Bridging distance:
Practical and pedagogical implications of virtual makerspaces

Abstract: Makerspaces are locations where people with common interests can work on projects, share ideas, tools, and expertise to make or create. There is an abundance of 'how to' guides and research studies on physical makerspaces, little research focuses on describing the *virtual* making processes and the experiences therein. This qualitative study explores the experiences of seven participants who engaged in a synchronous virtual makerspace. Meeting once a month over 16 weeks, members of the International Maker Educator Network (IMEN) participated in the making a robot. This case study describes how the virtual making occurred, the personal experiences of the makers, technology used to support virtual making, and the affordances and inhibitors of virtual making. Data are analysed through the lens of a professional learning community and the People, Means and Activities makerspace framework. The paper concludes with implications for virtual making in practice and future research opportunities.

Keywords: Makerspace; virtual makerspace; making; virtual making; professional learning community (PLC)

Introduction

Makerspaces are locations where people with common interests can collaborate on projects, share ideas, tools, and expertise to make or create (Davee, Regalla, & Chang 2015). They can occur in informal learning spaces such as community spaces and learning commons or libraries, as well as in more formal learning spaces such as classrooms. Irrespective of where the makerspace is located, the people involved promote and value play, collaboration, creation, and problem-solving. The incorporation of online communication tools and digital resources provides an opportunity to create online or virtual makerspaces. Similar to its physical version, virtual makerspaces involve creating, building and inventing by way of a more self-directed experience that occurs in a formal educative makerspace (Loertscher, 2015).

This paper draws from the experiences within the International Maker Educational Network (IMEN). The paper provides contributions to the field about a unique virtual maker experience which draws on knowledge and skills of the membership that is not geographical bound (Australia, Canada, & United States). In most makerspaces, participants are from the local geographic area. A second feature of this unique work is that the making occurs virtually with synchronous support from a facilitator that may also include an opportunity to continue the work through asynchronous means. The purpose of this article to is to share practical and pedagogical processes and experiences involved in virtual makerspaces. First, the article begins with a review of the literature to examine the makerspaces in different environments. Second, a case study is presented to examine the phenomena of virtual making. In this research, a subset of the members from an IMEN elected to explore the experience of making within a synchronous online environment. Within the case, the authors described how the virtual making occurred, the experiences of the makers, the use of technology to support virtual making, and the affordances and inhibitors of virtual making. Finally, the article concludes with implications for virtual making in practice and future research opportunities. The scope of this research bridges the opportunities available with online learning environments and the creative processes found in makerspaces.

What is Making?

Making is a creative process (Willett, 2016) that can involve the collaborative act of designing, building, and prototyping to address needs or develop solutions of personal interest. The work is interdisciplinary, generative, and distributed across platforms and levels of expertise (Brahms & Crowley, 2016). Making often involves some form of technology use (Galway & Gill, 2018) as demonstrated in the resurgence of making and do-it-yourself (DIY) community spaces that permit rapid prototyping through high tech tools such as 3-D printers and laser cutters. They can include activities that range from tinkering to creating, and involve hacking that uses no tech (analog making tools and materials), low tech, and high tech tools and materials. Both high and low technology makerspaces are quickly moving into community spaces, schools, colleges, and universities.

Arising from the work of Seymour Papert and his theory of constructionism, making in an educational context refers to the building of learner knowledge through construction with digital and/or physical tools (Papert & Harel, 1991). Scholars have suggested "proficiency with tools, techniques, and technologies" (Clapp, Ross, Ryan, & Tishman, 2017, p. 38), is a critical aspect of making. Additionally, the importance of dispositions necessary for successful making includes creativity, innovation, iteration, (Clapp et al., 2017; Peppler & Bender, 2013), persistence, and the embracing of failure, (Gierdowski & Reis, 2015; Oliver, 2016). Such attributes are combined to describe the *maker mindset* (Dougherty, 2013). This mindset is "an expression of the growth mindset that is evident in a maker's willingness to learn new tools and methods as well as an experiment without certainty of success" (Dougherty & Conrad, 2016, p. 145). Empowerment is also an integral trait for this mindset. Clapp et al. (2017) argued, "Maker empowerment is a sensitivity to the designed dimension of objects and systems, along with the inclination and capacity to shape one's world through building, tinkering, re/designing, or hacking" (p. 103).

The outcome of making in formal contexts is a pedagogical shift in learning "from students as consumers to students as creators" (Johnson, Adams Becker, Estrada, & Freeman, 2014, p. 14). Underscoring the process of this pedagogical shift, Vossoughi and Bevan (2014) suggested that making goes beyond a pedagogical use of "making as inquiry-based educative practice" (p. 5). In their work, they identified two additional motives for implementing making in educational contexts. These motives are: "making as entrepreneurship and/or community creativity" and "making as STEM pipeline and workforce development" (p. 5). Making can promote the learning of necessary 21st-century skills and competencies for students. That is, in the design and facilitation of learning through making, transferable skills can be embedded and supported to help students develop capacity in attributes such as communication, creative thinking, collaboration, critical thinking, and conflict resolution.

What are Makerspaces?

Makerspaces are gathering spaces for creating and prototyping. "Makerspaces 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). The term maker can generate "images of people working with their hands - designing, building, and crafting" (Clapp, et al., 2017, p. 5). Originally developed in informal venues where people gathered to have access to high technology tools and expertise for rapid prototyping of ideas, makerspaces have gained traction in formal education contexts. "While the focus is often on technology, makerspaces more generally concentrate on creation" (Slatter & Howard, 2013, p. 273). Such acceptance is likely due to the possibilities makerspace learning presents for learners as they develop the competencies and discipline knowledge advocated by government, industry and educational bodies.

Common broad categories of makerspaces include dedicated makerspaces, distributed makerspaces, and mobile makerspaces, as well as online communities to support ideation, creation, prototyping, and problem solving (Davee, Regalla, & Chang, 2015). Irrespective of their space, activity, and category, all makerspaces enable making.

Types of makerspaces. Dedicated physical makerspaces provide a specific, marked location to house tools, materials, and ongoing projects (Davee et al., 2015). This location may be at a library, learning commons, or classroom. Other affordances in a physical makerspace include a collective sharing of tools, materials, ideas, and expertise in an environment that evidences visible, innovative processes and prototypes being undertaken by other makers in that location (Wardrip & Brahms, 2016). Establishing and maintaining the materials and expertise needed in a dedicated makerspace may provide a significant challenge to organizations.

Distributed makerspaces provide location flexibility in that that they provide multiple access points for various making activities within an organization. For example, distributed makerspace tools and supplies are often located on different university campuses or flexible room spaces. Varied tools and materials are housed in different spaces including the learning commons, classrooms, and other flexible spaces throughout the building (Davee et al., 2015). Access to multiple making environments is provided, however, tracking materials and tools, booking spaces, and accessing expertise may be problematic.

Mobile makerspaces are in themselves makerspaces that can be moved. They house tools and materials that may be transported from location to location and can often be found in the form of carts, trailers, and vehicles (Davee et al., 2015; Moorefield-Lang, 2015). The affordances of mobile makerspaces include flexibility, availability, and convenient access to tools and materials (Wardrip & Brahms, 2016). Together, these characteristics address the very real issue of equity and access to making opportunities. Again, one of the challenges of mobile making can involve the opportunity of flexibility itself. That is, the management and responsibility for the upkeep and restocking of materials on the mobile cart can be problematic (Wardrip & Brahms, 2016).

The above makerspaces tacitly assume some form of facilitator or teacher-guided structure for designing the makerspace and its collection of tools and resources. Given this need of a guided space design, it is suggested that making can be supported in online environments of "peer-supported feedback and mentorship, as well as access to peer-created resources like tutorials" (Rafalow, 2016, p. 172). However, online or virtual environments need to be designed in such a way that they encourage newcomers and participatory identities (Litts, Halverson, & Bakker, 2016). Therefore, intentionality of design and technology are required to support a virtual environment for making.

What is a Virtual Makerspace?

Making can produce physical objects (e.g., a chair, a robot or a piece of clothing) or digital products (e.g., a video, an app, or a computer game). Similarly, makerspaces themselves can be physical or virtual locations. Whether it is a physical or virtual makerspace, digital and physical products can be created. Within the physical location, members of the group are together in the same location. Whereas in virtual makerspaces, the making is occurring in each person's physical location, but they are connected through the use of digital communication technology. For example, using synchronous technology, people in their various locations can be engaged in making their products but can share and discuss their work through the use of synchronous technology. The major difference between physical and virtual making is that maker can be at different geographic locations, using various materials and resources but are connected through digital communication technology.

Building upon the definition of making, *virtual making* is the process of synchronous and/or asynchronous making in an online environment. It can involve a virtual (i.e., Internet-driven or virtual-reality) environment to create, build, and invent (Loertscher, 2015) that supports makers in direction, asking questions, sharing work, and giving and receiving feedback (Oliver, Moore, & Evans, 2017) while at a distance. The makerspace trend normally involves a physical space for makers to come together to create and innovate. For example, "[w]orkshops, garages, studios, sewing rooms and backyards have long been spaces for making" (Wong, 2016, p. 143). However, there is an emergence for the promotion of virtual makerspaces. This call addresses the issues of equity and access (Oliver et al., 2017) and the ubiquity of the virtual makerspace (Loertscher, 2015). For maker educators, a blend of online and face-to-face opportunities and resources are seen to afford different, yet complementary, experiences. There is a preference for face-to-face making, but scholars acknowledge time and cost may prevent this form of communication (Remold, Fusco, Vogt, & Leones, 2016). The case study described in this pilot involved making a physical product (a cardboard robot with movable head and arms and with blinking eyes), in different geographical locations, with the makers connected via technology to be part of a virtual makerspace.

Lu (2019) has suggested that "digital makerspace in virtual environments has not yet been fully addressed" (p. 335). This paper makes begins to explore the gap in the literature of virtual makerspaces. There are various books and how-to-guides describe making and makerspaces. Yet, there is a "dearth of empirical research on makerspaces" (Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe, & Owens, 2014, p. 529). Building on what is known with making in physical spaces, the authors sought to examine: 1) the nature of the experience of virtual makers; 2) the affordances of virtual making; and 3) inhibitors of virtual making. Together, some members of an IMEN engaged in the experience of making and critically reflected on the learning that emerged to explore the new concept of virtual synchronous making.

Professional Learning Community

A professional learning community is a group who regularly meet to share expertise and experiences for ongoing professional learning purposes. It has been defined by Stoll, Bolam, McMahon, Wallace, and Thomas (2006) as “a group of people sharing and critically interrogating their practice in an ongoing, reflective, collaborative, inclusive, learning oriented, growth-promoting way” (p. 299). The concept is commonly linked with teacher learning, improving student outcomes and school improvement (DuFour, 2007; Senge, 1991; Scott, Clarkson, & MdDonough, 2011; Stoll et al., 2006).

Professional learning communities have their roots in the literature related to communities of practice and situated learning (Owen, 2014). In these communities’ colleagues work together in an open environment where membership is inclusive, and interactions demonstrate mutual trust & respect (Watson, 2014).

The following the elements or characteristics are common to Professional Learning Communities (PLC):

- Solving authentic problems or joint purpose (Barab & Duffy, 2000; Wenger, 1998)
- Support and scaffolding (Barab & Duffy, 2000; Stephenson, Bower, Falloon, Forbes & Hatzigianni, 2019)
- Individual and group learning (Barab & Duffy, 2000; Owen, 2004; Watson, 2014)
- Community develops over time (Wenger, 1998; Stephenson et at., 2019)
- Communal resources/artefacts (Wenger, 1998)
- Distributed leadership (Wenger, 1998)
- Shared values and purpose (Bolam et al., 2005; Newmann et al.,1996; Watson, 2014).

Prevalent in the literature is the notion of makerspaces as communities of learners (Fourie & Meyer, 2015; Maker Education Initiative, 2015; Sheridan et al., 2014; Willett, 2016). Derived from the work of Lave and Wenger (1991), makerspace researchers contend that personally situated learning takes place in community where members create and use artifacts to mediate learning. Working in community is a critical component of making and makerspaces.

Professional learning communities informed the development of the International Educator Maker Network (IEMN) described below. It provided a new approach to making, sharing and information dissemination which crossed over international boundaries, professional boundaries and accessed multidisciplinary expertise not normally found in a PLC. It also forms a conceptual lens from which the data for this study will be viewed.

People, Means, and Activities Conceptual Framework

This paper draws on the theoretical construct from the people, means, and activities educational makerspace conceptual framework (Hira & Hynes, 2018) to unpack the establishment of an international PLC, a virtual makerspace, and to explore the experiences of virtual making. The International Maker Educational Network draws on the attributes of a PLC to learn with and from each. Figure 1 illustrates how the people, means, and making activities are interconnected. The purpose of the framework, according to Hira and Hynes (2017) is to "situate the educational considerations for Makerspaces" (p. 1). For example, is the purpose of the makerspace to support formal learning? Is it to provide an informal learning experience designed to address a need or create a solution to a problem? Depending on the purpose, it will influence the people, the means and the activities of the makerspace. Hira and Hynes (2017) argued the framework

> can be used as a tool by educators and facilitators to be more purposive about the Makerspaces they are initiating or working within ... For example, a Makerspace in a school should procure means informed by the educational activities they want to undertake, which might not always necessitate the purchase of expensive equipment. (p. 6)

In this case the People include the PLC participants; the Activities include the making and testing completed synchronously in the virtual makerspace, along with the ongoing discussions about making between the participants; and the Means includes the technology and the virtual space where the making occurred. The PLC and virtual making takes professional learning in a community to a new level as it widens the net for accessing expertise. In the case of this research study, the organizational structure and technology figured highly into the participatory advancements of the learners. In this context, the framework is used to explain who (people- IMEN participants), how (means - virtual making context) and what (activities – cardboard robot using LED lights powered by an Arduino) was involved in the creation of the virtual makerspace. This framework is then used to help articulate the findings in terms of what factors influenced and/or inhibited the virtual making experience.

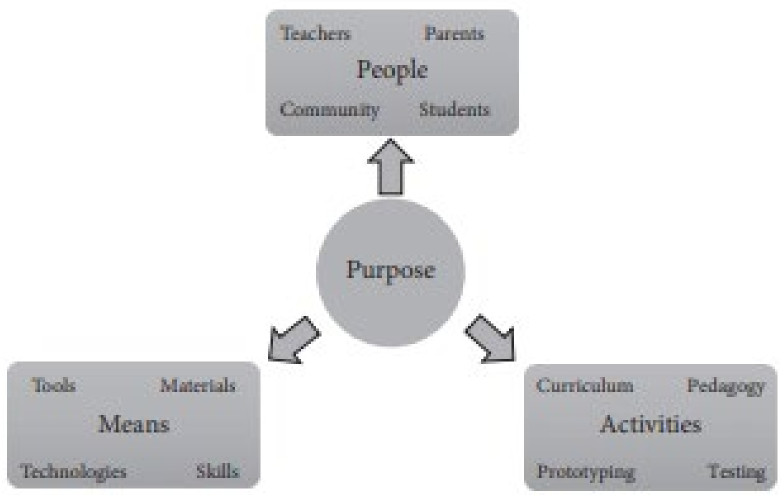

Figure 1: People, means, and activities framework for educational Makerspaces (Hira & Hynes, 2018)

Context of the Study

As educators and researchers look to keep ahead of current trends in education, they often seek ways of identifying, understanding, and sharing ideas within a PLC. Those involved in makerspace research and learning are no different. For example, the American Society for Engineering Education (2016) noted that there is a "need for more Maker network and networking experiences" (p. 15) in addition to developing a sense of community that promotes the sustainability of makerspaces. The IMEN is one such online PLC.

Drawing on Hira and Hynes (2018) conceptual framework, the first construct is that of People, who were the participants of the PLC. One outcome from a 2017 international maker symposium held in Canada, was the establishment of an International Maker Educational Network (IMEN). Interested people from a range of geographical locations, including Canada and Australia, come together as a professional learning community monthly in an online synchronous communication (e.g., web conferencing) environment. The members' making experiences came from a wide spectrum of backgrounds. There were educators initiating maker ideas in primary and secondary schools, school and tertiary librarians involved with makerspaces, and university lecturers and researchers who held expertise with online learning. The PLC provided opportunity for sharing, showcasing, and problem solving as part of the ongoing discussions about making and makerspaces. This community is characterized by active and "legitimate peripheral participation" (Lave & Wenger, 2012, p.29), where it is not expected that each member will be available for each meeting and that even when available some participants are welcome lurkers rather than leaders or active participants. IMEN includes 38 members and the number of participants each meeting ranges from 6 to 16. This professional learning community "provides ongoing opportunities to construct knowledge, to develop shared practice, and to solve real-world problems in authentic contexts (Fishman, Davis, & Chan, 2014, p. 712). The focus of discussions explored reimagining assessment in making, reframing teaching through making, exploring mobile making for rural and remote communities, and developing 21st century competencies through making alongside discipline specific curriculum outcomes. Given the virtual nature of the meetings, there were discussions related to the feasibility of running a makerspace online and considering the affordances needed to enable it, also practical discussions occurred about issues that were bubbling up in each members' context.

Second, the Means as outlined by Hira and Hynes (2018) involves the technology and the virtual space for making. As part of the initial discussion of an online makerspace, suggestions were made that if a virtual makerspace was to be created, then participants should actually 'make' something. The focus became centered on how to utilize online resources to communicate instructions, visualize the making, share ideas, and explore resources. As part of the exploration into the idea of virtual making, a video of some samples from a primary school makerspace led to examining the feasibility of making a robot online. Makerspaces offer the opportunity, as noted by Wong (2016), for people “to engage in hands-on creation in a collaborative environment” (p. 145). The goal was to construct a physical object - in this case it was a cardboard robot with movable head and arms and with blinking eyes. For the initial attempt, it was decided that all network participants would create a similar model, either individually or in small geographically located groups. Participants used similar tools, materials and adhesives, to allow consultation, scaffolded problem-solving, and the joy of shared making. This virtual making activity occurred once a month during the IMEN meeting over a 16 week period using Zoom, a synchronous videoconferencing technology.

Third, the Activities of Hira and Hynes (2018) framework includes the making and testing as part of the maker experience. This unique virtual making pilot activity engaged experienced teachers, teacher educators, librarians, and academics from a range of geographical locations from eastern and western Canada, and regional Australia. One member of the network who had expertise in facilitating robot construction volunteered to facilitate the virtual making. This individual prepared the plans and instructions and then distributed via email, so that all participants could print them at the different locations. A template was used for the design of the paper robot. Each month as part of the network meeting, a half-hour of was set aside to continue robot construction. For example, at one meeting, the cardboard robot was constructed by members in their various locations. Over the next meetings, LED lights were added and the connection with wires to an Arduino occurred. At another meeting work occurred individually with the programming of the Arduino for each person’s robot. Upon full construction and programming, LED lights blinked the eyes and paper arms and head moved. As this work progressed, web conferencing and cameras allowed people to show and share.

Many people who engaged in the project worked on their own. The synchronous meeting time was important for demonstrations, asking questions, and/or seeking help with a specific component of the construction. The use of the video camera to zoom in to see a problem and have the facilitator walk through the steps to address an issue were critical for the learning. As individuals worked through the steps, the just-in-time learning of using the Arduino and listening and learning from others as questions were asked, all impacted the learning experience.

The goal of the project was two-fold. First, to provide an opportunity for members of the network to engage in a maker activity that was not common to most. It provided a common lived experience for the participants. This project was considered a low-tech maker activity using paper, glue and straw and then connecting and programming the Ardunio to power the LED lights for eyes and move the arms and head. Four of the seven members had not created such a robot before and/or had no to limited experience using the Ardunio. Second, to explore the affordances of the virtual maker learning environment. The videoconference provided the virtual gathering of members to work together. The clarity of the audio and ability to zoom with the cameras played a critical role in terms of demonstrating and problem-solving. At one point, the facilitator changed locations to test the use of others cameras in an active learning classrooms. The challenge the choreographing the zooming in and out on the specific details while explaining and showing the key components. The key learning outcomes of the making project were the following: 1) To test the concept of virtual making; 2) To individually create a paper robot with moveable parts; 3) To program the Ardunio to move parts of the robot and light up the LED eyes; 4) To independently create the robot at the various sites with synchronous facilitation of learning; and 5) to continue the regular discussions about making in different contexts.

Method

This qualitative study occurred in a naturalistic paradigm (Lincoln & Guba, 1985; Stake, 1995). Behaviors of the participants were recorded, observed and individually reflected on as they happened without manipulation or control. A case study approach was taken to explore the participants' (authors') experiences as synchronous virtual makers. Yin (1984) defined case study research as an "empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (p. 23). Qualitative case study methodology can explore and quality and extent of an experience along with exploration of a program, event, group or individuals (Cox, 2008; Stake, 1978). The phenomenon studied was the experiences of participants, who are all the authors of this article, in virtual making. The study was bounded by the virtual making activity and discussions over four monthly one-hour meetings. Most members worked on their own, except for one location where the members worked on their own robot but in the same physical location. Given the authors volunteered to investigate their own experiences, no institutional ethical approval process was needed for the study.

Seven of 38 members of the International Maker Educator Network (IMEN) participated in the virtual making activity. This study used convenience sampling is a form of non-probability sampling where people were sampled because of their availability and convenience for the researcher, along with their willingness to participate in the study (Teddlie & Yu, 2007). Convenience sampling occurred where members of the network self-selected if they wanted to participate in both the virtual making and the individual reflecting writing and collective reflective discussions which occurred after the virtual making activity. The research participants included: One technology support librarian; two doctoral students who were former teachers; two teacher educator/researchers; one teaching and learning facilitator who completed doctoral work, and one sessional instructor. All members had between one to five years of experience of experience working, leading, and/or researching learning through making and makerspaces. Also, five (n=7) have extensive online teaching experience.

This case study research used a naturalistic inquiry approach (Lincoln & Guba, 1985) as it was situated in the real world environment exploring the natural phenomenon of virtual making with no manipulation or control mechanisms. Greene (1988) suggested that this type of research “cannot be carried out by people who see themselves as detached, neutral observers” (p. 175). As a result the participants held dual roles that of the researcher and the researched (Probst & Vicars, 2016). Advantages of participant research include prior knowledge of the context and familiarity; however, potential disadvantages include pre-conceptions, close mindedness, and exaggerated assumptions (Wellington, 2000).

The trustworthiness and validity of the study may have been impacted by the participant researcher status, however, the analysis and the interpretations of the individual reflections and the reflective discussions were checked by the participants as part of "member checking" (Stake, 1995, p. 155). Only "fuzzy generalisations" can be made from the study recognizing that in a unique phenomenon such as the virtual making completed by the participants of the international virtual maker network statement will be made with "built-in uncertainty" (Bassey, 1999, p. 52), acknowledging that the outcomes might apply more widely but there may also be exceptions. Because the participants were also the researchers, any disputes over coding and interpretation were discussed until an agreement was reached. Given this is a case study, our goal was not to generalize. Rather, with the use thick description it provided opportunity for transferability (Merriam & Tisdell, 2016).

The activity for the virtual making involved the creation of a paper robot with moveable parts powered by an Arduino. The activity was selected given the expertise of one of the members. This individual had experience facilitating this type of making in a physical environment. Given the group's interest in virtual making, this individual was willing to lead the virtual making of the paper robot.

The following research questions guided the study:

- What are the experiences of virtual makers?
- What are the influences of virtual making?
- What are the inhibitors of virtual making?

This qualitative research involved examining data from synchronous web conferencing recordings of the virtual making experience, personal written reflections from a subset of virtual makers (n=7), and discussions on the participants' reflections. Using apriory coding, based on the people, means and activities framework and also open coding (Fielding, 2001), data were organized, sorted and analyzed manually to create categories or common themes or patterns in the data. Repeated, similar and difference concepts were explored in order to answer the research questions (Ryan & Bernard, 2003). The data was viewed through the lens of a professional learning community and is presented using the people, means and activities framework.

Discussion of the Findings

The study sought to understand the experiences of a subset of participants within a virtual synchronous makerspace who were engaged in creating a paper robot with moving parts using an Arduino. Such a project turned traditional making 'inside out' in that it did not start with the physical space (i.e., tools and materials which bring people together). Rather, it started with a community of people who regularly met and who wanted to have the experience of making together. This group of people was separated by geographic distance, yet through technology were able to work together in creating their own paper robot. Through an alternate form of delivery, this community of makers changed the concept of is typically thought of as a makerspace to that of a virtual making environment. The research focused on the nature of the experience of virtual making with a project that was organic in nature and accessible for all involved. From the analysis of the data, findings are organized according to each research questions: 1) People: Nature of the experience of virtual makers; 2) Means: Affordances of virtual making; and 3) Activities: Influenced and inhibited of virtual making.

People: Nature of the experience of virtual makers. In this case study research, the People in the makerspace framework, were the participants of the IMEN who self-selected to participate in the virtual making and the reflective data collection activities. From the reflective data, participants expressed satisfaction with the experience of being virtual making. They appreciated the planning and the nature of the facilitation of the learning. The network established a PLC model where people worked on a common goal and shared their experiences, knowledge, and skills, however, peripheral participation for those without the previous experience was also welcomed (Lave & Wenger, 1991). They experienced the joy of creating and sharing and presenting their work with colleagues. One participant attested "while making and tinkering with the robot pieces, I felt a sense of peace, happiness, enjoyment, pleasure." Yet, they also experienced frustration, as confessed by a participant; "I got behind, and did not catch up, which led to feelings of frustration. I wonder if being "alone" at my house contributed to these feelings of frustration?" These questions reinforce the comments from the American Society for Engineering Education (2016) who maintained there "is the need to foster a strong sense of community among Makers" (p. 17). The notion of "[c]ommunity is an important aspect of participating in the maker movement-and the norms of that community are indeed important" (Clapp et al., 2017, p.6). Accordingly, this could be supported by a maker virtual PLC such as the IEMN where this research occurred.

This pilot project involved following one instructional plan wherein all created the same project. Challenges arose given the limited to advance spectrum of skill levels, and experiences participants had with the materials and resources being used, and limited local experts to support the work. Affirming this challenge, Waldrip, Brahms, Reich, and Carrigan (n.d.) identified that tools and materials should align with the knowledge and skill of the facilitator. Although this was the case in this project, the participants' capacity had more impact on the speed and quality of the making, particularly given the making was at a distance through virtual support.

All participants involved in the project embraced a maker mindset. They were open to playing, collaboration, problem-solving, innovation, reflection and learning from failure (Dougherty, 2013; Pierrat, 2016). As they worked through the various steps, they asked questions and shared insights of the work and applications of it in other contexts. Conversations about having a disposition toward making resulted in participants reflecting on how to prepare mindsets for diverse interactive making experiences versus recipe following. Additionally, reflections explored requirements to scaffold and facilitate learning to nurture depth and breadth of knowledge, ways to develop the ability to intentionally select and use appropriate tools, and ideas to develop processes that foster experiential forms of learning. As one of the participants acknowledged,

> Typically, when I do these making sessions, prior to the meeting, I have reviewed the notes, looked at the upcoming plan, set out the materials, and tinkered around with bits and pieces before chiming in with the big group ... coming in late today threw me off - I did not feel like I was in the right headspace to make. I ended up abandoning the making and just listening to the conversation. However, I wonder what this might mean regarding making. Was this just a one-off due to a very busy day? Alternatively, is there

> something about being in the right frame of mind or in the right space? Is there something about a makerspace environment that promotes making?

A critical factor that emerged from this experience was the need for a mentor and/or facilitator who embraces a disposition toward making. One participant commented, "it is not about the space - it is the mindset that counts." In such roles, facilitators need to have the needed disciplinary knowledge to help people understand the why and how, yet also know how to effectively troubleshoot problems. In this study, the facilitator curtailed many possible distance problems specific to the making through advance planning. One instance of advance planning led by the facilitator involved incorporating tools that would be commonly available in international settings (e.g., hot glue guns) and isolating what tools may be available, but not useable (e.g., soldering irons).

Within this making context, peer support also played an important role in fostering learning with and from others. "This learning opportunity reminded me of the advantage of working with a colleague. To have someone else check the plug-in and to ask questions". Relationships are an important element in making; it becomes a social experience where makers share their work and their expertise (Dougherty, 2013). In summary, the participants in the professional learning community for virtual making exhibited strong collaboration, joint hands-on activities, supportive structures, and distributed leadership.

What was evident from the study, was how virtual making is different from face-to-face making. The lived experience of the participants provided them an opportunity to reflect on how to design such learning with the synchronous communication technology but also how to facilitate the learning experience at a distance. Adding to the complexity, is the facilitating the learning at a distance where the educator does not have the ability to stand beside the learner or to do a quick demo. Rather, it requires developing confidence and competence in using the technology in purposeful and meaningful ways to support robust learning. This case study provides a practical example of how virtual learning through making can be done, and how to give educators the lived experience so to inform their practice as they work with their students.

Means: Affordances of virtual making. When working in a virtual making environment, technology is the key Means to keep connected and it can occur synchronously or asynchronously. Synchronously, participants are creating in their own location but are together online. Demonstrations and troubleshooting can be responsive in real time. By allocating the thirty minutes per meeting, there was time for project making, as well as real-time communication for problem-solving. Further, instruction and facilitation help were available outside the synchronous session, "with another workshop that was conducted 'off-line.'" In the synchronous sessions, it was a hands-on experience wherein the facilitator modeled techniques. Also, each maker was able to build a low-cost robot, and take away something concrete that they can then modify or adjust at a later date. Horvath and Cameron (2015) acknowledged that learners benefit from creating something tangible while learning and making. This aligns with concepts of co-creating knowledge and the personal creation of knowledge and products.

With asynchronous environments, people can be online at a time when it works best for them. Participants worked on their robot beyond the common synchronous time to either troubleshoot or just learn how things work: "I am going to spend more time with the robot on my own as I need to figure out the code and how to get the robot to connect to the breadboard." When considering the asynchronous environment, videos, and how-to-guides can be made available to help guide the learning. It might be beneficial to use a blend of synchronous and asynchronous to support all participants as they advance through the project. One participant remarked that it was important to think "about the wrap around time for each session which needs to be built into this virtual synchronous work." Karakostas, Palaigeorgio, and Kompatsiaris (2017) have suggested that Mixed Reality Makerspaces can merge digital screens or wall projections and physical making to provide learners with an immersive interface. In the virtual makerspace, the technology needs to accommodate the need for a one-to-large group, one-to-small group, and one-to-one interactions. These interactions may need to occur simultaneously; the technological capacity needs to support the pedagogical needs of the group.

When working with the Arduino board, the facilitator provided detailed instruction and demonstrated pins and wire connections. These steps could be repeated for people who needed further detail or wanted to have certain items better explained.

This was beneficial, yet challenging, given difficult camera angles and problematic camera zooming in on the work. Issues such as not having good visual displays, "seeing others making their robot on the big screen were helpful", or differences in Arduino boards, impacted the experience. These critical learning moments elicited discussions regarding how to address such items in future work. As a group, there was discussion regarding developing better instructional technique in combination with the use of various cameras at the facilitator station with one participant reflecting "one of the affordances for me is the camera and audio."

Staying true to the nature of making was evident in the work with the distributed expertise (Sheridan et al., 2014) in the group. As the project advanced to use LED lights and an Arduino, people with expertise were able to problem solve or share examples of what they have done for others to gain from such experiences. Members of the group could ask questions or explore solutions with others who had such experience in support of the project. At those times, people who were more advanced with the technology use may have been waiting for the novice users to catch up. One of the participants observed that "our fearless leader is on camera, trying to troubleshoot many of the questions coming from the less experienced makers like us." In facilitating learning in the virtual context, the facilitator needs to be able to support the breadth of experience and expertise to keep everyone moving forward in his or her knowledge and skill building at their own pace.

Initially, making information was shared in terms of resources and materials. A semi-detailed, recipe process was to be followed to complete the task. After the first synchronous session, careful attention was given to redesigning the resource materials to better scaffold the work as a means of supporting the nature of making and staying true to the nature of making about distributed expertise. An outcome from the experience was the acknowledgment of the various complexities related to skill building. That is, differences regarding a structured process that had identified steps, in contrast to supporting a prototyping process where different projects are developing. Specifically, one participant commented that "the visuals and explanations are important."

It was evident that this virtual making experience was collaborative, even though many people worked in individual locations. Irrespective of location, it was it was "a collaborative, messy workspace." There was a commitment to the group's learning goals, as well as group accountability (Pierrat, 2016). An open and trusting community (Lave & Wenger, 1991) was established wherein individuals felt comfortable to ask questions and to explore why something was to be done in a particular way. At the same time, members of the group shared expertise and skills that supported the learning of others. As one participant mentioned, "there was discussion and support occurring which helped to create the robot. It was the side conversations that not only helped in creating but also the aha moments*"*. Having said that, another participant reflected that taking risks and sharing their frustrations "could be a major challenge if the group dynamic was not one of trust*."* The participant went on to question if the group did not have high levels of community and creating a sense of belonging "would I speak up in the session? Would it be an email after to … ask for help? Alternatively, would I just leave it?" Together, these ideas support the understanding that virtual synchronous making does align to the focused goals of making is an "effective method of (1) fostering experiential learning and (2) engaging and connecting people to be creative, to communicate with and learn from one another and to work collaboratively" (Galway & Gill, 2018, p. 27).

Activities: Influenced and inhibited virtual making. For this case study, the activities included the virtual making and also the ongoing discussions around the role, scale, and sustainability of virtual and face-to-face making in different contexts. What was evident from the data in terms of factors that influenced the success of the virtual making experience was the willingness of the participants. Each in their location organized the technology and materials required for the virtual making sessions. They worked independently between sessions in order to be prepared the synchronous session. During the synchronous sessions, people felt comfortable and confident to ask questions and to seek feedback on the making activity. Given the simplicity of the cameras being used, it might have required manually manipulating the camera to provide a good angle or close up of the item being made so that the facilitator could see so to provide direction and technical support.

From the analysis of the data, some limitations, or inhibitors, were evident for virtual making. These limitations are pragmatic rather than theoretical, and all relate to the development of the learning environment for virtual making. Using synchronous communication technology across international time zones impacts who and when people can participate. For some, it was the end of a workday, and for others, it was the start of the day. Being conscious of time zones, and annual time changes are critical when working in a synchronous context. Find a time that works relatively well with everyone who wants to participate. Other elements of time also included "time to shop for the supplies, time organize the materials and time to have software loaded."

A lack of common terminology impacted the purchase of materials, as well as instruction. When creating the resource list, the facilitator ensured materials were common in all geographic locations. The facilitator became very aware that different terms were used in the various locations. One example was the description of paper-weight. In Australia, paper weight is referred to as grams per square meter (i.e., gsm). Whereas in Canada and the US pounds (i.e., lb) is a common weight. Notably, the US also uses paper weight to refer to the thickness (i.e., points). Accordingly, a 200gsm photocopy card would equal 135lb card stock, or 9-point thickness.

A common kit of materials was not distributed to the makers. Each participant was given the list of materials required for the project. "Having the same items as the plan, especially for beginners, means there is less room for error, and it is easier for the remote facilitator to troubleshoot within the limited capabilities of video conferencing." By giving the responsibility to the individual, some participants did not get an Arduino and were not able to complete the final stages of the project. A similar challenge was that not all Arduino boards are the same. The facilitator had to be able to work with the variations when providing support.

The facilitator had previous face-to-face experience guiding people in creating robots. When working at a distance, there were challenges regarding showing and demonstrating the robot. For example, the facilitator would hold up the specific item to the camera. However, the item might not have to be centered, or it was out of focus. Both of which impacted the distant maker. Notably, various cameras were tested during the project. A teaching station with multiple cameras to permit different sight lines would have enhanced the demonstration and trouble-shooting components of the work. A GoPro camera on the facilitators head may also have provided an effective bird's eye view. As a participant remarked, it would be "helpful to have the camera focused on the build."

Alternatively, another participant mentioned that using the camera "was helpful for others to see what we were doing and to see others as it helped me feel more like it was building community".

From novice to expert makers, there was a large spectrum of prior knowledge and skills that impact the instruction and pace of the activity. People who had prior experience with an Arduino knew where to connect wires for making LED lights work properly. People who did not have experience with the Arduino board had difficulty due to operational unfamiliarity. This was exacerbated for participants with little or general knowledge about electronics. As reported by one of the participants, my "lack of discipline knowledge didn't make the making impossible, but I think my lack of knowledge of the equipment, robotics, understanding how the components work etc. did make it more difficult and slower". Another participant observed that "with the build, it would be good to repeat and do it again." Highlighting the value of key discipline knowledge. This maps to the work of Clapp et al. (2017) who identified two maker-centered outcomes that "include cultivating *discipline-specific knowledge and skills* and *cultivating maker-specific knowledge and skills*" (p. 35). Within this project, it became evident the need for discipline knowledge, but also specific knowledge and skills associated with making.

Implications of Virtual Making

It was a small number of people who engaged in this initial virtual making activity. It was a trial to see if virtual making or making at a distance is possible before considering scaling up and exploring sustainability. Four implications for practice have been identified from the practical challenges that emerged from the data: 1) Scaling up; 2) Designing and facilitating authentic learning; 3) Access and use of technology, and 4) Sustainability. Each implication is discussed in detail regarding supporting the work of virtual making in formal educational environments.

First, is the challenge of how to scale up such a project? When exploring how to scale up, careful consideration should be given to making in the formal learning context, as well as shifting virtual learning through making into the formal education setting. The project involved a group of educators who enjoy learning through making. To be able to scale up and engage more educators, practical linkage to curricular topics may be required. The ability to show how such an experiential opportunity maps to specific learning outcomes may help educators to better understand how learning with making aligns with disciplinary topics. As part of this scaling up work, linking the learning to a specific discipline and curricular outcomes will need to occur. Given the complex nature of making, the focus should be on authentic and interdisciplinary projects wherein educators have the breadth of curriculum understanding to ensure learning outcomes are being met through the project.

Scaling up of projects may have two audiences, that of teachers and students. Makerspace facilitators or teachers required cost-effective and engaging professional development, especially for those in more remote locations, with easy access to resourcing and expertise that they are then able to share with their learners. This project providde a lived experience for such educators to develop confidence and competence with making that involved a low-cost project. It provided an example or a model for educators to use with their students.

Second, making is authentic, meaning it is relevant, connected to the real world or realistic (Koole, Dionne, McCoy, & Epp, 2017). It is the creation of something with no single correct outcome expected and it is often completed collaboratively. Within the project, a template was used to guide the activity yet variations were possible. The ability to learn how to use the Arduino gave participants new knowledge and skills that they could apply in different contexts and/or in solving other problems.

Making often provides a solution for a particular real-world problem or need through creation or prototyping. For example, a person may find they need to create a border around a flowerbed given soil erosion. A solution may be sought which may take some refinement before the problem is resolved. Furthermore, making can preempt a particular problem with an experienced maker creating something that has benefit for others. From this, educators should consider if students will explore a previously designed prototype, or adopt an independent prototype creation. Within the formal educational context, educators will need to carefully consider how to design authentic learning that maps to the curriculum. Consideration also must be given to whether knowledge and skill development occurs initially through the use of prefabricated kits or *proforma* activities (consumption) before the learners creating their own prototype or solution (creation). Alternatively, would just-in-time facilitation of new learning be more effectively aligned with the making? Moreover, whether they have access to alternative solutions to using tools or materials that are not available to them such as solving the problem of connecting LEDs to the robot without soldering. Also within these types of tasks, questions regarding how students will develop their capacity regarding 21st-century competencies or transferable skills (i.e., problem-solving, innovative thinking, collaboration, and design thinking). The American Society for Engineering Education (2016) suggested "[i]ntegrate Making principles, and practices can empower students by rendering them 'creators' rather than just consumers" (p. 28). That is, being able to design and facilitate authentic learning tasks may require further educational development for educators to develop their confidence and competence in facilitating learning through a making approach.

A third implication involves the nature and selection of the technology to support virtual making. As evidenced in this project, the needed bandwidth, hardware (including cameras), and access to web conferencing tools are imperative to virtual making. Effective positioning of the camera allowed the participants to not only hear the directions or responses but also see what was being explained. For example, a synchronous communication tool requires the capacity to use video, to allow individual and group work, as well as be mobile device friendly since virtual makers maybe engaging using their smartphone or from a laptop. The end device should not restrict who can or cannot participate. Further, with the asynchronous environment, it needs to provide access to a wealth of tools. Repositories for examples of work, how-to-guides that can be in various forms (text, video or audio) are helpful resources. However makers often require additional support through questioning and conversation that these how-to-guides don't provide. At the same time, the technology needs to support collaborative learning or an augmented reality experience. Access to technology at the far- (sites at a distance) and near- (local site) ends should not be the determining factor for virtual making. Rather, purposeful selection of the technology that supports the nature of the learning through making is needed. As such, access to, and use of, technology is a major factor regarding sustainability. Notably, Knibbe, Grossman, and Fitzmaurice (2015) have created a Smart Makerspace, which is a digital workbench, augmented toolbox, and power tools to provide immersive and integrated experiences for novice makers.

Fourth, sustainability is a major factor in virtual making. Resourcing the initiative to ensure equipment, technology, and materials are available at each of the locations is critical in both physical and virtual makerspaces. In the project, each site was well equipped with technology and/or the educators were able to access what was needed as the project evolved. However, when moving forward with virtual making, it will be essential to have such discussions in advance so the necessary materials and resources are secured for the virtual making to be a successful experience. Identification of the responsible funding organizations and individuals are necessary. Questions surrounding this include: Who is responsible for funding and where can it be funded? Also, is this a governmental institution responsible for education (e.g., Ministry of Education) or a regional responsibility? Further, will the resource and equipment be purchased locally or distributed as a kit? Approaches that do not provide each site with their own equipment and resources can be problematic given probable lack of uniformity. Substitutions of resources or materials will result in the facilitator and others not being able to effectively problem-solve. In contrast, kits of materials and resources can be assembled and sent to the participating locations. This would ensure all members participating in the activity have the same resources and equipment. Funding and timely distribution become the main challenges of this model. An issue with providing the kits is that it may introduce an overly-prescriptive approach that restrictive creativity and the potential for making.

Another layer related to sustainability is the aspect of educational development for educators facilitating maker learning in these virtual environments. They need to have not only the disciplinary knowledge but also knowledge and skills to support facilitated, scaffolded experiential learning at a distance. Limited by not having the option to pick up the concrete material yet required to troubleshoot at a distance, may be frustrating. This approach requires strong communication skills, as well as the ability to provide various means of support for learning. Supporting facilitators involves developing their capacity to design and facilitating learning through making in virtual environments. The American Society for Engineering Education (2016) have suggested that some of the sustainability factors as discussed above can be achieved through the development of Maker networks, such as the IMEN, by providing professional development opportunities, and by collaboration with other stakeholders.

Limitations and Future Research

The researchers of this study were also a subset of the participants in the virtual making experience. This insider positioning means they provided the data and analyzed the data. That is, they held dual roles of the researched and the researcher. As participant researchers, the authors were at the center of the data. This closeness can provide higher levels of understanding. Yet, it may raise concerns about the researchers' ability to interpret data in an unbiased manner and in turn impact the validity of the research outcomes. Being involved in the project and analyzing our own data has the potential for skewing of the findings. With an expanded research team, the opportunity for confirmatory bias is reduced as it is unlikely that all research participants will have had the same experience of learning, or reflection from that experience. To reduce the risk of confirmatory bias multiple participants' views and multiple data sources were used.

This study was a pilot program with a group of participants who are advocates for making and tended to have experience and expertise working in virtual learning environments. In addition to implementing the study with a large population, future research could expand the pilot to look at virtual making in support of regional, rural and remote locations. The affordance of technology provides the virtual space for making, yet also allows experts to join the work that may not be available in the local geographic area. When exploring the expansion of virtual making in such geographic locations, it also provides the opportunity to trial virtual and augmented reality and virtual labs. Bandwidth, technical infrastructures, and resources will be critical factors for future studies.

As observed in the pilot study, the facilitator plays a pivotal role in support of knowledge and skill development. Further investigation needs to occur regarding how to prepare facilitators for leading this type of learning and teaching in face-to-face makerspaces. Adding further complexity is providing the necessary and needed support and training to prepare facilitators to support learning in virtual making contexts.

Conclusion

As makerspaces gain in popularity within higher education, school education, library, and community spaces, it is important to share stories of success and failures and to identify implications of making is specific contexts. Making for learning or pleasure, like other creative endeavors, is open-ended, active, messy and non-linear. Given the limited formal research available about virtual making, this research contributes to the field by sharing the stories of the participants, providing examples of affordances and limitation within a virtual making context, along with unveiling implications for virtual makerspaces.

This article represents both individual and collective learning within a virtual maker learning community. Despite the limitations described above, the technology provided the ability for people in various locations to work together in creating their own robots. Given the trust, openness, and support of the professional learning community, members learned with and from each other even though they were located in both north and south hemispheres. Virtual making illustrates the potential of how makers from various locations can bridge the distance via technology to achieve common goals.

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