking things in more ways than one, code, time management, health and prototypes. It was in the fixing of these things did I learn and turn my mistakes into knowledge which has stayed with me. I have used this reflective ethnographic methodology in approaching my thesis and a way of keeping my life in balance.

Chapter I: Introduction

Kit-bashing is a practice started by train model makers; they would break open old models and use parts useful to making new ones. This practice allowed them to be resourceful and inventive with what otherwise would be waste. I wasn't a model maker growing up but breaking into my toys was my favourite hobby. Finding out how they worked and discovering the fascinating components once you had glimpsed into their underbelly.

I call this thesis *Break it till you Make it* because the work had me challenging a lot of my assumptions about digital making. Was working with unremarkable materials like cardboard and tin foil a worth Digital Futures thesis? I had lofty ideas joining the program to build a low-cost replacement for the LEGO Mindstorm. The programmable toy brick, which was first theorized by Seymour Papert and was brought to fruition in 1998 with the help of Mitchel Resnick a professor of Learning Research and the director of the Lifelong Kindergarten group at MIT (Massachusetts Institute of Technology) Media Labs. I also researched using the Scratch to code my alternative version, Scratch is a block-based programming language also created by MIT's Lifelong Kindergaten group.

How can I make digital learning ubiquitous in schools by lowering the cost of engagement? I kept running into digital toys, apps and kits which were black box solutions to digital learning, the maker movement has several companies springing up to produce S.T.E.A.M (Science Technology Engineering Arts and Math) toys: Little Bits, KiwiCo and Snap Circuits to name a few. Most of which are priced at the 50 dollars plus mark, with school versions going into the thousand-dollar range. Some also offered online training workshops and material with similar price tags.

It was the *Thinking through Making* an elective I took at during my Summer term at OCADU which really challenged my ideas of what it means to engage with making, tools and the affordances of materials. One of the most fascinating aspects I was made aware of is material science, the mailability of material and its transformational properties. Something as ordinary as paper, is highly transformative, it can be sculpted as papier mâché, used as a sealant when mixed with glue or transformed into works of art with origami and that is barely scratching the surface. This transformational property of stuff makes material science fascinating. In the book *Stuff Matters by* Mark Miodownik questions our assumptions about materials, their affordances and the fascinating science behind their properties, he gives us a lens by which to look at *stuff* in a whole new way. During my first class in the elective we were asked to use carboard to prototype what we intended making, the studio was stocked pile high with recycled *free* carboard. We could use as much as we wanted and encouraged to try out anything as there was no consequence of cost. I wish that was the aha moment but it was not, I was fixated on creating a high-tech device which would be highly interactive and engaging for children. I had made one such prototype in my creation and computation class in term one. This project got accepted into the Toronto Kids Digital Festival held at the OCADU campus in 2019. The plan was to play it safe and just build a bigger and better version of this interactive installation for my thesis. So, here is what changed.

It was at this stage I started bringing my materials and prototypes home to share them with my kids. They would sometimes break it or at times make it even better, this ping-pong process is a

recurring theme in my thesis journey with my children. They have been a source of inspiration and wellspring of ideas. I have to admit at times I have outright stolen some of my son's creations for projects, breaking apart his Lego creations for a stop motion project, which when played back revealed how it was put together. Looking over his shoulder as he would teach himself scratch and leant to interface it with the Makey Makey. [The Makey Makey is a microcontroller designed for kids, it too originated from MIT Kindergarten Lab, the founders and inventors are Jay Silver and Eric Rosenbaum. The microcontroller can be programmed with Scratch to create physical interactive objects and control on screen events]. I started introducing conductive fabric, thread and other electronics for my son and daughter to tinker with. I broke apart an old PlayStation controller to show my daughter age 7 at the time the inner workings and the parts that made up the controller. I was kit-bashing all sorts of electronics and materials if they were safe to have around my kids. What I noticed was their digital literacy was growing, they no longer looked at a controller the same way or materials, they now had properties depending on the state they were in. My son understood the basics of conductivity, a closed circuit and was breaking into scratch games to modify the code connect it with physical objects. I hadn't spent much, the Makey Makey was around 45$ and everything else was stuff I had because of studying at OCAD or was lying around the house. I thought about the high-priced STEAM digital maker workshops for children in Toronto and the many families including me could not afford spending around 250$ for digital learning workshops.

This is when I took the step away from building version two of my installation and built my first prototype. I designed an interactive game with my daughter. It involved crafting items with felt. (see chapter 4). The workshop format was starting to take shape, and I enjoyed this format because it allowed space for dialogue and questioning. My daughter was asking "why am I making these felt items and how could they possibly work in a game?". This is the thread of encouraging inquiry I was building into to design all of the later work. The idea is that it should feel like magic, and then you unveil it to the curious mind. The material, tools and technology curation process had started. How could I come back to the seed of the idea, low-cost digital play-based learning, affordable and accessible. The workshops were meant to take down barriers of engagement, it was not presenting children with complexity, but pulling back the curtain gently to peer into the digital world.

This thesis had three stages a play-based methodology of how I approached the workshops, the literature I drew up, why democratizing digital making matters and lastly the outputs from the workshops. Which were two-fold, two new prototypes which are being adopted by the community centre I worked with and future work which revolves around safety in maker spaces.

Chapter II: Digital Makersphere

This is an unconventional name for a literature review, because it is written in response to and in reflection of my design practice. The literature read to clarify if what I was making had meaning and if so, what world view did this tiny puzzle piece fit into. The approach taken mirrored Resnick's theory presented in his book *Lifelong Kindergarten* (10- 14). The iterative loop of: Create > Share > Reflect and Imagine. In my case it also included writing, in academic terms it would be a background, literature and contextual review rolled into one. This is in no way a comprehensive body of literature on the subject of project-based digital learning. My scope and time was limited to uncovering the literature pertinent to my iterative process.

Constructivism and Constructionism

All of the workshops are situated under the theories of *Constructivism* and *Constructionism*. Theories put forth by Jean Piaget and Seymour Papert respectively. Piaget was a Swiss psychologist studying cognitive development in children, Parpert was his student and built on his theories and ideas to formulate his own theory of constructionism.

Although they are similar sounding and share a lot of similarities in their methodological approach there are nuances in the methods and the differences are worth understanding.

Constructivism theorist "argue that students situate the learning experience within their own experiences and the goal of instruction is not to teach information but to *create the conditions* in which students can interpret information for their own understanding" (Smaldino et al. 23)

The difference, "Constructionism--the N word as opposed to the V word--shares constructivism's connotation of learning as "building knowledge structures" *irrespective of the circumstances of the learning*. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe." (Papert and Harel)

In my methods I was leaning towards constructivism as the environment was totally out of my control but the act of "building knowledge structures" was, designing took the form of intent, and not just creating an open-ended sandbox of the right conditions. (Papert and Harel)

Future Schools and Making

I then found myself thinking about future schools and what place project-based learning had in them. Ken Robinson in his talk "Do Schools Kill Creativity" in 2007 at a TED conference says "everyone has talent and creativity but the schooling system has it beaten out of them over time.". His sentiments are mirrored by other pedagogues (Resnick 13; Piaget 5-11). I therefore looked for what solutions were being proposed to counter this lack of creative expression. *The Futurist* magazine published an article by Arthur B. Shostak a retired professor of sociology, proposes such a solution. In it he outlined the building blocks for future schools, the article has specificity and gives stakeholders a roadmap to build upon. Much like Piaget it focusses on environments and spaces it will need to nurture a new generation of creative thinkers. He also advocated hands on learning in collaborative workspaces, this constructivist approach is echoed

by many other experts in the field of education (Montessori; Libow and Stager12-21). “Create: It’s not enough to imagine.” (12) Resnick proclaims. I couldn’t agree more.

I then looked for how the government had responded to the call of future school’s in terms of today’s curriculum. The National Education Association had established the Partnership for 21st Century Skills (P2I) published what is now known as “The Framework for 21st learning”. This was two-year research study to identify the skills needed for the next generation of learners. The outcome is what they call the 4 C’s: Critical thinking, Communication, Collaboration and Creativity. By their own admission in the report they state it has been a challenge to integrate these new skills into the existing curriculum and is their focus for the future.

One such initiative to explore the relationship between makerspaces and 21st century education was conducted by, the Bay-Area abundance foundation and Project Zero at the Harvard Graduate School of Education in Cambridge, Massachusetts. The aim was finding which process of the maker experience were beneficial to students and how they could reflect them in an educational setting. What “the team quickly discovered was that, while making in the classroom was not a new concept, maker-centered learning suggested a new kind of hands-on pedagogy---a pedagogy that encourages community and collaboration (a do-it-together mentality), distributed teaching and learning, boundary crossing, and responsive and flexible teacher practices” (Clapp et al. 2, 4).

The overlap between the skills of 4C’s and the maker-centered classroom was promising. Finding how digital making fits into this eco-system was next. Since most maker media is skewed by images of jumbled micro-controllers (Clapp et al. 5). My side quest was making these workshops appealing to children and educators who did not see themselves as tech savvy inventors. Adam Savage the co-host of the popular show *Myth Busters* writes “Putting something out into the world that didn’t exist is making” (4). I needed to explore the digital realm on the makerspere next.

Digital Manipulatives and Projects

The research paper on lifelong kindergarten gives context to physical play in the classroom and the history of manipulatives. Friedrich Froebel a German pedagogue who put physical play at the core of his kindergarten school; he designed 20 objects called "gifts" these were the first form of manipulatives used in teaching. The simple definition of a manipulative is an object that can be moved and manipulated. Their work (Martin,1994; Resnick, Martin, Sargent, & Silverman,1996) at the MIT labs took manipulatives to the next level by adding computation to it. This made algorithmic thinking accessible in the classroom. The authors have outlined the benefits of “design projects” and their application to real world skills, namely; Interdisciplinary thinking (bringing different concepts together), pluralistic thinking (getting away from right and wrong and focusing on the solution), reflection (looking at the process and allowing for revisions) and putting kids into the minds of others to think about their objects.(Resnick)

In three of my workshops the participants would design rudimentary digital manipulatives, these would interface with the Makey Makey (a child friendly microcontroller designed by Jay Silver and Eric Rosenbaum), which gave it computational interaction and allowed for touch interaction with conductive objects like tin foil. They also would made a contraption with the Micro-Bit (a

microcontroller designed by the British Broadcasting Company). This device would give them wireless capabilities and also interfaces with scratch, via the use of a plugin. The next task was managing my expectations for the outcomes, which I must admit gave me a lot of anxiety about the expected outputs. This is not uncommon, as many teachers would like to do project-based work in the classroom but they are fuzzy about the expectations and lean to a polished end result from the students (Ch. 1, par.3). But the main idea is that through engagement they discover new ideas and concepts, which fosters confidence and sense of self-reliance and a polished outcome is not the intended goal of project-based learning. (Sallee Beneke et al., Ch. 1, par.6)

According to the authors, Syivia Chard and Lilian Katz in the book "The Project Approach" outlines a framework for project-based learning in the classroom. In a project-based workshop an educator is an "ethnographer", drawing on the collect experience of the students, looking for teaching moments and being a resource (63), in my case I had no opportunity to interface with the children prior to the study and was drawing upon my prior experiences and projects. In introducing new materials, one of the guiding principles is "Use materials to teach a specific concept, such as gears, friction…"(65). (Libow and Stager) In my case that was tin foil, the specificity was conductivity. This was the recurring question from three students, "what is conductivity and how does it work in tin foil?". I would consider that a success as it opened up pathways for further exploration and dialogue something missing in Keychain projects.

"Keychain Syndrome" are one of the main reasons we need digital making to be part of school and non the band aid solution of playing with toys for 45mins in with a quick win state. They are mostly designed by libraries, science centers and private institutions offering STEM based learning opportunities to children. (Peppler et al. 67). They are also inaccessible to children who do are not able to attend those venues or afford the high price of private institutions.

I also pondered on the premise that "Children are not hackers" presented in the book *Makeology.* The authors explain how the hacker culture which came out of hi-end technology schools and the Silicon Valley has been associated with digital making and the image of being brilliant whiz kid is damaging. The "sink-or-swim" mindset kills room for experimentation and alienates people who don't identify with that image, the especially damaging to a school's maker culture. (Peppler et al. 64-71). This informed the way I communicated the workshops to the children and also the staff, we were not hacking and proving our abilities of getting it right, as that creates isolation and sense of failure for other participants. It also is a deterrent to staff and volunteers who don't feel technologically adept to run a digital workshop.

Equal Opportunity

When looking for the reason low-cost and accessibility mattered, I looked closer to home. In 2013 The Global Mail a Canadian newspaper published an article titled "A tale of two schools: The correlation between income and education in Toronto" it calls out the disparity in access to educational resources and between two postal codes in the city of Toronto. It goes on to say "In Toronto, where income inequality is highest, wealth and test scores at Canada's largest school board are correlated." this statement is validated later in the article by citing "When it comes to gifted students, nearly 60 per cent came from the three highest income deciles, according to a 2010 TDSB study. Fully a quarter came from the very highest income group, and only 11 per cent

were from the three lowest deciles." The caveat to counter that argument today would be that parents are free to apply to any school but as Liz Sandals points out in the article "introducing school choice could exacerbate educational inequality, because low-income families don't necessarily have the means to drive their kid across town to a higher-ranking school."

I then tried to understand the impact of this divide in terms of access to ICT (information, communication and technology) in schools. The authors researching Canadian schools concluded "students whose parents have little or no formal education were less likely to report several types of computer use, particularly using the Internet and e-mail, doing data entry…." this in contrast to Those from families with higher levels of education are more likely than others to agree that "it is very important to me to work with a computer." That is, better educated parents seem more likely to instill in their sons and daughters the importance of having computer skills.". (Looker and Thiessen). This holds true in digital making and bridging the gaps for children interested in computational making. Having parents who have higher education and from affluent neighbourhoods have ways of bridging the gap for their child's interest with programs offered outside of the public education system. The schools that are also placed in more affluent neighbourhoods get better funding and are able to provide a higher quality of digital access. This is not a problem that can be solved easily, nor am I saying this project is an end all solution but I think TDSB trustee Sheila Cary-Meagher said it best "In our saner moments we know that we probably won't. But the minute you say 'You can't really expect to do that,' you lose the impetus, you lose the passion," (Alphonso and Grant)

Summary

The literature informed my process and the methods I set out to use in the project. Using constructivism as the basis for project-based learning I designed workshops around that methodology. The 4 C's: Critical thinking, Communication, Collaboration and Creativity were used as a lens to look critically at the intended outcomes of the workshops. The main one being creativity and trying to give the children a sense of agency in the process. This can sometimes be very challenging in larger groups and is one of the reasons the "Keychain Syndrome" is so prevalent in larger group settings. When designing project based workshops the two key factors are cost per child and also an environmental cost of the materials used. It is easier to ignore the environmental cost and a conscientious decision has to be made to think about its impact. This is an essential part of the workshop planning process.

ICT (information, communication and technology) needs a special mention in digital making workshops. In schools and community centres basic ICT is mostly always present. What makes or breaks the workshops sometimes is the quality of this infrastructure. The training the staff and teachers are given. The COVID-19 crisis has flipped the switch for pedagogues, and many educators who have not previously used digital tools to communicate with their children find themselves at a loss. ICT training is no longer optional and any school looking to foster future skills, have to address both ends of the spectrum: digital workshops for teachers and also how that training will translate to supporting the children's learning. Managing a safe classroom online and giving students training on using digital learning resources to learn has fallen on the shoulders of teachers and administrators. There are also skills specific to teaching with digital tools which are very different from managing a physical classroom environment.

Chapter III: Methodology

The outcomes are presented front and center in this paper because it takes away the ambiguity of what was done and how it was approached. This research study is mainly driven by the methodologies and methods I have used to explore low budget digital making in schools and community centers with limited access. The project set out to build a maker space environment where none existed and conduct five workshops on digital making.

Project Outcomes

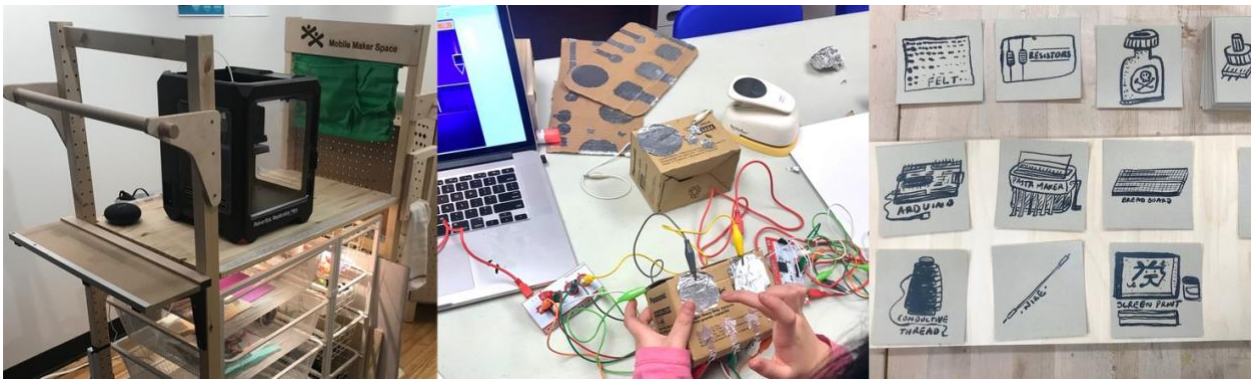

Figure 1: Primary and Secondary outcomes from the Research

Figure 1 shows two of the main outcomes from the project, on the left is the mobile maker cart which was a substitution for building a makerspace. The rational and iterative process that led to the design and affordances is covered in Chapter 4, Project III. The middle image is from a series of five workshops that used low-cost materials and inventive ways of using ordinary crafting tools in digital making workshops.

There are two secondary projects that were created as responses to the workshops. They are ideation cards (Figure 1 far right) to plan and engage in the reflection of the workshops. The second, ten D.I.Y(do it yourself) stop-motion stations for children to document their work and make animations. After surveying the children, the stop motion workshop was well received and implementing a long-term solution at the community center was educationally beneficial. The lightboxes were funded by the community center and I built the initial prototype which lowered the cost of the materials by half.

Framework for the Study

This research used action-based methodology for the mobile makerspace and a play-based one for working with children. The main overarching methodology is action-based research by Könings et al. The authors published an article outlining their work in building a set of educational building in the Netherlands. They involved all the stakeholder in a participatory co-design method and an iterative cycle to co-create the building architecture. This in a way is already a mixed methodology which included the stakeholders as co-creators which comes from a participatory design practice. Although my study was not designed with staff/volunteers and participants. I had to take into consideration their concerns and constrains while designing the components of the study.

Action-Based Research

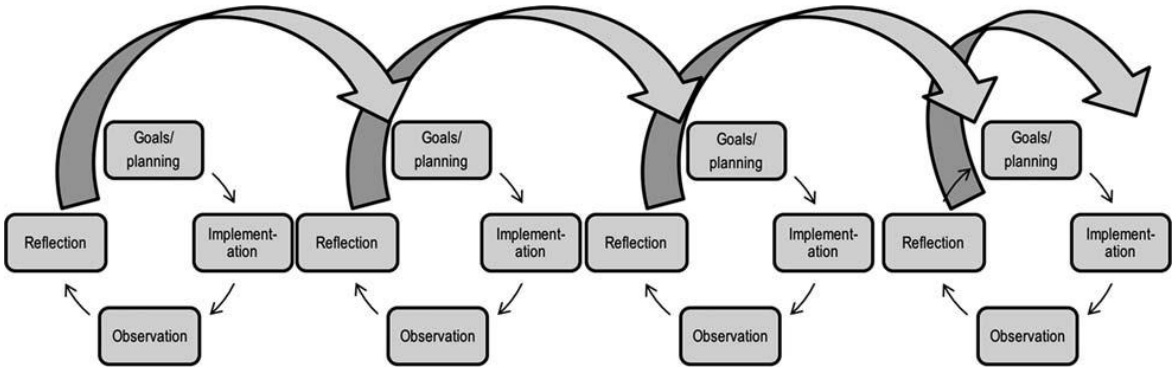

Figure 2: Spiral of repeated cycles of planning, implementation, observation and reflection (Könings et al.)

Figure 2 shows the cyclical nature of action-based research, in my case I was using an action-based method right from the start of the project. This interview method included:

- I met with the stakeholders at the community center to get the necessary approvals.
- Talking to them about the feasibility of building a makerspace, budgets, future plans and what tools existed at the centre.
- Staff and volunteer knowledge to draw upon.
- Consent approval processes and ancillary concerns outside my field of knowledge.

Those are just few of the iterative cycles I went through to plan the logistics and work through the REB(research and ethics boards) application.

It is at that time I realized the study by Könings et al did not include children and thus was missing a critical part of what I needed for my methods and also a one for qualitative analysis.

Playful Participatory Research

That brings me to Project Zero, a research study done by Harvard Graduate School of Education on playful participatory research with schools and educational environments. The observational data and hypotheses informed the tools I designed to record my observations from the workshops. The topics the researchers studied were Creator Spaces (collaborative spaces where

people create much like makerspaces) and how they affected the participants, the environments and its affective quality. This study reflected the needs of my research in terms of creating a makerspace and the affect it would have in conducting the workshops (Baker et al. 7-8).

Playful Participatory Methods

Project Zero study was once again incomplete for me to lean on because although the paper had many methods listed in broad strokes the specifics of working with children were missing. They had professional pedagogues working with children for the study. In my case I was not a pedagogue and had no credentials to lean on for safe and ethical codes of conduct. Also, what playful participation meant in a workshop setting, needed to be answered. I also was looking for some qualitative ways to measure the success of my research in respect to the outcomes and observations.

My work with schools at my day job as a game designer had me testing the games in schools, thus I was aware of ethical codes of conduct in the digital space. This led to finding Global Kids Online an initiative from the London school of Economics and UNICEF was a stellar resource for what I needed. They had clearly outlined on their website ("Tools | Global Kids Online") all the tools which included, qualitative and quantitative ways in which they collected data, the storage of confidential information, accent and consent forms, the list is exhaustive, and all open source. This is the resource referred to, for the methods of engagement, data collection and observational studies. I also leaned on their methods for ethical conduct and safety.

Overview of the Methods

For this study I had two main prototypes. First, building of the maker space, which evolved into a Mobile Maker-Cart. The second was the five workshops designed to engage kids in digital making in a project-based setting. Each workshop was an open-ended project, with loose guidelines of the final outcome. I shared with them the expectations but within that sandbox they were free to iterate anyway they pleased. They also had the explicit option to stop participating at any time.

The methods were purely qualitative in nature because there was no hard data involved. The only hard data was the cost of materials and tools. The qualitative methods were:

1. Aggregated observational data, none of the participants full names were collected in the data, all hypothesis where made based on the aggregation of what worked in terms of creative play, the questions raised and what they might have not liked in the workshop.
2. Interviews with the staff and volunteers who were running the workshops with me and feedback from the stake holders.

Expert Interviews

As a part of the reflection after the workshops I created four podcast. I interviewed eight experts who were influential to the project. These interviews were published as a part of the projects website and are part of the digital OCAD repository. I used this to also speak about topics like safety which I would like to expand upon in future work and the maker community at large.

Below is a brief summary of the interviewees and the topics we explore:

Adam Tindale & Nick Puckett (OCAD Faculty)

Advisors on the this thesis project. They will be sharing their perceptive on the development of the research and their own practice in as professors in OCAD. The ways they design their project-based classes and challenges that they face with student outcome in open ended projects.

Barbara Rauch & Jay Irizawa (OCAD Faculty)

Barbara Rauch and Jay Irizawa were professors of the elective 'Thinking Through Making' in the summer term of 2019. Their class in project-based making was highly influential in shaping this project. They will speak to how they deigned the class and the outcomes they expected from such an open ended class structure. I will also be talking to them about safety in makerspaces as it was one of the only maker classes that insisted on shop safety before engaging in the OCAD studio spaces.

Catherine Fraise (Founder of workspaceeducation.org)

Workspace education is designed for home school and private school students. They are entirely project-based in their approach to learning. Catherine will share her journey, why the school has been recognized as a thought leader in the educational space and how she sees this research project contributing to the conversation and the ideas being used in co-learning micro schools.

Andrew Duff (Creative Director of the Maker Festival in Toronto)

Andrew is the creative director on the maker festivals in Toronto and will be talking to how he has seen the maker festivals evolve. His involvement with schools and setting up maker fairs in various schools in the east end. I will also talk to him about safety at maker fairs and how my son got burnt on his fingers while participating with poorly trained volunteers at the time. We will also talk about the Future of making unconference which he organized and my experience of participating in it for this research.

Omid Ettehadi and Maz Chabayta

Omid and Maz are students in my cohort and have projects that overlap my own, we will discuss the overlap between our projects and how it relates to the topics of the maker culture, materials and safety in maker spaces.

Refer to Appendix C for the podcast episode list and access information.

Case Study

Figure 3: Chibitronics classroom kit. Web Store

Chibitronics is a paper computing project with circuit stickers by Jei Qi et al. This project builds on the previous done by Ji Qi. Chibitronics has made custom led stickers, light sensors, touch sensitive switches and a custom micro controller called the Chibi chip. The cost of these kits ranges from 35USD for a start kit to 125USD (Figure 3) for a classroom kit with no batteries included, most of the components like the LED's and copper tape have single use as they a stuck to paper. A replacement role of copper tape is 10USD. The authors say the crafting process has two objective, crafting a closed ended circuit that works and the other open ended which can be a creative expression communicating a thought or feeling (Qi et al.)

Figure 4: Paper circuits with tin foil

In response to the paper circuit I created a low-cost version of this project. Instead of 10$ copper tape, a pasta cutter is used to make strips with tin foil of the similar size, and using gumdrop LEDs which are 2$ a dozen. I glued them on carboard with clue sticks, sandwiched a battery between the carboard to create a housing and a switch (figure 4). A classroom could workshop this multiple times for $22 CND or less because only 1/4th of the tin foil and glue sticks is used in a single workshop. Fixed cost like the pasta cutter are not accounted for as they are one-time purchases or may be borrowed. Mine was $7 at a thrift store.

Chapter IV: Projects

The following projects are what led to the final workshops, they are presented chronologically:

Figure 5: The Material Curation Process

Project I: The Algorithm Game

In the design process, I first started curating materials and tools to conduct the workshops. I was inspired by Montessori and natural materials as shown on the left (Figure 5), these were aesthetically pleasing to me. They were natural materials like wool, cloth, clay and metal. What changed was my advisors questioning the availability and cost of these materials per child. Every project has a dollar cost attached to it and crafting produces a lot of waste. Scaling any workshop to thirty students and conducting them multiple times might make these workshops very hard to sustain, also if the materials are considered precious, they put limitations on the children to experiment with the medium. This led to the search for low-cost materials. The image in the centre was an early prototype of laser cut objects with conductive cloth backing. This would be used for an interactive tea party game, connecting to scratch via the Makey Makey. The image on the right are low-cost materials found in most early year's classrooms and most accessible to educators in terms of cost and availability. (Figure 5)

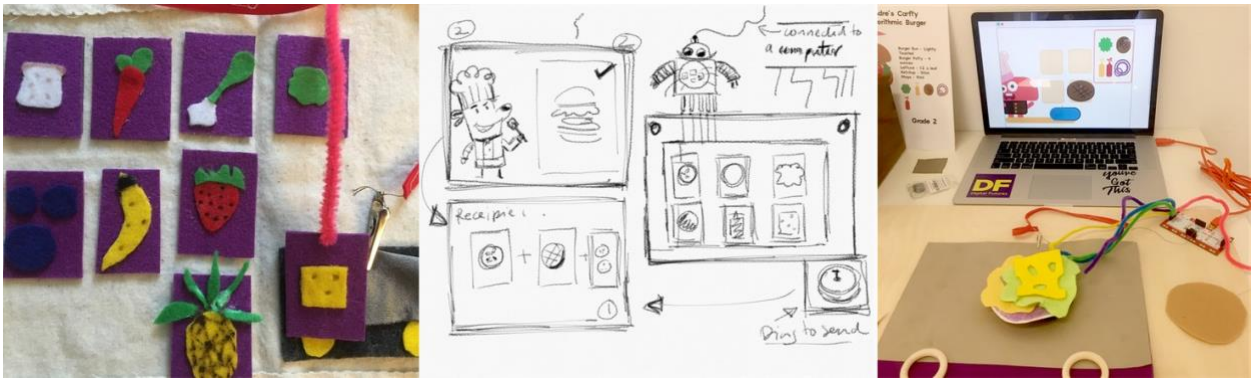

Figure 6 Early Proof of Concept, Algorithm Game

Using the low-cost materials, I created a game with the help of my family (Figure 6), the image on the right shows the items crafted by my daughter, age 7 at the time, I used conductive fabric to transform the felt into interactive objects and chenille stems as conductive wire. The idea for

using recipes to convey *how algorithms work* was the core concept of the game. The idea came form Martin Erwig book *Once upon and Algorithm.* He describes an algorithm as a recipe that when executed correctly produces the desired outcome. It has a set of rules and instructions but also can in include variation in a strict set of steps (2). The images on the right is the completed game coded by my son in scratch, age 10 at the time. I still haven't checked the code for bugs as its just worked, he has shared the code on his scratch repository online. He added an enhancement to the code since then; clicking the completed food item allows you to eat it one bite at a time. To unpack the rational of the game above I had to understand some core concepts of algorithms and representation, this knowledge was uncovered through the second iteration of the finished prototype, Figure 6 far right.

Algorithms and Representation

An important part of computational thinking is understanding algorithms, at this point in the prototyping process I wasn't thinking of project-based learning rather interactive games. The idea was participants co-creating physical game objects they could later use to control interactions in the game. Algorithms have two important functions "*to directly manipulate the data, or they decide which instructions are to be performed next and how often*" (7). These can be thought of in forms loops conditions which check for the right answer and then perform an action, in code they would be written as "**repeat** *step* **until** *condition"* and "**while** *condition* **do** *step"* (178-183). I will briefly talk about representation as this game incorporates that concept too. "Representation consist of at least two parts, namely, something that represents and something that is represented" (49). If you think of it in concrete terms your name, represents you the physical person. In the game the children will come up with a name of a vegetable (eg: Onion) and then create a crafted object to represent that word. In computational terms they are called *Signifier* and *Signified (51).* (Erwig).

Project II: Tools for Workshops

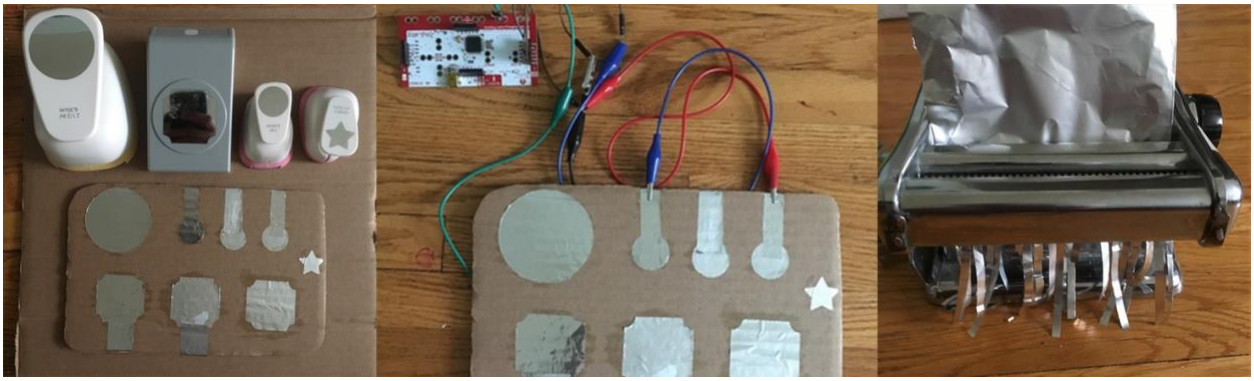

Figure 7: Tools to Cut Tin Foil

I have covered the use of the materials in the case study of this document (see to chapter 2). These are the tools used to manipulate the tin foil and create different interactive elements on cardboard. Figure 7 shows paper crafting punches on the far left which were used to cut shapes.

Project III: Building a Mobile Makerspace

Figure 8: The Mobile Maker Cart

The initial plan was to setup a small work closet to store materials for the makerspace workshops at the community center. As it happened the community centre had plans to do future workshops with the materials and a more permanent solution was required. After researching viable options of building such a space, it was out of scope and budget for the centre. These were the needs analysis of the space.

- Hold the workshops in any available room, since no dedicated space existed.
- Have the materials accessible and move them to the location required.
- The cost of creating the space was undefined at this point.

Taking this into consideration I looked at what options were implemented in schools for ad-hoc makerspaces. The answer was quickly evident, schools have been using carts for decades to bridge the gap for items like televisions, library books and most recent mobile computing devices like laptops and computers. This was what was needed a maker cart. A quick search online for industrial maker carts brought up price list of $500CND for a base workable model and the top end goes into the $1000+ CND range.

The solution was to build our own, the plan initially was to build a custom cart in the university woodshop but that idea was quickly squashed. The goal of this project was accessibility and building a custom cart is out of scope for most schools or community centers. It had to be a D.I.Y project you could assemble in a few hours and also be mobile in every sense.

The solution presented in figure 8 is a mobile cart that can also be considered an IKEA hack (Yap), the only bespoke items are the handle and the peg board. It does include the base and wheels from Home Depot.

Figure 8 Shows its fully assembled state on the left, disassembly in the middle and portability of transporting it in a hatchback car without the need of a full-size van or moving truck.

The functions: (i) Cost effective mobile solution for materials and tools (ii) Run electronics off it. (iii) Can be easily disassembled to transport (iv) The cost comes in at $250CND or less, 50-70% less than a commercial cart.

Chapter V: Workshops

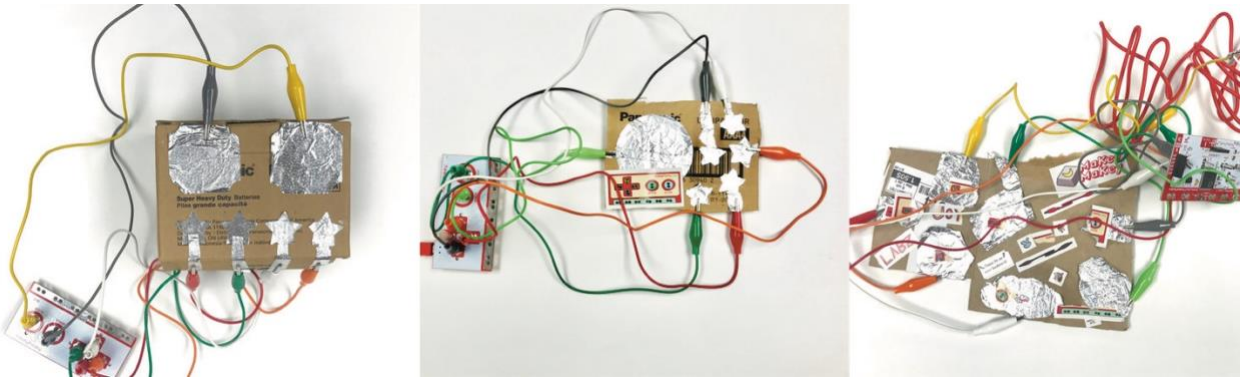

Figure 9: Game Controllers Created by Participants

Introduction

The projects in chapter 4 led to the creation of the five workshops. These were held at a youth and children's community center in Toronto. It was done after a rigorous approval process with the research and ethics board at OCAD University. The study had 6 children ages 9-11yrs of age. The choice of the participants were decided by the community center. It was based on their interest and consent from the parents/guardians. There was verbal assent from the children.

The play-based methodology and methods were part of the design process of the workshops, the play-based nature had some workshop ideas morph into activities that best supported the participants and were within the bounds of the ethics board's approval. Once such activity was the stop-motion workshop, the intend use was modifying an old camera to make it capable of stop-motion capture but the constrains of obtaining the right cameras had the workshop morph in a stop-motion workshop using an old iPhone 5 camera.

Maker Cart

The logistics of the running these workshops was made possible by the maker-cart created in project 3 (see chapter 4). It held all of the needed material, had an affective quality and gave context to the workshops. We also ran the laptop and music off the cart during the sessions. The community center is now the final home for the cart and was partially funded by them.

Workshops Outcome

The research that culminated towards the creation of the workshops was presented and the IACLC (International Association of Co-learning Communities) conference in Bethel New York on February 9th 2020. It was well received and got shared on their website, blog and newsletter.

The community center considered the workshops a success and is in the process of securing funding for a full makerspace and digital fabrication studio. They have built a second maker cart for their satellite center using the part list. I was commissioned to design and source the technology for ten stop-motion stations, they will be installed in the computer labs.

Following are the workshop details and the outcomes from each.

Workshop I: Basic Circuits

Figure 10: Workshop I Building Basic Circuits

The Project: Build a house and wire it with a light

Tools and Materials: Tin Foil, Carboard boxes, Paper punches and a Pasta cutter.

Fixed Goal: Get the light to go on by building a circuit.

Creative Task: Wire a house and design it anyway you want.

The images show the activities in done in the first workshop. Far left has a child turning on a light on their completed structure. The middle was the absolute fascination of making a mess with the pasta cutter. Far right an alternative circuit when the completed the primary task, I introduced them to chenille stems and the fact that they can be used as conductive material if the ends were stripped of the fuzz. (Figure 10)

Questions that were asked by kids from this workshop:

1. What is conductivity?
2. Why is it not lighting up? An opportunity to talk about polarity in LED lights and Batteries.
3. Why is tin foil and chenille sticks conductive?
4. Can I make tinfoil strips to take home?
5. They children felt a sense of accomplishment and took the projects home to show their parents/guardians.

Cost for the workshop materials: $3 CND for the foil, 2$ CND for the LED lights

Bonus activity: $1.25 CND for chenille sticks, $2 for Foam balls other parts were crafting scraps

One-time cost: Pasta cutter and Paper Punches (fixed one-time cost not included)

Challenges and comments of the volunteers:

- The children had come in straight after school and took a long time to settle down.
- Classroom management skills were missing and it felt chaotic at first
- They wanted to see a finish prototype. This is something I did not provide, based on the constructivist approach, so it does not skew the child self-expression.

Workshop II: Circuits and Microcontrollers

Figure 11: Workshop II Building Game Controllers using Circuits and Microcontrollers

The Project: Build a game controller and interface it with an existing game

Tools and Materials: Tin Foil, Carboard boxes, Paper punches, a Pasta cutter.

Technology: Makey Makey Microcontrollers and two laptops.

Fixed Goal: Build a circuit which gets the signal to the microcontroller.

Creative Task: Design the controller anyway you like, given you have to touch the ground.

The images in figure 11 depict the activities done in the second workshop. Far left has a child has a working controller with the ground wire connected to the bottom of the box making it very comfortable to hold.

Questions and comments from this workshop:

1. What is ground? Why do I have to keep touching it?
2. Can we connect it to fortnight? Fortnight scratch version got opened on the laptop.
3. This is so fun!
4. Can I take the microcontroller home?
5. The children opened the scratch book and started trying to code interactions.

Cost for the workshop materials: $3 CND for the foil

Bonus activity: I gave them a piece of conductive cloth and they tied it on their wrist and became touchable controllers. This was very well received by the staff and volunteers present too.

One-time cost is not included in running the workshops:

- Six microcontrollers provided by the community center (fixed onetime cost not included)
- I used my own laptops

Challenges and comments of the volunteers:

- The children had heard the name and seen those microcontrollers before, none had used it. Some boys said they did but had no knowledge of what it did.
- Some children were impatient and wanted to just play on the computer, the girls liked crafting the controllers and spent a lot of time on the details.

Workshop III & IV: Contraptions and Wireless Microcontrollers

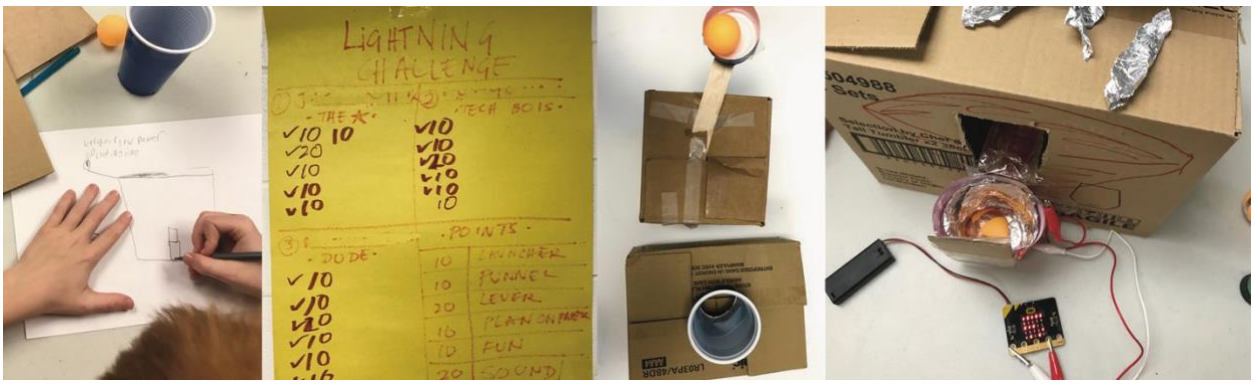

Figure 12: Workshop III & IV Build contraptions and Circuits and Microcontrollers

The Project: (i) Build a contraption to launch a ball and (ii) Wire it to a wireless microcontroller to keep score when the ball drops in the cup.

Tools and Materials: Tin Foil, Carboard boxes, Paper punches, a Pasta cutter, ping ball balls and plastic cups.

Technology: MicroBit microcontrollers and one laptop.

Fixed Goal: Build a circuit that detects the ball drop and counts the score on the microBit.

Creative Task: Design a contraption with some functions to get added points

The images in figure 12 depict the activities done in the third and fourth workshop. Far left has a child has a planning a contraption on paper, the second image is a score chart to for functions the teams added to their contraptions. The ones after are completed contraptions and the far right shows the score being counted on the ball drop.

Questions and comments from this workshop:

1. What is a microBit? No one had seen one before.
2. Can we not draw? Planning on paper was not well received.
3. Can we have a speaker for sound? That ask was not clearly defined.
4. How is it doing that? I was not able to teach them to code the miroBit so I only shared the process of uploading the code to the microcontroller.

Cost for the workshop materials: $3 CND for the foil, Cups and pin pong balls $2.50 CND, craft sticks $1.25 CND.

One-time cost is not included in running the workshops:

- Six microcontrollers provided by the community center (fixed onetime cost not included)
- I used my own laptop

Challenges and comments of the volunteers:

- The foil on the ball keeps coming off, because the glue was not strong enough. We ended up substituting with a copper tape which worked better for the round surface.

Workshop V: Stop-Motion and Digital Editing

Figure 13: Workshop V Stop-Motion and Digital Editing

The Project: Make a stop-motion animation and edit it.

Tools and Materials: Lightbox and Lego

Technology: Old iPhone 5 and camera stand, free app call “stop motion” on the iPhone.

Fixed Goal: Make a stop motion animation

Creative Task: Edit it to add sound, music and a title

The images in figure 13 depicts the activities done in the third and fifth workshop. Far left has a an iPhone setup with a commercial lightbox, the second image one of the action screens for the kids animations, with a chroma key filter for sky. Far right is the rapid prototype from using an IKEA storage box and a lamp instead of a commercial light box.

Questions and comments from this workshop:

1. Oh this is easy! This was while demonstrating the software and explaining the process
2. This is fun and how can I add sound and music? This was a good teaching moment and the kids were quiet tech savvy at using the app

Cost for the workshop materials:

One-time cost is not included in running the workshops:

- One iPhone or android phone. The same app can be used with windows desktop computers and a webcam.
- Camera tripod and lightbox

Challenges and comments of the volunteers:

We had only one setup and the children had to wait their turn. The two girls later collaborated and made a short movie.

This was extremely well received and got adopted as a permanent option in their computer lab.

The original intention was modifying the firmware of old digital cameras to do stop-motion but that did not work out due to technical difficulties.

Summary and Insights

The workshops took place in a span of 4 weeks. I reflected on each workshop as it happened and tweaked the next one. This meant excluding tools and materials I had previously introduced or pacing the workshop differently. Pacing is one of the really important aspects of workshop design as it sometimes happens in real time depending on the energy of the room. At times the children were receptive to what I had to say and at other times there was chaos which had to be reined in. Also the learning was not linear as there are a lot of one-on-one questions which don't get transferred to other participants unless they are in ear shot or paying attention to the instructor.

Working with other volunteers who may depend on your expertise to answer questions can also be a challenge but this improved exponentially over time as they gained skills over the span of the workshops. Documenting my insights just after the workshops was what I found most beneficial to retain something I had just experienced.

Here are some of the main insights I gained from the methods and workshops:

- While working with children as a non-expert and not an authority figure Ii had to pivot straight into making without much lead up explanation. I had to do this on more than one occasion because the children were high energy after school and I had no classroom management skills to brief them on expectations and outcomes.
- Having a controlled set of materials accessible might have been better as a lot of waste was created when free access to paid materials was given without explaining cost.
- A missed opportunity was talking to children about the recycling of materials and how they could recycle the project if they did not intend keeping it.
- Setup, Clean-up and maintaining the space should be planned into workshop design, I did not do this as I was new to the space. I did get the children to start cleaning up after the first workshop as I was left with a huge mess to clean up and put away materials.
- It's very hard to keep track of sets of electronic hardware like the Makey Makey and all the alligator clips that come with it. Give each child ownership and set an expectation that they have to bring back what they have been loaned.

I did not provide any structured breaks as this was a 1.5-2hr workshop. This may change based on the nature of the workshop, in my case it was play-based so there never felt there was a time we needed to stop from any intense task. The children naturally steeped in and out when they needed a break. Some children did stop participating at times but that is a natural part of working with children and I had to let them find their own pace of engagement.

Chapter VI: Reflections & Conclusion

Reflections and Outcomes

Through this thesis exploration I tried to answer the questions, can we democratize digital learning using a low-cost project-based approach?

I developed a project-based pathway of iterative projects, reflected on the outcomes and created the final workshops. Following are the outcomes:

- I proved that low-cost digital projects are a viable option for a small school and community centers, non-experts like myself, the staff and volunteers could facilitate the workshops.
- We participated alongside the students in a playful participatory method, collaborated, questioned our assumptions and came up with creative projects.
- They looked like mashups of cardboard with foil stuck to them but they gave children a vocabulary for new questions and understand underlying fundamentals of digital making.
- They cost pennies on the dollar for a student and most can be done in large groups repeatedly without much overhead. It is also the rudimentary nature of the workshops that took down barriers to engagement.
- We were able to tackle 21st century skills through digital project-based learning and a constructivism approach. The environment was not ideal but we created mobile solution which added an affective quality and added purpose to the projects.
- We got permanent adoption by the community center to sustain the program which will help hundreds if not thousands of children coming to the center. Some of whom might never get access to this learning through conventional school or extra-curricular high cost programs.

If I could change one of the processes it would be having the opportunity to work with the children and facilitators to develop the workshops. Getting their participation, ideas and building it out from there.

I was able to present these ideas at two conferences in the last months of the project. The Future of Making unconference at the Ontario Science Centre on February 2nd 2020 and the IACLC(Independent association of co-learning communities).The presentation at IACLC has led to thought leaders in the field giving kudos to the research and have asked for the paper to use the methods and run these workshops in their micro-schools and home schooling communities.

Last but defiantly not least, through this journey I was able to clarify my own learning style and why I found traditional schooling methods so tiresome. I'm able to help children, who like me might never have the opportunity to have project-based learning, digital or otherwise as part of their school curriculum. It has given me a vocabulary and methodology to bring the merits of this approach to my village of Toronto.

Expert Interviews Podcast

The podcasts were not part of my original methods but after I completed the workshops I was able to reflect upon the critical turning points and how different people were influential in the process. To debrief I wanted to a record of a candid discussion these experts and influencers. They included my advisors, professors, industry experts and students in my cohort whose projects influenced my own.

I was able to share my experience and get a first-hand opinion of how they seen the project evolve over time. The industry experts were able to share their own journey and also the gaps they see in the digital Makersphere in respect to children. I was able to address the issue of safety in makerspace and relate it back to my son's experience at a maker faire, where he got second degree burns from a soldering iron.

The most important aspect of the podcast interview process was clarifying some of my thoughts with these experts and have a way to share it with a larger audience who may not be read this academic paper.

Some insights I gained from the interviews:

- How the COVID-19 virus which had made home schoolers of us all, was now getting children to engage in project-based learning at home. The importance of ICT training for teachers is no longer optional.
- Project-based workshops could have a fixed goal but having a open ended approach offers a great deal of opportunity for creativity from the participants.
- Thinking though the process is just as important as the end product when it comes to learning.
- Taking calculated risk with ambiguity is much more rewarding in the research process.
- The research and ethics board application really forces you to think critically about your methods of engagement.

Conclusion

Through this process I realized I was challenging a mindset. The idea that digital learning has to be exclusive, expensive and needs special skills to engage children in the learning. The workshops can be thought of as working with the DOS prompt on an old computer. They go back to the fundamentals of what circuits are, conductivity and converting an electrical signal into a command on a computer screen. I initially titled this thesis *Digital Spelling*, which meant the ABC's of digital making. Through this process I was able to scratch the surface of that concept and expose some of the methods of engaging in digital making with ordinary materials. Lastly what was most rewarding was learning how co-learning communities and home schoolers found this approach useful as they are also faced with the similar barriers to access and funding. Thinking and learning through a reflective practice is highly rewarding and something I will carry forward.

Future Work

This work has traveled me across the border and back, it has taken new life in the world and has moved out of my care and into the hands of others. I see my role as an advocate to support the people and communities who I have inspired. With this is mind I have the following tasks at hand:

- Create a website where this project can live on and people can contact me for support.
- Continue investigating tools, material and resources to add to a repository on this site.
- Work with the Toronto Art Council to open a tool Library and community maker space in Scarborough, as none exist.
- I'm acting as a resource and advisor on the maker space and digital fabrication lab at the community center.
- Speaking at local conferences and running workshops at the public libraries when possible.

Lastly, I don't see this as work, this is a passion project, the intention is for it to stay that way and pass on the flame one person at a time.

Speculative Outlook

To conclude this thesis I would like to speculate about the future of digital education based on what I've leant through this research. I truly believe that the 4C's identified by 21st century education and the Project Zero are of critical importance. But not all the 4C's in my opinion should be weighted equally. I feel they can be consolidated into two: Creativity and Collaboration. Critical thinking and Communication stem from creativity and collaboration. According to Rita King a futurist who coined the word "Intelligence Era", says we need to focus on collaboration for the next generation of thinkers and innovators, take things slow and think deeply about what matters. ("Rita J. King: Developing Your Imaginative Superpower"). If the COVID-19 pandemic has thought us anything it is need to be able to pivot at a drop of a hat and learn new skills to stay relevant in the workforce. Schools have switched to virtual education and given children a plethora of tools, resources and information to self-learn, but they have no training to manage the chaos or their digital lives and filter their experience in a meaningful way. This ability of learning how to learn, will be the number one skills of the future, to take control of ones learning and weigh the importance of all their resources.

In the future digital learning fundamentals like physical computing and code will take their place alongside spelling, numeracy and science. To exist in a networked world where data controls every aspect of our lives it is critical to understand how our digital lives mesh together with our physical one. Just like learning to use the DOS prompt on a computer forces you to understand the nature of data, so does physical computing change how one perceives our digital world.

As children engage in digital learning new tools will get created but more importantly those tools will come from the children and educators. In carpentry a master craftsman outgrows their tools and from their mastery of the medium they start inventing tools to make their task easier or improve the efficiency of their labour. I believe when digital learning becomes ubiquitous in the early years classroom, the higher grades will become master digital craftsmen for the next generation.

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Appendix A: Maker Cart

Maker Cart Part List

These Items are from IIKEA Canada and the Home Depot Canada

Table 1: Maker Cart Part List

No.	Item	Store	Notes	Cost (CND)
1	Ivar side unit x 2	IKEA	Side unit, 20x49 " (50x124 cm)	$32
2	Ivar shelf	IKEA	Shelf, pine, 33x20 " (83x50 cm)	$14
3	Ledberg Led	IKEA		$15
4	Sunnersta x 3 & rail	IKEA	The cups in the front	$6
5	Power bars	IKEA	I recommend getting a longer chord bar as the one from ikea is too short.	$7
6	Joaxel units (20419964,1042992,40419958)	IKEA	The mesh laundry baskets	$100
7	Base Board birch	Home Depot	This was a mistake; you can use a cheaper board for around $20	$37
8	Casters	Home Depot	2 fixed 2 swivel, you can reduce cost by buying cheaper wheels	$45
9	Nuts and bolts	Home Depot	I over spent here as well I did not have the right idea for screws	$30
10	Peg board	Home Depot	Optional	$12
11	Dowel	Home Depot	Optional	$12
12	(Part#707392916604) Angle	Home Depot	Angles for the legs	$7
13	Miscellaneous items		Zip ties, tablet holder	$10

Instructions

Most of the cart is just assembly it was based on ideas present on the website IKEA hackers (Yap), you will need a power drill to attach the wheels to the base and some tools for assembly. **Strong ZIP ties** are of key importance to attaching the laundry shelf supports, without that the structure will wobble, I did not use a permeant solution because it can't be unassembled if screwed on.

If you would like to make the handle and attach a holder for the paper role it will need power tools and wood working skills, here are some of the photos of the assembly and more details pictures of the cart close up. I used standard wood glue before I secured them with screws.

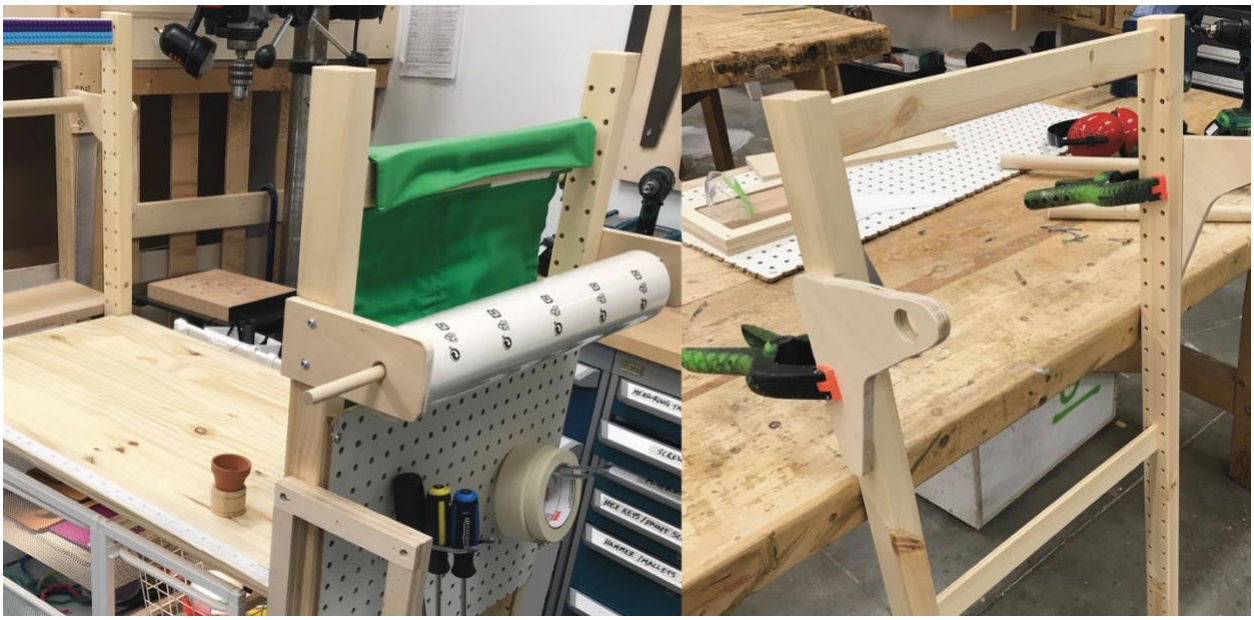

Figure 14: Closeup of the Bespoke Brackets

Figure 15: Addition images of the sides of the cart

Appendix B: Ideation Cards

Ideation Cards

These are the ideation card which can be printed on demand. Card stock paper is preferable.

A downloadable pdf version is on the OCAD Digital Repository. Ideationcards.pdf

Figure 16: Ideation and Planning cards

Appendix C: Podcast Episodes

Podcast Recordings:

The podcast are available on the OCAD Universities digital repository:
http://openresearch.ocadu.ca/

Episode 01: Part 01: A Joint conversation with my advisors Nick Puckett (Primary Advisor) & Adam Tindale (Secondary Advisor)

Part 02: I speak with Catherine Fraise, the founder of Workspace Education and the IACLC (Independent association of colearning communities)

Episode 02: I talk with to Dr. Barbara Rauch and Jay Irizawa about the course "Thinking Through Making" and its influence on my final project.

Episode 03: A candid conversation with Andrew Duff the Creative Director of the Toronto Maker Faire and the Future of making unconference held in February of 2020.

Episode 04: In the final episode I talk with two of my cohort, Omid Ettehadi and Maz Chabayta who are both makers and how our projects overlapped and their contributions to my process.