Does Your School Have the Maker Fever? An Experiential Learning Approach to Developing Maker Competencies

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Abstract

The maker movement in education is linked to better, more authentic learning that can help students develop 21st century competencies. Maker experiences, like any experiential learning, can be limited by decontextualized, recipe-style labs and fail to deliver on the promise of engaged learners ready to learn on demand and solve the ill-defined problems of the 21st century. Our multiphase research program on maker culture in education held a series of exploratory workshops and social events to discover the competencies required to turn experiential learning with technology into maker experiences that meet 21st century needs.

Experiential learning is a valued approach in education, but can be limited by recipe-style labs, decontextualized skill development, or reliance on kit building. Maker culture is a form of experiential learning with technology that promises engagement of learners via iterative, ill-defined problem solving and self-directed learning to satisfy 21st century needs. However, when appropriated for educational experiences (rather than used as a means to solve personal or community challenges) maker culture faces similar risks as all learning: that technology will amplify existing practices, rather than transform them (Davidson, 2007; Price, 2014). Technology and experiential learning are not the sole components of a *maker experience*. This article reports on the first year of a multiphase research program on maker culture in education. We held a series of exploratory workshops with children, women, and men from all strands of life, with a wide range of educational backgrounds and technology experience. We conducted a mini-maker faire, built arcade game tables and a 3D printer, held weekly *maker jams* in our lab, and set a design challenge to develop a gamepad for people living with Parkinson's disease. In light of maker culture literature, we analyzed participant experiences to discover what they suggest about the competencies required to turn experiential learning into maker experiences that meet 21st century needs. We also looked for what characteristics of experiential learning activities appear to assist or undermine those maker competencies.

Context

Over the past 10 years, a body of literature has started to suggest that maker culture can address 21st century skills. Maker culture embodies do-it-yourself tinkering using tiny, affordable open-source computers, electronics, and recycled items to further sustainability, equity, social innovation, democratization of innovation, and community building (Andersson, 2015). Makers engage in self-directed experiential learning through risk-tolerant, persistent problem solving in interdependent communities tackling complex, socially relevant problems. In contrast to the long-term vertical career paths of the past, 21st century individuals face ongoing instability, heavier workloads, diverse global teams, short-term contracts, and frequent changes in expected skills (Patton & McMahon, 2014). Continual, self-directed learning and habits in "curiosity, persistence, flexibility, optimism, and risk-taking" are needed to turn "happenstance" into valuable opportunities (Mitchell, Levin, & Krumboltz, 1999 in Patton & McMahon, 2014, p. 392) and build diverse stepping-stone experiences that lead to unimagined results (Stanley & Lehman, 2015).

We know that integrating technology in teaching is challenging (Selwyn, 2015; Watson, 2006) and does not guarantee a change of pedagogy (Bennett & Lockyer, 2008; Davidson & Desjardins, 2011; Price, 2014; Underwood et al., 2010). The current shift from technology literacy to computer coding in schools (Dredge, 2014; Kemp, 2014) to develop problem-solving skills (Kemp, 2014) risks failure because procedural approaches often used in schools are not personally meaningful to the students (Somanath, Morrison, Hughes, Sharlin, & Sousa, 2016). A linear, objectives-driven approach hampers innovation through contrived exercises, recipes, and rewards constrained by today's imagination (Stanley & Lehman, 2015), such as one-size-fits-all skilling-up using lab tasks, programs in which everyone learns coding for the sake of coding, or assembling kit electronics that can only execute a finite number of operations. Using technology products with too few affordances or limited coding opportunities provides short-lived learning experiences that learners struggle to apply to other problems for themselves or others.

With the demand for STEAM (Science, Technology, Engineering, Arts, and Mathematics) activities and 21st century competencies, we need to encourage learners to develop skills for collaboration, creativity, problem solving, creative computational thinking, and critical thinking. The rise of makerspaces in schools, libraries, and community centers and the popularity of experiential learning give us an opportunity to refocus on iterative design and engineering to solve meaningful problems (Hira, Joslyn, & Hynes, 2014).

Literature Review

Between Teaching by Transmission and Learning by Experience

Teaching by transmission, such as lectures, is a passive experience that gives students a false sense of security about learning and fails to elicit misconceptions (Berrett, 2012; Mazur, 2013). Modern graduates must access information as needed, and adapt to change (Barnett, 2009; Felder, Brent, & Prince, 2011). Rather than plod through defined problems, graduates must confront unfamiliar and ambiguous situations from multiple perspectives, and develop imperfect answers while considering potential consequences (Tsui, 2012). Technology-based skills become decontextualized and outdated in schools (Blikstein, 2013). Although technology has immense potential to support learning (Kozma, 1994), it can be undermined by dated teaching approaches (Price, 2014; Clark, 1983). School labs may focus on rediscovering known principles using defined equipment in limited time periods, while engineering approaches require problem-solving studios with iterative, rapid prototyping in diverse teams that embrace failure while developing complex, original solutions (Blikstein, 2013).

Making is a booming trend for developing 21st century technology skills. Digital *makers* participate in digital do-it-yourself (Andersson, 2015; Fox, 2014) using tiny, open-source Raspberry Pi and Arduino computers with sensors, motors, and networking, as well as 3D printers, laser cutters, woodworking, and crafts. People use *making* to solve problems, defy consumerism, and shape their world (Charny, 2012). Making is promoted as way to develop 21st century skills, but it risks being appropriated by institutions, stripped of risk and empowerment, and delivered in safe, correct recipes that meet demands for control and predictability.

A growing body of literature reports on learning through making (Cohen, Jones, Smith, & Calandra, 2016). In education, the maker movement brings new opportunities because of innovative tools and technologies, including 3D printing, robotics, microprocessors, wearable computing, and a variety of programming languages (Weareteachers Staff, 2013) that are accessible to a wide public through open-source platforms and makerspaces. The next section details the various types of makerspaces and their affordances.

Makerspaces

Makerspaces come in all shapes and forms. While some makerspaces are permanent and dedicated spaces, some are pop-up spaces that can be set up for special events and some are mobile and can serve several communities (Kafai & Peppler, 2014). Makerspaces support multidisciplinary, individual, and collaborative learning through iterative error- and risk-tolerant tinkering, offering multiple points of entry including repairing items, building robots, and creating (Sheridan et al., 2014). The concept of visibility is very important in these environments, which includes "open cabinetry, see-through bins and visible access to the tools, materials, and existing objects that spark ideas for new makes" (Peppler, Halverson, & Kafai, 2016, p. 5).

Makerspaces draw young learners off their couches to help people feel useful by solving problems, sharing their growing expertise, and learning to "stick with things more when they're not working" (Sheridan et al., 2014, pp. 518–519). They focus on tinkering through ideation, iteration, creation, and collaboration (Peppler, Halverson, & Kafai, 2016). Makerspaces exist in several formal environments, such as schools (Burker, 2015), and informal environments, such as museums (Sheridan et al., 2014), libraries (Harris & Cooper, 2015; Haug, 2014,) and community centers (Sheridan & Konopasky, 2016).

In creating makerspaces, educational institutions strive to allow participants to develop technology skills and conceptual knowledge (Blikstein & Krannich, 2013) in electronics, material properties, 3D modeling, and about how we interact with objects and how objects interact with each other. Some maker activities in school makerspaces include 3D modeling and printing, woodworking, designing electronic toys, and using dismantled broken technology for new purposes. Although increasing in numbers, Wohlwend, Keune, and Peppler (2016) point out that these types of activities in schools are still rare. In a case study, they designed elementary school makerspaces with four orientations of making: play, design, technology, and collaboration. They noticed that some students tended to work solely around circuits and when they were done, they didn't seek to collaborate or play. Others went straight to collaboration to ask how others made what they were doing. While some were ready to work in teams, others just wanted to take what they needed and leave. Their study begs school makerspace organizers to embed tinkering and collaborating into the design of their spaces to provide meaningful activities for students. This is supported by Wardrip and Brahms (2016) who suggest that principals and teachers need to analyze their school space and determine how making may fit the school infrastructure, whether it be integrated to several classes or it be a dedicated makerspace. With the diversity of maker activities, what is most important is that whoever is assuming the leadership keeps in mind that successful implementation is to engage students in STEAM learning developing 21st century skills important for workforce development (Benton, Mullins, Shelley, & Dempsey, 2013).

Museum-based makerspaces offer environments for family participation. Some researchers explored how museum makerspaces can involve young children in making activities as meaningful participants (Brahms & Crowley, 2016). Their research has shown that children are able to conjugate personal, social, and material resources and as they develop better relationships with resourceful adults, they develop refined knowledge and skills that they turn into refined practices (Brahms & Crowley, 2016).

Library makerspaces focus on offering patrons new opportunities to try out new technologies, to play with tools and interfaces (such as 3D printers, virtual reality, or visualization technologies) that are not available in all homes, to create sound, to get initiated to computer programming, or to engage in traditional crafts (Britton, 2012). A recent study (Moorefield-Lang, 2015) found that the core issues are relate to the locus of control regarding the decision to create a makerspace in the library (as it is usually not the librarian's idea), the staffing of the makerspace, and the training of librarians to work in a makerspace. However, makerspaces in libraries are worth pursuing because library makerspaces are safe spaces to try new things and fail without many consequences. Libraries bring new ways to become engaged in learning, which as Curry (2017) points out, can upset the current capitalist model, but they have the potential to give resources to a wider population and bring hope to people that never thought they could develop technology or creativity skills, and the freedom to obtain the education they want.

Community makerspaces are designed around the ethos of resourcefulness (Sheridan & Konopasky, 2016). According to these authors, community makerspaces grow organically and are built from needs and wants from the community members who want to develop enhanced skills, including creativity, complex problem solving, persistence, collaboration, and courage, and share them with others. In fact, these spaces have life because of the engagement of community members who thrive on sharing what they learn with others, on asking what they can do with what they have, and on feeling satisfied from making things without spending money they don't have. This ethos of resourcefulness can be designed through the space, through being open and transparent, creating opportunities, and encouraging bootstrapping.

Upon visiting makerspaces and observing maker activities in educational locales, we noticed that maker activities can be appropriated for disciplinary curriculum content without exploiting their potential to prepare learners for 21st century demands. That is, maker activities can result in unintended consequences. For example, maker activities can produce *technofetishists* who consume kit electronics and engage in technical competitions, rather than social innovation (Hertz, 2012). Maker culture can become a *lifestyle choice* (Dieter & Lovink, 2012) of privileged people who tinker with blinking lights and mediocre DIY (Csikszentmihalyi, 2012). Makerspaces can become services for hire, rather than collaborative communities, and maker classrooms can become incubators for electronics consumers and technical workers to serve industrial and military needs (Hertz, 2012). Blikstein (2013) notes risks from digital making in education depending on underlying values: (1) *keychain syndrome*, whereby participants focus on production of simplistic, but attractive maker products, such as 3D-printed keychains, rather than engaging in risky processes of failure and adaptation; (2) lack of time for failure or multiple iterations and lack of space to continue work outside of class and develop working relationships with peers; and (3) structuring *making* around short school periods, and limited resources such as one 3D printer operated by a single expert, instead of allowing hands-on iterative prototyping. In contrast, Blikstein (2013) notes the potential rewards of fostering an ongoing, process-focused maker activity in a dedicated space: students exploring recreational and artistic interests in unusual ways and persisting through failure and developing diverse teams all while happening to learn STEAM-specific skills.

Given that experiential learning with technology can engage people disadvantaged by traditional education, but risks being turned into predictable kit-building and keychain production that fit into tidy schedules and supports existing curricular demands, it is clear that technology is not the key component of a maker experience. Therefore, in this study we focused on the competencies that can be developed in educational makerspaces and in other contexts that require 21st century competencies.

Methodology

Research Approach

We recruited over 100 participants in schools, colleges, universities, and community centers for a series of maker events and workshops. Our participants were children, women, and men from all strands of life, with a wide range of education and technology experience. As we adopted a participatory research approach (Heron & Reason, 1997), "participant" also includes "maker advocates" (participants who engage in helping novices become makers).

This article considers a selection of data from the following events:

1. a mini-maker faire with a fabrication showcase of a 3D-printed shoe and an iPad-controlled espresso machine by experienced makers, and interactive tables where participants with no maker experience could experiment with technologies such as light emitting diodes (LED), electric motors, coding, and soldering;

2. a collaborative build of a Prusa i3 3D printer kit with a team of graduate students and fab lab enthusiasts;
3. weekly *maker jams* in our lab, open to the university and the broader community;
4. a design and build of game controllers for people with specific disabilities; and
5. arcade table builds using Raspberry Pi single board computers, inexpensive IKEA tables, and reclaimed computer parts—one with children at a community centre, and another with university students.

Our data collection spanned from June 2016 to May 2017. Given 21st century needs for people who can address ill-defined and unfamiliar problems in unexpected contexts by learning and adapting as needed while engaging in iterative and collaborative prototyping using modern technology, we asked the following research questions:

1. What do participant experiences with experiential learning with technology suggest about the competencies they need to meet such 21st century needs?
2. What are the characteristics of those experiential learning activities that appear to assist with or undermine those competencies?

Data Collection and Analysis

As part of our research program on maker culture in education, we are documenting competencies that emerge from maker culture activities and events. We developed data collection instruments to monitor participants within their maker experiences, namely an observation grid (to capture data such as the location of the activity, the environment, the purpose, the materials used, and the interactions among participants, and between participants and maker advocates), some qualitative research instruments including field notes, post-mortem reflections, observation checklists, and informal and semi-structured interviews. We also use participatory action-research tools and techniques, such as those developed by Chevalier and Buckles (2009), to better structure dialogue with participants as maker activities began, progressed, and ended. We extensively document events with photos and videos to allow observations afterward.

After each event, we hold a research team meeting to discuss the observation grids, our field notes, and postmortem reflections to discuss events that surprised us, activities or attitudes we need to pay attention to, and discuss potential emerging themes, namely those that suggest specific competencies to focus on. The informal and semi-structured interviews are transcribed and analyzed using HyperResarch, a qualitative data analysis software.

The data we discuss in this article were analyzed using statements and connecting them to concepts and themes, using a grounded theory approach (Strauss & Corbin, 1990). This allowed us to reflect on competencies that have been discussed as desirable in the maker-related literature (e.g., learning to ask questions, persist when encountering failures, build trust and relationships) and beyond. With multiple rounds of reflections on the emerging competencies, we identified several categories. We then triangulated these categories with elements we had identified in our field notes and in our multimedia documentation. This allowed us to identify themes for the categories of competencies that were needed to succeed in maker activity, and what characteristics of experiential learning helped or hindered those competencies. Our thematic analysis was conducted by two researchers with multiple rounds of feedback to revise and fine-tune emerging themes.

Findings

This section presents themes emerging from our participants' experiential learning with maker activities to address 21st century needs. Five themes emerged regarding success in maker activities: initiative, playful learning, authentic adaptation, interdependence, and over-resourcing.

Initiative. Participants who truly wished to engage in maker activities sought to get their hands dirty. They showed up to multiple events and were willing to take on challenges, to try new things, and to learn new tools as needed. In contrast, during planning meetings, some potential collaborators showed no interest in prototypes from another participant, but wished only to contribute their existing academic expertise.

We saw a direct relationship between developing maker competencies and the willingness to learn new tools. A minority of participants felt comfortable using power tools and when it came to showing another person how to use them, they did not feel competent enough to use them safely and did not want to touch them. One participant said, "No I refuse to use the power tools. I am too afraid to injure myself and I don't feel confident that I can use them with precision." After a competent teacher taught her the basic elements of safety and let her manipulate the tool with wood scraps, the participant spent a considerable amount of time building an arcade game using the power tools to fit components into an IKEA Lack table. One participant said, "I am confident I can use a drill and a saw. I have seen people use them, I have used one myself before and I know I can do it." When the time came to use the tool, she said, "I need someone to watch over me because I have not done it often enough."

Any maker activity requires the use of tools, whether physical or mental, but it is not always clear which tools will be needed in advance, whether for complex builds, such as a 3D printer or an arcade table, or more simple builds such as a remote-controlled car or a Bluetooth sound system. For example, upon dismantling old speakers during the arcade table build, one participant broke a wire and was ready to throw them out. Although the broader project did not require soldering, we introduced the skill to resolve the immediate problem. The participant said,

> Once I removed the speaker from their cases, the wire broke. I changed the wire for a better quality one and soldered it. I also put a blob of hot glue in case the wire moved too much. I didn't realize we could glue wires.

Our first lesson was that learning with maker-led activities requires us to get our hands dirty.

Playful learning. Many makers who showed up to our workshops or challenges were novices to maker culture driven by curiosity instead of expertise. Expertise can be a barrier: during planning sessions for the research project, potential collaborators did not engage with our sample prototypes, and preferred to offer their existing academic expertise. During workshops, maker advocates faced a challenge of holding back: participants complained that the 3D printer build was overly controlled because, as their self-efficacy rose over the first day, they were feeling too constrained by a structure that limited their freedom to make mistakes. During the community arcade table build, the children were at times disengaged when adults took over planning and measuring to ensure it was correct.

We held maker jams on sustainability and reusability themes where participants dismantled old technologies for reuse in other projects. For example, when dismantling a DVD drive, one participant said:

> I read that I could use the servo from the DVD drive in my car, so I started dismantling one. I had no idea how to remove the servo. I removed one part after the other and at one point there was one piece I could not remove. I looked with a magnifier to see if I was not missing something but there were no screws. Then someone told me to pry it open. I used a screwdriver as a lever until the part gave. I realized I had a super magnet in my hand.

Disassembling technology to discover its reusable components was a powerful learning experience that no kit can teach because there are no recipes or rules to follow.

While building an arcade table with children, we decided to build a prototype and test the parts and the design as we progressed. Every time they completed key steps of the build and tested the console, they high fived and did a short celebratory dance. Upon finishing the arcade table, one child said, "My favourite part of the whole project was that we learned to solder," a skill they had learned when fixing a broken part. When asked what he would do differently next time, the participant said, "I would build another table for two players instead of one." Building an arcade table is a challenging 20-hour project, but the children were enthusiastic about their new skills and wished to build a more complex version. The use of mock-ups, repairs, and design iterations suggests that they were embracing playful iterations to improve the project.

Our second lesson was that learning with maker-led activities requires us to embrace playful iteration.

Authentic adaptation. Makerspaces are specifically designed to provide the tools and collaborative space that support maker activities, but not all maker activities happen in makerspaces. Some of the challenges and workshops we held were in spaces that were not specifically designed for maker activities, which reflects the expectation that participants need to be able to practice maker competencies outside of a lab, and educators may not have access to lab space.

The multi-week arcade table workshop we held at a community centre started upstairs in a quiet office, but was moved down into the rambunctious common room, where youth shouted while playing table tennis and foosball, in order to better integrate with the broader community that was too timid to participate. While participants assembled the joystick and buttons, table tennis balls were flying and children were running around us to get their balls. One research assistant received a ball on the head while trying show a participant how to code. This was challenging because the activity required focus, but for the children, it did not matter. One child came a few times to kneel and beg one of our participants to play table tennis. Our participant said, "Not now. You don't understand. I need to do this.

I'll play another time," even though at other times he had confessed he had a hard time focusing on school activities. In a later week, the same child came to work on the project despite injuries from what appeared to be a schoolyard fight.

Adaptation to changing participants was required in many workshops. In the 3D printer build, the maker advocates agreed to a small group, but two additional people joined on the first day for a group of 10. On the second day, a participant brought her two young daughters (who often sought her attention), and yet another participant joined. After lunch, four participants left for other commitments. These changes disrupted group dynamics and resulted in new participants requiring assistance with catching up on the build to complete it. Similarly, weekly maker jams, scheduled between 5:00 and 7:00 p.m., attracted different levels of participants who were often so focused that they stayed late.

With changing locales, participation, and open-ended schedules, managing parts and tools can get chaotic. One participant started keeping a list for makers to note when they checked out a tool. Another participant numbered and labelled tools and parts with blue and green masking tape to track use in the field. At the end of the year some makers started taking responsibility for managing tools and suggested that some tools and parts be kept locked at all times to reduce loss and limit confusion.

Our third lesson was that learning with maker-led activities requires us to manage activities in imperfect environments.

Interdependence. Participants who engaged in maker activities valued learning through interdependent interactions. Interdependence can be challenging because its success requires sharing control of an experience, and sharing expertise, rather than taking over to demonstrate competence. For maker advocates, the desire to achieve a working 3D printer by the second day, or a finished and working arcade table when energy was running low, could lead to taking control.

In contrast, while building the 3D printer, whoever didn't know how to strip wires was the person nudged into doing the wire stripping. In any other circumstance, the skilled person would have picked up the wire strippers and stripped the wires. However, to ensure that everyone could strip wires, skilled participants encouraged novices to learn by doing. One participant said, "I know how it's done, but I prefer not to do it." Another participant said, "Why don't you want to do it?" The first participant said, "Because I'm afraid I won't do it well, or I might break something." The other participant explained that we had plenty of wire so we could make as many mistakes as needed. This had a double impact where less-skilled and intimidated participants learned hands-on, and those who already had the skill were able to shift their expertise into coaching.

Also during the 3D printer build, a poorly manufactured part for the 3D printer did not fit. Some participants were convinced that one of the rods was too big. Other participants helped with the troubleshooting and decided to remove an identical part to see if it fit and it did not. One participant decided to use a caliper to measure the slot and suggested that a small amount of metal should be removed. Enlarging the slot too much could cause a major problem, so participants agreed to use the most skilled person in the team to grind away a fine layer of metal. However, after his departure, there was a grinding noise during operation suggesting a second problem, which was resolved by bending the bracket more open by hand. Participants negotiated a balance between moments where novices could learn skills by engaging hands-on, and moments where major mistakes should be avoided by deferring to more skilled assistance. However, had all participants remained engaged until the troubleshooting process was complete, everyone would have more fully understood the multiple problem-solving issues at stake.

For maker activities to be successful, participants needed to be able to take turns in trying a new skill. For example, during an arcade table build with children, two participants were dismantling speakers from their plastic housing. An older participant kept grabbing the tools from the younger participant, and when asked if he wanted to try, the younger participant said, "I don't care, let him do it." We were not sure how to interpret his reaction, but we made sure that he was able to engage in later dismantling when the occasion arose and he was happy to do it. In the final interview, he said his favourite part of maker activity was learning how to dismantle things and use new tools. We wondered how we might help impatient participants shift their inclination to take control into a new skill of coaching.

Our fourth lesson was that learning with maker-led activities requires us to embrace interdependence.

Over resourcing. When participants engage in maker-led activities that are not commercial kits, extra time and resources need to be factored in or maker advocates may take too much control and focus on efficiency, accuracy, and completion of the originally envisioned final product in order to meet artificial constraints.

When participants tried to hack into retro gamepads for an accessibility challenge, nothing they planned initially worked. Many attempts were required to understand how to dismantle the game pads, how the circuit worked, and what amount of pressure was necessary to create a working circuit using the extended controls. One participant, recognizing the importance of investing time in some learning, invited an electrical engineer friend to assist, and said, "I need to figure out the basics. Once we have that, we can build the extended controls later, but there are a few things we need to understand first."

On several occasions, participants worked on fabrications that were unattractive, but represented stepping-stones in self-efficacy. One participant, who built an Internet-enabled weighing scale using a microcontroller, load cell, and ABS pipe, showed his fabrication to the planning team. One collaborator, who was a programmer, looked at the exposed wires and said it looked like a rat's nest. This is exactly why he wanted to use developer kits. The wiring is figured out and he can focus solely on the code. The participant who had fabricated the prototype noted that it merely represented a working proof of concept. The conversation highlighted a difference between learning through purposeful and iterative fabrications versus learning to code with ready-made products.

During the maker faire, participants sat around exploration stations and engaged with sewing blinking LEDs into fabric flowers, building robots out of motors and markers, programming in the Scratch language, and controlling commercially available programmable robots. Some of the projects that were meant to introduce kids to robotics captivated university students. One participant said, "I was so proud of my robot!" Two other participants stayed around this table for several hours to do a robot combat. They wanted to know which robot would win over the other. The programming station generally intimidated participants. The wearable electronics station, which was meant as a demonstration of creating a circuit with a light emitting diode (LED) using conductive thread, became a circle of seamstresses where participants sat for several hours. Participants in general said that it was relaxing to sew the wearable electronics, but the programming activity was intimidating. However, having sewed the blinking LEDs into fabric flowers, some were motivated to learn more about programming, which they thought was more complex. This suggests that providing a variety of consumable materials and more time for playful learning can encourage participants with no maker experience to enjoy maker activities and seek further experiences.

During an arcade table build, after holes for the controls had already been cut in the table surface, some participants argued about the layout of the controls and whose hand the buttons would serve. The build was dismantled and its parts were reused in another build, with the loss of a table deemed unimportant despite some participants' concerns about waste. One participant said, "We can use it as an example for future workshops."

Our fifth lesson was that learning with maker-led activities that requires us to make progress happens over bumpy roads, not on super highways.

Discussion and Lessons Learned

To address criticisms of traditional education, we examined experiential events where volunteer participants actively applied technology (such as microcontrollers and reclaimed parts of computing products) to build a solution with others without prior training. In this section, we address our research questions: given 21st century needs for people who can address ill-defined and unfamiliar problems in unexpected contexts by learning and adapting as needed while engaging in iterative and collaborative prototyping using modern technology:

1. What do participant experiences with experiential learning with technology suggest about the competencies they need to meet such 21st century needs?
2. What are the characteristics of those experiential learning activities that appear to assist with or undermine those competencies?

What do participant experiences with experiential learning with technology suggest about the competencies they need to meet such 21st century needs? Our study supports findings in the literature that participants can learn from and be engaged with hands-on making (Cohen et al., 2016) of diverse non-curricular projects (Stager, 2013). We engaged a wide variety of participants ranging from children to middle-age, from middle school to post-graduate education, with a variety of projects including building an arcade table, and building a 3D printer. Regardless of age or education, learning included jumping into activities without prior training, learning new tools as needed, adapting to imperfect locales and changes in participants, engaging in interdependent collaboration, and making time for learning from mistakes.

Our study supports findings in the literature that participants facing learning challenges can learn through *doing* without strict recipes (Somanath et al., 2016) and engage with and persist with maker activity (Sheridan et al., 2014). Most of our maker experiences occurred over several days, and the arcade build with the children occurred each Friday afternoon over a number of weeks. Despite educational challenges, entreaties from peers, and schoolyard tensions, the children persisted with the project until the end and took great pride in their accomplishment. Despite challenges in our 3D printer build, such as poorly manufactured parts and changes in participants, our participants were modelling and printing a sample object by the end of the second day.

Our analysis suggested key themes of initiative, playful learning, authentic adaptation, interdependence, and over resourcing. These themes can be developed into "maker competencies" to meet 21st century needs:

- Participants show "initiative" when they embrace novel challenges, and new hands-on tools as needed to meet those challenges, by building on what is familiar without hiding in what is comfortable.

- Participants show "playful learning" when they demonstrate playful curiosity and iterations of design, repair, and rework in order to optimize long-term learning while achieving short-term goals.

- Participants show "authentic adaptation" when they adapt to authentic environments with changing participants and gaps in resource management.

- Participants show "interdependence" when they actively balance collaboration to redirect competition and control into mutual vulnerability, mentorship, and humour to optimize learning through risk-taking.

- Participants show "over resourcing" when they provide extra time and resources to allow for mistakes, exploration, and revisions in goals as part of a learning process while pursuing a solution.

What are the characteristics of those experiential learning activities that appear to assist with or undermine those competencies? If our "maker competencies" are the desired outcome of experiential learning, we must ask whether our maker advocates (the people participating within an event to help novices become makers) are approaching experiential learning from a "maker competency" perspective:

1. Are they creating situations (and adjusting them) such that participants are nudged into demonstrating and fostering initiative, playful learning, authentic adaptation, interdependence, and over resourcing?
2. Are they demonstrating the desired competencies through their own participation?

As noted previously, the literature suggests that experiential learning with technology can engage people disadvantaged by traditional education, but risks being turned into predictable kit-building and "keychain" production (Blikstein, 2013). Technology alone is not the key component of maker competencies. Any activity can be turned into a risk-averse recipe to be followed in a lab by dependent learners and assessed for meeting a predetermined goal within constrained time and resources (Blikstein, 2013).

Although ill-defined and ambiguous problem-solving is the goal of maker activity (Tsui, 2012), some of the events in this study were defined in the sense of achieving an arcade table previously documented on the Internet, building a 3D printer from a kit, and constructing a game controller for people living with particular health conditions such as Parkinson's disease. Coding was limited to configuration of existing software. While we cannot claim that our workshops and events were all ill-defined and highly technological, we gained insight on variations of maker activity design. We noticed that not all novice makers needed structured designs, but without some structured experiences to start with, some participants might never engage in maker activities. For example, blinking a light with an LED is a good introduction to circuits that needs to be integrated into a more purposeful activity or social innovation.

This article refers to maker advocates as participants because we adopted a participatory paradigm for our research program. Heron and Reason (1997) suggest that the participatory worldview, "allows us to join with fellow humans in collaborative forms of inquiry" (p. 275) and "the choice and assertion of a participatory worldview is fundamentally experiential" (p. 276). The participatory approach is a good fit with maker activities, but it requires devolving responsibility across participants. It can be tempting for "educators" to view themselves as responsible for creating experiences for others, to remain as experts who plan, guide, control, evaluate, and troubleshoot a project to ensure continued progress, to look competent, and to achieve the desired end product. Davidson and Desjardins (2011) describe this as typical of teacher-centered, product-oriented pedagogy. In contrast, a more learner-centered, process-oriented pedagogy is needed where maker advocates shift their role into nudging participants into developing the maker competencies we identified: initiative, playful learning, authentic adaptation, interdependence, and over resourcing.

For the 3D printer build, maker advocates over-planned and organized the first day such that participants noted the lack of challenge as their confidence grew over the course of the first day. For the maker advocates, the goal of a working printer by the end of the second day was more important than allowing participants to make mistakes. For the arcade table build with children, maker advocates loosely followed a process borrowed from the Internet, and at times took over planning, measuring, and marking activities while leaving the tool use to the children, particularly as the weeks passed and energy waned.

Future endeavours in "maker" learning would focus maker advocates on how to ensure participants' initiative blossoms in a vacuum of expert answers and predefined challenges; that playful learning supports risk-taking and over-resourcing ensures there is time and resources to support it; that the maker event adapts to its surroundings and its participants' experience even as it grows over a day; and that maker advocates promote interdependence, which may mean suppressing concerns about efficiency and facilitator competence in order to support others' learning.

Conclusion

This study examined the use of experiential learning with technology in the form of maker experiences to engage participants hands-on at a maker faire, and to build arcade tables, a 3D printer, and an alternative game controller.

The significance of this study is the exploration of hands-on experiential learning with technology with participants ranging widely in age, experience, and education in order to identify *maker competencies* to meet 21st century needs. This study suggests that initiative, playful learning, authentic adaptation, interdependence, and over-resourcing are key competencies to support maker activity. These characteristics of maker activities can be used when creating, observing, or evaluating learning experiences by asking the following questions: Did we seek to “get our hands dirty”? Did we embrace playful iteration? Did we manage in an imperfect (but authentic) environment? Did we embrace interdependence? Did we support progress over a bumpy road? And for more experienced participants in a group, did they coach more through asking questions, and do less?

While we cannot generalize the findings of this study, the maker competencies we identified are transferable to other groups of novice makers and maker advocates. Though we used a selection of the data of a large-scale research program we are conducting, the results we selected were confirmed during several workshops and are therefore credible and confirmable. This study focuses on several discrete maker experience events. Future research could engage in longitudinal study and examine the same participants over multiple events with related maker activity. For instance, the children at the community centre wished to create a multiplayer version of their arcade table, and the 3D printer offers numerous hardware upgrade and firmware coding possibilities. Such research could examine the application of our maker competencies in the creation, monitoring, and evaluation of future maker experiences including experiences wholly constructed by participants to address personal or community needs.

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