International Journal of E-Learning & Distance Education
La Revue internationale de l'apprentissage en ligne et de l'enseignement à distance

ISSN: 2292-8588 **Vol. 35, No. 1, 2020**

Fostering Learning through Making: Perspectives from the International Maker Education Network

Jennifer Lock, David Gill, Thomas Kennedy, Stephanie Piper and Alwyn Powell

Abstract: How are we preparing teachers to design and foster learning through making where disciplinary knowledge and skills are applied and developed? One approach that addresses this question can be found from the International Maker Educational Network (IMEN); an online professional learning community built upon shared interests in educational making. Members meet regularly to share their maker context and experiences and what can be gleaned to help support developing capacity to design and facilitate learning through making. In further studying their professional practice using a self-study methodology, four IMEN members shared their respective maker contexts, illustrating examples of making in formal and informal learning environments and what is being learned from their experiences. These cases provide examples of strategies and approaches that are being used to support learning through making and provide insight into developing and utilizing knowledge and skills in fostering learning through making in P-16 educational contexts. The article concludes with three recommendations for practice to support educators and teacher educators in fostering learning through making.

Keywords: Learning, Making, Makerspaces, Maker Mindset, Teacher, Teacher Educator

Résumé: Comment préparons-nous les enseignants à concevoir et à favoriser l'apprentissage en faisant en sorte que les connaissances et les compétences disciplinaires soient appliquées et développées? Une approche qui répond à cette question peut être trouvée dans l'International Maker Educational Network (IMEN), une communauté d'apprentissage professionnel en ligne fondée sur des intérêts communs dans la création de l'éducation. Les membres se réunissent régulièrement pour partager leur contexte et leurs expériences de créateur et ce qui peut être glané pour aider à développer la capacité de concevoir et de faciliter l'apprentissage par la création. En étudiant davantage leur pratique professionnelle en utilisant une méthodologie d'auto-apprentissage, quatre membres d'IMEN ont partagé leurs contextes de créateur respectifs, illustrant des exemples de fabrication dans des environnements d'apprentissage formels et informels et ce qui est appris de leurs expériences. Ces cas fournissent des exemples de stratégies et d'approches qui sont utilisées pour soutenir l'apprentissage par la création et donnent un aperçu du développement et de l'utilisation des connaissances et des compétences pour favoriser l'apprentissage par la création dans les contextes éducatifs P-16. L'article se termine par trois recommandations pratiques pour aider les éducateurs et les formateurs d'enseignants à favoriser l'apprentissage par la création.

Mots clés: Apprentissage, Création, Makerspaces, Maker Mindset, Enseignant, Enseignant Éducateur

Introduction

The maker movement is quickly growing in our schools and libraries in P-16 education. Makerspaces are gathering spaces where individuals engage in using various materials and resources as they "embrace tinkering, or playing, in various forms of exploration, experimentation, and engagement, and foster peer interactions as well as the interests of a collective team" (Wong, 2013, p. 35). As we observe the continuous growth in experiential learning through making, how are educators developing their capacity to design and foster learning through making where disciplinary knowledge and skills are applied and developed?

The International Maker Educational Network (IMEN) was launched in winter 2018.

IMEN is a group of interested educators from Canada and Australia who regularly meet once a month using web conferencing. As a professional learning community, members share their work, participate in virtual making activities, and engage in rich discussion with regard to learning in making and makerspaces. Through these ongoing discussions, IMEN members are learning from each other in support of the maker movement in their educational contexts (Lock et al., 2020).

In this article, we as a group of IMEN members have selected to illustrate, using cases, how teachers and teacher educators are creating opportunities for learning through making. The four case examples represent informal and formal learning in P-16 education, on campus or at a distance, where technology is used in learning through the making approach. Each author presents their case example by outlining their maker context, the nature of the particular making activity, and what is being learned from the experience. Through these cases, the authors identify strategies, approaches, and challenges experienced when using a maker approach to learning. Further, these cases can be used as potential models to help educators conceptualize and/or implement learning through making within their educational contexts.

The article concludes with a discussion of implications for practice to support educators in developing their capacity to foster learning through making for knowledge and skill development.

Literature Review

The P-16 education community acknowledges the potential and richness of learning through making and in makerspaces through the growing implementation of makerspaces in formal and informal learning environments in schools, higher education, libraries and museums (Crichton & Childs, 2016; Halverson & Sheridan, 2014; Hynes & Hynes, 2018; Irie et al., 2019). These learning environments are "pushing us to think more expansively about where and how learning happens" (Halverson & Sheridan, 2014, p. 498). Three components of the maker movement, according to Halverson and Sheridan (2014), are "making as learning activities, makerspaces as communities of practice and designed learning environments, and makers as identities of participation that afford new forms of interaction between self and learning" (pp. 502–503). Learning through making is grounded in constructionism and often involves a multidisciplinary approach that engages various literacies in both the process and production of the artifact (Halverson & Peppler, 2018). Makers need to be able to create and invent without the support of instructions (Dougherty & Conrad, 2016). Making is occurring in formal and informal educational contexts both on campus and online, as well as in the community (Halverson & Peppler, 2018).

The maker movement, as defined by Anderson (2012), is the "new industrial revolution". This movement shares three common characteristics:

- "People using digital desktop tools to create designs for new products and prototyping them ('digital DIY')";
- "A cultural norm to share those designs and collaborate with others in online communities"; and
- "The use of common design file standards that allow anyone, if they desire, to send their designs to commercial manufacturing services to be produced in any number, just as easily as they can fabricate them on their desktop" (Anderson, 2012, p. 21).

Makerspaces are agents of change influencing how educational stakeholders conceptualize learning, how they engage in designing and facilitating the learning, as well as how technology is used in teaching and learning (Peterson & Scharber, 2018). These spaces vary in access to and use of digital technology, from low-to-high tech. In a low-tech makerspace, makers may work with such materials as "markers, paint, fabric, LEGO blocks, clay, power tools, and even (non- electronic) hand tools" (Webb, 2019). In contrast, a high-tech makerspace may include such tools as "virtual-reality headsets, 3D printers and scanners, Makey Makey or Arduino circuitry kits, or video game consoles" (Webb, 2019). The technology used in makerspaces will vary and will be used to support the nature of the learning through making.

With greater focus on experiential learning and the resourcing of makerspaces in P-16 contexts, educators need to be "equipped with theory, knowledge, and skills about making" if they are to be able "to integrate making in formal learning settings" (Hsu et al., 2017, p. 592). As part of this evolution and to support robust learning through making, educators like students need to develop and foster a maker mindset, which "is an expression of the growth mindset that is evident in a maker's willingness to learn new tools and methods as well as experiment without certainty of success" (Dougherty & Conrad, 2016, p. 145). Educators not only need to embrace a maker mindset, they also need to model and create conditions to support students in developing such a mindset.

Within the maker learning context, educators may need to develop an understanding as well as confidence in designing robust making activities and/or creating conditions for students to engage in the experience of learning through making. The maker learning activities, projects, or problems need to deeply engage students in constructing knowledge and not only be limited to constructing products or artifacts (Valente & Blikstein, 2019). They will need to be able to select materials and resources, including technology, that appropriately supports the making process.

Risk-taking and learning from failure are critical components of making. It can be challenging for students and educators "because it connects the development of iterative design provocations and a mindset that embraces failure" (Lock et al., 2018, p. 10). Robust learning through making in P-16 requires educators to have confidence and competence with their disciplinary knowledge and skills so they can support learning that embraces inquiry, problem- solving, and/or prototyping as part of the design process and artifact creation. When designing and facilitating a making learning environment, educators, like their students, must also engage in risk-taking and be accepting of failure. Their teaching practice needs to embrace the notion of collective and collaborative knowledge and allow time for iteration as part of seeking solutions (Lock et al., 2018). Within this complex role, an educator may be called to be "an observer, intervening only when further rigor or the need to pass on a gem of wisdom from experience becomes necessary" (Fleming, 2015, p 47). In facilitating making, educators need to act as mediators, challenging students, creating conditions that promote interaction with objects being produced, and helping students understand the concepts and strategies used. Through these interactions with the students, teachers can help students construct new knowledge, as well as reach a higher level of comprehension about what they are doing. (Valente & Blikstein, 2019, p. 260)

From the literature, we are seeing an increase in the integration of learning through making in P-16 educational contexts which is impacting student learning (Jones et al., 2020). Along with the investment in the infrastructure to support student learning, where are the opportunities and/or experiences for pre-service and in-service teachers to learn through making or to learn strategies and approaches in how to best design and facilitate such authentic learning experiences? By integrating and implementing best practices of learning through making with technology, which may also include robotics and coding, into teacher education, we provide an opportunity for pre-service teachers to develop both technological and pedagogical skills through an engaged approach to managing and facilitating learning in technology-enhanced environments (Raulston & Alexiou-Ray, 2018). "Makerspaces and teacher education can be transformed by each other" (Kjällander et al., 2018, p. 18). By giving pre-service and in-service teachers opportunities to engage in learning through making, it provides a forum for the lived experience, to reflect on practice, and to consider application in their own teaching practice. It allows them to look beyond the space and the resourcing, to examine and reflect on the nature and scope of the learning.

According to Jones et al. (2020), there is limited research focused on how to prepare educators in designing and facilitating learning through making in formal education contexts. They argued that teachers need to have the experience of learning through making in order to integrate this approach in their own classrooms. The aim of our study is to reflect on current practice within four educational contexts that embraces learning through making. Through the illustrative case examples, we seek to acknowledge strategies and challenges encountered in supporting robust learning through making. Through reflective practice, it is our goal to identify implications for practice in preparing educators to design and facilitate learning through making where disciplinary knowledge and skills are applied and developed.

Research Design and Methods

We selected a self-study methodology given we were ‘‘studying professional practice settings’’ (Pinnegar, 1998, p. 36). The purpose of our self-study was “to better understand, facilitate, and articulate the teaching-learning process” (LaBoskey, 2004, p. 857) in relation to how to prepare educators in designing and facilitating learning through making. Our inquiry was guided by the following research question: Reflecting on current practice of learning through making, what are some recommendations for practice in preparing educators to design and foster learning through making where disciplinary knowledge and skills are applied and developed?

As a small group of members of IMEN, we selected to use a collective self-study method (Samaras & Freese, 2006) to share and illustrate examples of our professional practice in terms of leading learning through making. In the four authors’ case narratives, they each described their maker context and their specific making activity. Each case concluded with what the author has learned from the experience. Through the analysis of the cases, we identified strategies in developing capacity and engaging disciplinary knowledge and skills in designing and fostering learning through making in P-16 contexts. The self-study methodology allowed us to focus on "learning from experience that is embedded within teachers' creating new experiences for themselves and those whom they teach" (Russell, 1998, p. 6). The benefit of self- study is that the "articulation of a pedagogy of teacher education might emerge and be both meaningful and applicable in the practice of others in the teacher education professional community" (Loughran, 2005, p. 13).

Cases

The following four case studies illustrate examples of learning through making in both formal and informal learning contexts:

- Case One: K12 Educative Maker Programs
- Case Two: Delivering Maker Skills via Distance — A Mail Out Maker Kits Program
- Case Three: Pre-service Education through Design and Make
- Case Four: Teacher Educators Engaged in Virtual Making

Case One: K12 Educative Maker Programs

Thomas Kennedy, Educator, Eric G Lambert School, Canada

Non-curricular maker programs in K-12 institutions are championed by teachers who have adopted the maker mindset and endeavor to support constructionist learning opportunities. While these school-based programs can look different from one jurisdiction to the next, they can also be structured as parallel programs that align with national and international organizations that offer purposeful maker activity. Teachers can adopt and implement established programs such as the Marine Advanced Technology Education underwater remotely operated vehicle (MATE-ROV, https://materovcompetition.org), and Skills Canada (Skills Canada, 2020, www.skillscompetencescanada.com) to lay a foundation for their local maker initiatives. I have always considered each to be categorized as a maker activity as they encourage participants to solve, create, design, and redesign as they prototype solutions to challenges proposed by the program scope document. Although these educative maker programs diverge in theme and technical perspective, they converge in their focus on developing skills and engaging in purposeful, technical activity.

MATE-ROV is an international program designed to engage participants in STEM-based activity and prepare them for potential careers within technical marine-based disciplines. The program is framed around a fictitious call-for-proposals where school-based teams develop a prototype similar to a real-world company. Limitations are communicated such as size constraints, but otherwise, teams have creative license when it comes to the design and fabrication of their ROV. The program promotes teams to innovate using tools, materials, and processes as they engage a cyclical design process. While each season brings new challenges, skill development remains the primary focus as participants engage both hard and soft skills as teams fabricate, demonstrate, and present their prototype at competition. On the day of the competitive event, the tethered ROVs are placed in the water and piloted to engage the physical tasks placed at the bottom of the pool. The competition intentionally creates a real-life feeling that teams are responding to a demand for marine technology. Regional affiliates of MATE host thirty competitions internationally in three classes: Scout (intermediate, ages 12–14), Ranger (secondary, ages 15–18), Explorer (post-secondary).

Skills Canada is a federal initiative with provincial jurisdictions to encourage and support a coordinated Canadian approach to promoting skilled trades and technologies to youth. The educative maker program strives to raise awareness of skilled trades and technologies by bringing youth into a competitive spotlight and to improve competencies, self-esteem and the achievement level of individuals pursuing careers in skilled trades and technologies.

Competition categories include, but are not limited to: Graphic Design, TV Production, Wind Turbine, Prepared Speech, Workplace Safety, Website Development, Coding, Robotics, Cooking, IT Software, Photography, 2D / 3D Animation and Job Skill Demonstration. Like the MATE ROV program, Skills Canada competition categories are governed by a scope document. The expectations of each competition area are outlined in their respective scope documents, published each year to the event website. It outlines the skills required for the unseen demonstration at the day of the competition which highlights the importance of domain specific technical competency while also highlighting general competencies in numeracy, oral communication, collaboration, continuous learning, reading text, writing, thinking, document use, and technology. Competitors pre-register and prepare in each category throughout the season to develop the necessary competencies to compete with representation from other schools within an unseen framework on the day of the competition. The annual provincial competition hosts all categories for each of the three levels: intermediate (grade 7–9, ages 12–14), secondary (grade 10–12, ages 15–17), and post-secondary. The Skills Canada experiences explored as a part of my research fell within the intermediate category.

My own educative maker programs were built upon the engagement of young makers within the MATE ROV and Skills Canada frameworks with particular emphasis on the gradual release of my responsibilities. Student-based communities of practice emerge within educative maker programs as responsibilities gradually transition away from the teacher mentor to the student makers. The growing community of competent makers collaborate within the program to bring newcomers into full membership.

As both educative maker programs host a terminal activity or competition, the experience of competing amid student makers from parallel programs has brought makers from local communities of practice together within a larger group. As participants prepare for the expectations of the competition, they also reflect on their own identity amid a larger community of practice that they would normally never engage with if not for the event. Early experiences in school-based maker programs lay the groundwork for a technical identity but this connected identity is built upon the shared histories and experiences of the local membership. The maker identity must be complemented by an engagement with parallel programs that value the same competencies, the larger maker community of practice. Educative maker programs that culminate in competition offer participants the opportunity to situate themselves within the larger community of practice which, in turn, strengthens their technical identity for potential trajectories in skilled trades and technological fields.

Case Two: Delivering Maker Skills via Distance — A Mail Out Maker Kits Program

Stephanie Piper, Community Engagement Coordinator, University of Southern Queensland, Australia

The University of Southern Queensland (USQ) is a leading provider of distance education in Australia and has approximately three quarters of its students studying online or by distance. On the Toowoomba USQ campus, the Library Makerspace specializes in providing equipment and training in 3D printing, 3D modelling, electronics and hands-on projects in a physical space. One of the challenges of the on-campus makerspace is to explore alternative ways to connect with, and engage, distance and online students—both undergrad and graduate students—in its possibilities.

The Maker Kits Project was launched to provide an opportunity to online and distance students to get involved with making. Four different kits are mailed out in batches of 30 over an annual cycle, including kits such as Arduino and Sensors, Home Automation, Wearable Technology and Robotics Basics to teach various maker skills. For example, in the Arduino and Sensors kit, students are taught how to blink an LED, read a photoresistor (light sensor), and move a servo motor. This involves learning to use the Arduino development environment with a breadboard to create circuits, and how to troubleshoot a project. A project to engage maker skills via distance through a library makerspace Maker Kits Project is the first of its kind. The Maker Kits Project provides an example to other institutions to see the successes and areas for improvement in this type of student engagement.

The aim of the Maker Kits Project is to encourage the growth of maker culture and maker skills within the university by providing students with an opportunity to access hands-on equipment. The program is funded through the Student Amenity Fee grant and has delivered 120 free maker kits to USQ students across Australia over the past two years. Kits were paired with online workshops, covering the basics of circuits, working with Arduino electronics and machine language code. This project was featured in the NMC Horizon report in 2018 as an exemplar project (Adams Becker et al., 2018).

The total budget requested for this project was $3,600AUD, and each kit comes in under $15AUD. Kits are assembled from bulk ordered parts and designed from scratch. As such, kits can be assembled cheaply, but it does require a team of volunteers to put the kits together before they are shipped to the students.

Students can submit an expression of interest (EOI) to partake in the program for each of the four rounds over the year. The program EOI's received generally outweigh the number of kits that can be distributed at the time. Usually around 140 EOI's are received per round with only 30 kits available.

Kits are mailed to students who have been selected through the EOI process. When the program initially began as a pilot program, students were selected based upon their ability to participate in a selection of live workshops to guide participants in using the kits. However, the majority of students who received a kit did not attend the live workshop session. All content provided in the sessions is accessible in an 'access anytime' style, through a series of instructional videos. Content is available at www.bit.ly/makerweb.

While the popularity of the program was initially high, maintaining engagement with the students in the Maker Kits program proved to be difficult. Only a small percentage of students partook in live workshops and chose to fill out surveys about the program. Despite this, the feedback on the program from the few who engaged was generally positive. Students reported that they felt their confidence increased after undertaking the kit and are more motivated to try out other electronics projects with Arduino. Other feedback included skills that students would like to learn, including working with LCD screens, using motors, 'internet of things' (IoT) projects, and camera recognition. To improve on this engagement level, it would be better to provide the program at a nominal cost to students, where they may feel more motivated and invested in the program once a cost is paid. Free activities, while breaking down the barriers to entry, do not have the same level of engagement than those provided at cost.

The Maker Kits Project pilot program highlights how making and makerspaces can engage communities regardless of where students are located.

Case Three: Pre-service Education through Design and Make

David Gill, Assistant Professor, Memorial University of Newfoundland, Canada

Memorial University's Faculty of Education offers a wide variety of options for undergraduate students seeking to qualify as K–12 teachers. Included in these options is a degree in primary/elementary education with a conjoint STEM diploma. Inquiry-, problem-, project-, and design-based learning theory and practice are core to our pre-service teacher education experience, and as such, this case resides within the context of problem and design-based approaches to making. Each year, as a part of their "Learners and Teachers" seminar, our pre- service teachers are given a 24-hour module to engage in a design and technology activity to help them understand the articulation of "T" in STEM. It is in this module that they are introduced to the ideas of design and make pedagogy and the nature of technology as process and product through a simple problem scenario about the unassuming beaver.

Making activities and experiences can range from open-ended tinkering to purposeful design and prototyping. This continuum of purpose provides an excellent framework for pre-service teachers to explore the pedagogical and practical aspects of engaging in making activities within a formal school setting. To move the exploration past simple discussion, our pre-service teachers are placed in the shoes of their future students as they work through an authentic design and a make scenario that is positioned at the purposeful end of the maker continuum. The pre-service teachers are presented with a problem scenario that places a small town at odds with the local beaver population. Within the presented scenario, beavers are introduced as industrious engineers and prolific reproducers that have started to threaten the only road into town. Generally, the pre-service teachers identify with this localized authentic problem, and a number of them have firsthand experience with similar scenarios. The pre-service teachers are challenged to research, design, and 'make' a prototype that could be implemented to reduce the friction between human and beaver. They are then given two general constraints—their solutions can not harm the beavers and they cannot relocate the main road into town.

How does technology fit into this scenario? The pre-service teachers are specifically instructed that they must develop a technological solution to the problem and are given access to a variety of trending digital technologies available at the primary/elementary level in local schools. These technologies include: BBC micro:bit, Makey-Makey, Littlebits electronics, Scratch, SketchUp and Tinkercad, 3D printers, and general craft and construction material. After giving all the pre- service teachers brief tutorials on the functionality and capability of the individual technologies, most of the time in the module is devoted to researching, designing, making, re-designing, re- making, and presenting their working prototypes to peers and instructors. Pre-service teachers create a wide variety of solutions ranging from scale models of habitat and automated drainage systems to interactive information displays on beaver behaviour. The consistent factor of the pre-service teachers' work is the integration of technology into applications that go beyond simple understanding of isolated functionality — their making puts these technologies into a context, and context is very important for authentic learning.

For the problem with beavers, our pre-service teachers are charged with applying technology to a unique situation within a supportive learning environment. Observations and their feedback have led to a number of insights that may have some significance for teacher educators interested in pursuing design and make within their own contexts. Two of those insights relate to the nature of formal education and the power of authentic technological learning scenarios to move students beyond the scope of an initial activity. First, challenging the mindsets of pre- service teachers that have been successful in our current education system can be tough. They come into the project with the idea that there is a 'right' answer. Prompting and watching them move from this position generates a lot of meaningful discussion about the purpose of school and education in general—it becomes a metacognitive exercise about their future role as educators. Second, this module demonstrates the power of a well-crafted, open-ended problem to be a catalyst for individual students to move beyond the boundaries of a classroom activity. This was evident from the project taking on a life of its own as different groups began to dig much deeper than was required to understand various aspects of both the real-world context and the technology. This manifested itself through pre-service teachers going into the field to document beaver habitat, consulting with experts, poling elementary students during their practicum, and digging deeply into the historical and social context of the problem. These actions became points of reflection on the nature of education and the role of teachers in facilitating meaningful learning situations. This case illustrates that design and make activities can be one method of achieving meaningful learning experiences for students.

Case Four: Teacher Educators Engaged in Virtual Making

Alwyn Powell, Mathematics Curriculum and Pedagogy Lecturer, University of Southern Queensland, Australia

The STEAM (Science, Technology, Engineering, Arts and Mathematics) learning opportunities for teachers in making are well documented. Making as an online task is not just about discussing designing and making a product, but rather it is in the actual sharing of making a product. To this end, discussions were held in the inaugural sessions of IMEN to make a robot (Lock et al., 2020) over several meetings that would be suitable for an elementary school. This led to sharing of blackline masters over the Internet—each participant building a common robot, sharing, and checking understanding at each step.

The robot design emanated from a similar project I developed for a Queensland primary school makerspace. The first task was to design a series of components that would lead to the making of the robot that each participant could access wherever they were in the world. To this end, nets of specific mathematical shapes (e.g., cubes, prisms, and cylinders) were designed and shared to be parallel constructed at the next meeting.

The specifications and tools needed were also shared.

The printing of the blackline masters required some clarification of the language used in the initial instructions because of the different imperial and decimal measurements used. For example, in Australia the photocopy card (cardstock) used is measured in grams per square metre (e.g., 200 GSM) and in North America the measure is in pounds. Similarly, a single 6mm hole punch equated to a ¼ single hole punch in North America. In making the robot, several tools (e.g., scissors, hole punch, scorers, & rulers), materials, and adhesives were discussed and needed to be used. It was highlighted during these sessions, that children in schools today were not safely and correctly using these basic tools and were not provided with safe access nor instruction in the use of tools, such as scissors and boxcutters. Explicit explanation through the on-line medium was required. Instructor skills, including careful listening to responses, patience, reflection on responses, and cultural and language considerations were imperative.

In each session, suggestions for sourcing adhesives, materials, and tools for the next session and beyond were discussed and provided. This was especially important for such things as the Arduino Uno and program download. The adhesives used included PVA glue (wood glue, white wood glue, white craft glue, Elmer's craft glue, Aquadhere) and hot glue. Safety issues surrounding the use of tools, materials and adhesives were discussed especially with regards to sharp and pointed tools and hot glue.

Making the robot was a long-term project and as such required pre-planning to get the resources needed and storage of the same in the down times, like regular elementary classrooms. Making online also brought to the forefront solving problems such as connecting LED lights to the robot eyes without soldering, and yet suitable for the next step of programming the robot.

Sustainability by reducing waste was achieved by allowing photocopy masters to have items for two people on each sheet, as for use in an elementary classroom. However, this caused some interesting challenges for when participants had to construct sections of the robot, off camera, in between monthly meetings. At each step of the online making, it raised challenges. For example, connecting the components to the Arduino was no different. Slightly different Arduino platforms and programs required different solutions and drivers which challenged the group to solve, when trying to upload a simple coded program that made the robot turn its head and wink whilst raising its arms. In its initial stages the focus was on how the componentry fitted together then problem solving why a LED light might not turn on, including checking the polarity and the digital socket connected. The conversation needed meant that queries were able to be asked when the maker encountered problems not just at the monthly meetings.

The development of the robot occurred over several months before a moving blinking robot was finally achieved and during that time a common understanding of the techniques, language, tools and materials used were discussed. Incidental discussions on types and use of tools and safety, STEAM, and ideas for teaching design were shared.

Over the past two years with IMEN, I have led and/or engaged in various maker projects. The first project utilized getting tools and materials used. The second project engaged with sharing ideas and particular skills of different participants making using a variety of other tools and materials. The third was to consider a novel shared design and making project. An idea was put forward, as it was the fiftieth anniversary of the moon landing, could we design and make a Mars advent calendar. The group discussed what was required, made recommendations, then each member separately drew a sketch of what it might look like. These were then shared and combined into our Mars space-ship advent calendar.

Overall, the work to date in the IMEN has followed a design continuum including explicit instruction in construction and safety using tools, materials and adhesives, online problem solving and engagement of participants, drawing and illustrating, learning new skills and sharing creative ideas online. Challenging ideas of what people know and how to access new and relevant knowledge for the design project at hand, ways to encourage and persist in creative ideas were some of the concepts taken from the project thus far.

Discussions, Implications, and Limitations

With each case, the authors provided examples of how making can occur within formal and informal learning environments both on campus and at a distance. Each example illustrated the breadth of the nature of the learning that is occurring through making. Discipline knowledge and skills are needed in the design of the making activities, in supporting the making process, and in assessing the learning. For example, having fundamental knowledge of coding is necessary in troubleshooting and supporting students as they move from novice to expert with the specific digital technology (e.g., Arduino, BBC micro:bit, Makey-Makey, & Tinkercad). As students are engaged in using the technology as part of making, educators will be observing the learning to be able to determine the nature and degree of the support needed and/or to ask relevant probing questions to move the learning forward. It also requires determining what types of support are needed for the learners as they work on their making activity (e.g., workshops, demonstrations, and curated resources). From a formal education perspective, educators also need to be aware that assessment practices should fit the unique representations of knowledge and skill that can be demonstrated by their students in a maker learning environment. In relating their own experience in implementing maker pedagogy in their middle school Math and History classes, Salisbury and Nichols (2020) reflected on shifting to non- standardized assessment methods when linking maker activities with formal learning objectives. While making can be a creative and liberating experience from regular classroom routines, it should still fit within the greater context and objectives of the curriculum if it is to experience wider adoption.

Learning through making may not have one pathway. Rather, there may be multiple pathways and solutions to problems students are being asked to engage in as part of learning through making. “[C]onstructionist notions of making-as-learning, play-as-learning and self-directed learning form the foundation of makerspaces in education” (Irie et al., 2019, p. 404). As such, educators need to be confident in being flexible and responsive to the just-in-time learning occurring through making. It requires creating conditions to support iterations and prototypes, and the learning through failure that may vary from learner to learner within the makerspace. Formative, as well as summative assessment play a critical role in supporting the learning process.

From the four case narratives, three key implications for practice have been identified in how we need to prepare educators to design and foster learning through making where disciplinary knowledge and skills are applied and developed. First, educators should have the experience of being makers, to have the lived experience of making. This experience provides insights into the nature of this form of experiential learning, but also with the frustrations that comes with such learning. The idea of lived experience in developing confidence in pre-service teachers has also been supported by the research of Gill and Galway (2019) as they reported that makerspaces are perceived by pre-service teachers as effective models for pedagogical and technical skill development. Second, from such lived experience, educators will develop a greater raised consciousness to what type of discipline knowledge and skills are required to support learning. Cohen et al. (2017) have suggested a potential quadrant-based continuum for maker activities that can help educators identify the level of “makification” that their initiatives fall under. The continuum relates playful to deliberate learning goals to the level of private to collaborative process required. Understanding the nature of their planned activities within this continuum can be a metacognitive tool for seeking out and exploring further appropriate professional development. For example, this may involve the development of proficiencies using specific technology or developing greater subject matter expertise to support the design and facilitation of the maker activity. Third, in addition to developing a maker mindset is the need to model it for learners. Modeling a maker mindset helps learners to appreciate the richness of learning through making. Gill and Galway's (2019) research supports the idea of modeling as pre-service teachers reported modeling and mentorships as one of the strongest supporting elements for them in developing their own understanding of how makerspaces can be integrated into varied educational settings. Further, this also provides opportunity for modeling assessment practices that are appropriate for such experiential, hands-on learning experiences.

While one limitation is the self-reporting nature of the data collection, all authors have many years (e.g., two authors combined have approximately 30 years) of experience as makers and as facilitators of making within their educational context. The next step of this work is to conduct further research to identify what strategies and approaches educators are using or need to use in developing their capacity to design and facilitate learning through making where disciplinary knowledge and skills are applied. In such research, it will be important to include educators who are new to making or novice makers, as well as others who have wealth of experience and expertise in supporting learning through making.

Conclusion

As educational institutions invest in technology and resources in support of creating makerspaces, there is also a need to invest in developing the confidence and competence of educators to design, facilitate, and assess learning through making. As argued by Cohen (2017), “it becomes incumbent on teacher education programs and other types of professional development programs for in-service teachers to help teachers develop their relevant technology knowledge, self-efficacy, and belief system” (p. 9). Educators need to have the opportunity to engage in using making technology as makers as part of informing their practice.

“Makerspaces are promising pathways that may catalyze reimaginations of teaching and learning” (Peterson & Scharber, 2018, p. 51). As P-16 education embraces the breadth of possibility for learning through making, careful attention needs to be given on how to support educators in developing their capacity in designing, facilitating, and assessing learning through making that fosters disciplinary knowledge and skill development.

References

Adams Becker, S., Brown, M., Dahlstrom, E., Davis, A., DePaul, K., Diaz, V., & Pomerantz, J. (2018). *NMC Horizon Report: 2018 Higher Education Edition*. EDUCAUSE. Retrieved from https://library.educause.edu/~/media/files/library/2018/8/2018horizonreport.pdf

Anderson, C. (2012). *Makers: The New Industrial Revolution*. Crown Publishing Group.

Cohen, J.D. (2017). Maker principles and technologies in teacher education: A national survey. *Journal of Technology and Teacher Education, 25*(1), 5-30.

Cohen, J., Jones, W. M., Smith, S., & Calandra, B. (2017). Makification: Towards a Framework for Leveraging the Maker Movement in Formal Education. *Journal of Educational Multimedia and Hypermedia*, 26(3), 217–229.

Crichton, S., & Childs, E. (2016). Taking making into schools through immersive professional learning. In J. Novotna & A. Jancarik, *Proceedings for the 15th European Conference on e-Learning ECEL* (pp. 144–150). Academic Conferences International Limited.

Dougherty, D. & Conrad, A. (2016). F*ree to make: How the maker movement is changing our schools, our jobs, and our minds*. North Atlantic Books.

Fleming, L. (2015). *Worlds of Making: Best Practices for Establishing a Makerspace for Your School*. Corwin.

Gill, D. D., & Galway, G. (2019). Pre-service technology education teachers' perceptions of experiential learning through makerspaces. *Developing a Knowledge Economy through Technology and Engineering Education*, 177–185.

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

Halverson, E., & Peppler, K. (2018). The Maker Movement and learning. In R.K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed.) (285-294). New York, NY: Cambridge University Press. https://doi.org/10.4324/9781315617572-28

Hynes, M. M., & Hynes, W. J. (2018). If you build it, will they come? Student preferences for Makerspace environments in higher education. *International Journal of Technology and Design Education*, *28*(3), 867-883. https://doi.org/10.1007/s10798-017-9412-5

Hsu, Y., Baldwin, S. & Ching, Y. (2017). Learning through making and maker education *TechTrends,* 61(1), 589–594. https://doi.org/10.1007/s11528-017-0172-6

Irie, N. R., Hsu, Y. -C., & Ching, Y. -H. (2019). Makerspaces in diverse places: A comparative analysis of distinctive national discourses surrounding the maker movement and education in four countries. *TechTrends,63*(4), 397-407. https://doi.org/10.1007/s11528-018- 0355-9

Kjälander, K., Åkerfeldt, A., Mannila, L., & Parnes, P. (2018) Makerspaces across settings: Didactic design for programming in formal and informal teacher education in the Nordic countries. *Journal of Digital Learning in Teacher Education, 34*(1), 18-30. https://doi.org/10.1080/21532974.2017.1387831

Jones, W.M., Cohen, J.D., Schad, M., Caratachea, M., & Smith, S. (2020). Maker-centered teacher professional development: Examining K-12 teachers' learning experiences in a commercial makerspace. TechTrends, 64, 37–49. https://doi.org/10.1007/s11528-019-00425- y

LaBoskey, V. K. (2004). The methodology of self-study and its theoretical underpinnings. In J. J. Loughran, M. L. Hamilton, V. K. LaBoskey, & T. Russell (Eds.), *International handbook of self-study of teaching and teacher education practices* (pp. 817– 869). Kluwer. https://doi.org/10.1007/978-1-4020-6545-3_21

Lock, J., da Rosa dos Santos, L., Hollohan, P., & Becker, S. (2018). It's more than just making: Insights into facilitating learning through making. *Alberta Science Education Journal. 45*(2), 10-16. http://dx.doi.org/10.11575/PRISM/32937

Lock, J., Redmond, P., Orwin, L., Powell, A., Becker, S., Hollohan, P., & Johnson, C. (2020).

Bridging distance: Practical and pedagogical implications of virtual makerspaces. *Journal of Computer Assisted Learning*. Advance online publication. https://doi.org/10.1111/jcal.12452

Loughran, J. (2005) Researching Teaching about Teaching: Self Study of Teacher Education Practices, *Studying Teacher Education, 1*(1), 5-16. https://doi.org/10.1080/17425960500039777

MATE ROV Competition. (2020) Retrieved May 25, 2020, from www.materovcompetition.org

Peterson, L., & Scharber, C. (2018). Learning about makerspaces: Professional development with K-12 inservice educators. *Journal of Digital Learning in Teacher Education, 31*(1). https://doi.org/10.1080/21532974.2017.1387833

Pinnegar, S. (1998). Introduction to Part II: Methodological perspectives. In M. L. Hamilton (Ed.), *Reconceptualizing teaching practice: Self-Study in teacher education* (pp. 31–33). Falmer Press.

Raulston, C. G., & Alexiou-Ray, J. (2018). Preparing more technology-literate preservice teachers: A changing paradigm in higher education. *Delta Kappa Gamma Bulletin*, *84*(5), 9-13.

Russell, T. (1998). Introduction to Part I: Philosophical perspectives. In M. L. Hamilton (Ed.), *Reconceptualizing teaching practice: Self-Study in teacher education* (pp. 5–6). Falmer Press.

Salisbury, K., & Nichols, T. P. (2020). School makerspaces: Beyond the hype. *Phi Delta Kappan*, 101(8), 49–53. https://doi.org/10.1177/0031721720923792

Samaras, A.P., & Freese, A.R. (2006). *Self-study of teaching practices.* Peter Lang.

Skills Compétence Canada. (2020). Retrieved May 25, 2020, from www.skillscompetencescanada.com

Valente, J. A., & Blikstein, P. (2019). Maker education: Where is the knowledge construction. *Constructivist Foundations*, *14*(3), 252-262.

Webb, K.R. (2019). *Makerspaces: High-tech and low-tech locations to expand creativity in the academic library*. Retrieved from https://libraryconnect.elsevier.com/articles/makerspaces-high-tech- and-low-tech-locations-expand-creativity-academic-library

Wong, T. (2013). Makerspaces take libraries by storm. *Library Media Connection 31*(6), 34-35.

Authors

Dr. Jennifer Lock, PhD, is a Professor and Vice Dean in the Werklund School of Education, University of Calgary. Her area of specialization is in the Learning Sciences. Dr. Lock's research interests are in e-learning, change and innovation in education, scholarship of teaching and learning, and learning in makerspaces. Email: jvlock@ucalgary.ca

Dr. David Gill, is an Assistant Professor of Technology Education in the Faculty of Education, Memorial University of Newfoundland. Dr. Gill's current research interests include pre-service technology education teacher pedagogical and technical skill development and the role of design and make outside official technology education curricula. Email: dgill@mun.ca

Dr. Thomas Kennedy, EdD, is a K12 Technology Education teacher and educative maker program mentor at Eric G Lambert School in Churchill Falls, Newfoundland and Labrador. Dr. Kennedy is also a per-course instructor in the Faculty of Education's Technology Education program, Memorial University. His research interests are in maker identity development, constructionist learning environments, and educative maker programs. Email: tomkennedy@ericglambert.org

Ms. Stephanie Piper is the Community Engagement Coordinator at USQ, looking after the library Makerspace. She is also co-founder of Elkei Education, introducing electronics skills and positive role models to young girls. With a background in biofabrication, Steph also teaches classes in 3D printing, Arduino and Hardware development. For more info, see http://www.piper3dp.com/ Email: Stephanie.Piper@usq.edu.au

Dr. Alwyn Powell, PhD—Previously a mathematics curriculum and pedagogy lecturer at the University of Southern Queensland, Australia. His research interests are in the area of practical experiences of primary school children in the STEAM disciplines, especially in the development of fine motor skills and the use of tools, materials and adhesives. Email: Alwyn.powell@usq.edu.au