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Works of heart: Revisiting creativity and innovation through maker pedagogies

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Abstract
This qualitative research case study advances both theory and practice related to the use of maker pedagogies by examining the creative trajectory of one Master's level graduate student in an online critical making course at a Canadian Faculty of Education. It discusses the contemporary maker movement and traces the student's transformation from consumer of digital products to producer of innovative digital artefacts, which we refer to as 'works of heart'. The article shares the framework 'Movement to Maker', developed by the authors, which offers a way to track the development of student creativity in addition to other transferable skills and global competencies.

Keywords
creativity; innovation; maker pedagogies; global competencies; transferable skills; makerspaces

Introduction

This study advances theory and practice related to the use of maker pedagogies to develop key global competencies, with a focus on creativity and innovation. Makerspaces are creative spaces where people gather to tinker, create, invent, and learn. The growing number of makerspaces and repair cafes reflects a human need for creative expression and self-directed learning. As they gain popularity, makerspaces, rooted in design thinking, creativity and innovation, are beginning to move into the realm of formal education. As a result, there is an increasing need for professional development for teachers, to provide educators with opportunities to develop their own competencies in maker pedagogies. The rise of STEAM education, where the Arts are embedded into Science, Technology, Engineering and Mathematics, suggests that educators recognise the importance of integrating art and design thinking into STEM learning to 'build interpretive and creative skills' (Adams Becker *et al.*, 2017, p.11). Maker pedagogies (the teaching and learning practices used in a makerspace – be it a physical space, online space or mindset) promote important principles including inquiry, play, imagination, innovation, creative and critical thinking, problem solving, collaboration, and personalised learning. There is a gap in the literature related to making in higher education, particularly at the graduate level and in subjects outside the field of engineering.

As educators grapple to identify the skills and competencies that students will need to succeed in a digital world, creativity and creative thinking have been identified as crucial to learning (Fullan, Langworthy and Barber, 2014; OME, 2016). In a review of prominent national and international global competency frameworks, it was found that 'measurable benefits in multiple areas of life [regardless of trade or occupation] are associated with critical thinking, communication, collaboration, and creativity and innovation' (OME, 2016, p.12). While traditional conceptions of creativity have been associated with the fine and performing arts and with the humanities, it is also valued in the fields of design, architecture, engineering and mathematics (Upitis, 2014). Contrary to a popular societal belief that one is either creative or not, creativity can be developed from an early age (Craft, 2002; Upitis, 2014). Upitis argues that creativity is 'an approach that is brought to an activity – a mindful, open, flexible, critical, and experimental way of being…[and] it is a driver for innovation of all kinds' (Upitis, 2014, pp.3-4). Innovation in society is necessary to solve the social, economic and environmental problems in our communities (Upitis, 2014).

In the Ontario Ministry of Education's 2016 discussion paper *21st Century Competencies*, innovation and creativity are identified in a list of key global competencies (OME, 2016). One approach to developing global competencies more generally and creativity and innovation more specifically, is the integration of digital experiential learning through maker pedagogies. The maker culture of these innovative learning approaches promotes play, inquiry and, importantly, learning through mistakes. In this case study, we immersed a class of Master's level education students enrolled in a Critical Making course at the University of Ontario Institute of Technology in the practice of creative making with both digital and real-world artefacts. The artefacts acted as a vehicle for collaborative knowledge sharing and generation, deep learning and meaningful engagement in the students' creative processes. We challenged them to reach outside their comfort zones, to take risks, and to experiment with new tools, technologies and pedagogical approaches to learning. For the purposes of this paper, we focus on one in-depth case that illuminates how these graduate student participants created what we call 'works of heart' that are intensely personal, creative and transformational in terms of the students' teaching and learning, and personal growth as makers. The case study describes the 'Movement to Maker' framework, developed by the authors, which offers a way to track the development of student creativity in addition to other global competencies.

Theoretical considerations

Situated within a constructionist approach to education (Papert and Harel, 1991), digital making connects the physical processes of constructing something with digital media. Making with digital media is not new in education: teachers have been working with their students to create digital stories and other digital texts for many years. The recent advent of user-friendly digital tools augments the fabrication process, making it easier for students to create multimodal, multimedia and digital artefacts.

Digital tools can facilitate everyday creativity and making. With the internet particularly, there exists the power of making and being seen – connecting with others in geographically separate locations. As Gauntlett explains, 'the internet enables us to design and make lovely ways to show off our creative abilities, exchange ideas, and build networks of like-minded people who can support and inspire each other' (2016, p.3). Importantly, in terms of education, making enables students to inhabit the position of producers rather than simply that of the consumer. It re-introduces creativity into curricula that have been increasingly devoid of such endeavours, particularly as policy makers and politicians call for standardized assessments and accountability. The 2017 Horizon report, which is published by the New Media Consortium and predicts the impact of emerging educational technologies and trends, identifies makerspaces as a key development in technology in primary and secondary education contexts over the next few years. The report argues that the:

> advent of makerspaces, [and other] classroom configurations that enable active learning, and the inclusion of coding and robotics are providing students with ample opportunities to create and experiment in ways that spur complex thinking. Students are already designing their own solutions to real-world challenges (Adams Becker *et al.*, 2017, p.4).

Makerspaces tend to include digital tools such as micro-computers, soft circuits, wearable tech, 3D printers, programmable robots, virtual reality and more. Depending on the context of the makerspace, there may be a focus on unplugged or low-tech tools, especially in schools where access to the more expensive tools are cost prohibitive. These technologies position the users as creators and require participants to draw on a variety of skills including interpersonal skills, coding skills, troubleshooting skills and more (Somanath *et al.*, 2017).

The design process is embedded in making, especially in educational contexts. While there are a variety of different design models that have been adapted for use in primary and secondary education – including the Engineering is Elementary model (EiE, 2018), the Human Centered Design Model (IDEO, 2015) and the Works Engineering Design Process (Works Museum, 2016) – these frameworks facilitate a human-centred approach to problem solving.

In the Critical Making course students were encouraged to explore different models of the design thinking process, but typically followed the process espoused by most engineers: empathise, define, ideate, prototype and test. Connected to each of the modules for the course, were design challenges focusing on different kinds of technologies, for example 3D printing, e-textiles, coding and robotics amongst others. Students were challenged to develop a personally meaningful problem to solve and to design an artefact to address that problem (and to revise and refine it iteratively). The students shared their designs and prototypes with peers online.

Methodology and methods

A design-based research (DBR) approach was most suitable in the context of the Critical Making course. Our primary goals aligned with those of DBR, to produce 'new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings' (Barab and Squire, 2004, p.2). Most of the graduate student participants were educators at various stages of their careers and an important learning objective included directly impacting their professional practice. Participants engaged with five different online modules related to digital making. As a result, they had multiple opportunities to explore, critically analyse, remix, design, innovate and reflect on their making using a variety of different tools, technologies and materials. These experiences were shared on an on-going basis with their peers and the course instructor. Many of the students also created blogs, websites or tweeted about their creative processes and artefacts online.

Using case study methodology, 'to develop a complete, detailed portrayal of some phenomenon' (Schwandt and Gates, 2018, p.346) matched our purpose – to develop an understanding of, and communicate how, participants engaged with and in an online maker community during their progression from consumer to maker. For the scope of this paper we focus on one participant on the Critical Making course.

Participants

The overarching study involved 24 graduate education students in an online Critical Making course that was part of a Master's in the Digital Technologies programme at a Faculty of Education in Canada with a focus on STEAM education, where the Arts are a valued part of the making and learning process. The students were diverse in age, education background, technological experience, gender and geographic location. For the purposes of this paper, we selected one student from the course who was exceptional in the work he produced (the quality and the quantity) and in the ways he engaged with the communities of learning and practice, both online and in-person (making with and for his unique, embodied communities, both family and local). To ensure high ethical standards in the research, we included member checks to verify participants were satisfied that we had represented them accurately.

Setting

Students and the instructor met every other week for 3 hours in real time on Adobe Connect (an online discussion platform) to discuss issues and share making experiences. On the alternate weeks, students engaged in hands-on making activities in their own time and used Ning (a social media platform open to participants only), along with Twitter and blogs to share resources and ideas about making. Making activities were guided by the STEAM 3D website's Maker Modules (STEAM3D, 2018). The modules were organised based on different topics and types of technologies typically found in makerspaces (for example: electronics, wearable technologies, 3-D printing, programmable robots etc.). Each of the modules was broken into three sections: 1) Research (scholarly articles with guiding questions); 2) Media (equipment overviews, tutorials for different skill levels); and 3) Field activities (a series of suggestions about how to apply the skills developed through the tutorials). In each module, students had the option of 'hacking their field activities' to create something not explicitly suggested. The suggestions were there for students who encountered difficulty with idea-generation. Students documented their making experiences through video and still images, and posted them at the end of each asynchronous week so that their peers would have time to view and comment before the next synchronous class online.

Data collection

At the start of the course students completed an online survey about their attitudes and experiences related to making, documenting their expertise with digital tools and media. The surveys were used to develop a baseline of participants' starting points, to identify shifts in thinking and growth in competencies with attention to creativity and innovation. Data sources also included online chat conversations; process-work journal entries, final product reflections and photos, posted to their portfolio websites and/or the discussion-thread posts, which were based on the weekly readings and each module's field activities. Finally, we conducted exit interviews with those students who consented so we could better understand their work, processes and experiences.

We chose Nathan (a pseudonym) as our case study because he was active in the online community posting thought-provoking comments in his responses to peers and rich, theoretically-based reflections in his portfolio blog posts. Nathan was aged in his mid-30s and worked at the Ministry of Education in a remote northern community in Canada. The quality of Nathan's work was exceptional and exemplary of deep learning. Nathan also continued to engage in further critical and digital making at the course's completion as he was hired as Manager of Distance Learning at a college.

Data analysis

Analysis of the data took place after the course was completed. Using the Movement to Maker Framework developed by the authors, we analysed the data with thematic codes and drew on content and visual analysis (Margolis and Zunjarwad, 2018). We also triangulated the data to gain a more in-depth understanding of what we were seeing and to add a layer of reliability to our interpretations.

The 'Movement to Maker Framework' was developed by the authors and was shaped by our observations of learners in our maker-focused research. Components of the framework were also verified against and adapted from a variety of scholarly and practitioner-based sources. Our original framework was a combination of those by Spencer (2015) and Kafai *et al.* (2011), consisting of five phases through which a learner moves when transitioning from consumer of digital tools/content to maker and innovator using these same or similar tools. Spencer's (2015) framework includes seven stages through which a learner progresses: exposure; active consuming; critically consuming; curating; copying; mash-ups; and creating. We also looked to Kafai *et al.* (2011) who identify 'three sets of practices: observing and deconstructing media; evaluating and reflecting; and referencing, reworking and remixing' (2015, p.105). Drawing on these two frameworks, we created our own unique 'Movement to Maker Framework', depicted in Table 1 below.

Awareness	Analysing	Remixing	Reflection	Innovation
Awareness to new ideas, materials and genres.	Analysing what is already out there for quality and quantity.	Taking elements from other work and remixing it to learn creative / aesthetic / digital techniques in more depth.	Evaluating what works, what does not, challenges and successes.	Taking knowledge of what exists in the genre, individual and peer feedback and creative ideas to make something new that is meaningful and helps solve a problem.

Table 1: Movement to Maker Framework

When initially conceived, we assumed there would be progression from awareness to innovation; however, as our team reflected on this framework, we realised that it was not quite an accurate representation of the process of development towards becoming a maker. First, the state of 'Reflection' tended to happen throughout the development process and needed to be reconsidered not as a final phase, but rather as an element interwoven throughout all other states of maker development. Then we concluded that an individual does not move in a linear pattern toward maker / innovator in all instances. At times an individual will begin at the remixing stage and move forward or backward depending on the learner's preferences and/or other variables in their learning environment. As a result, we then revised this initial framework to include the affective states and dispositions a learner exhibits depending on which state of making they happen to be inhabiting during the learning process. We adapted these states from Barron and Martin (2016) to connect affective states / dispositions and states of making. This provided us with a better understanding of how the students were learning and developing and which transferable skills and competencies the learners were acquiring in the process.

Findings / discussion

Nathan explains that, at 'the beginning of the course I had almost no knowledge of making (in the context of critical making in an educational framework)' (student feedback 'Nathan', 10/02/2017). He comments that he 'saw the course offering, found it very interesting and saw it as an opportunity to stretch my boundaries as the final course in my M.Ed program.' The course content enabled Nathan to start building his awareness of making and the associated tools/pedagogies.

In one of Nathan's first blog posts, he discusses his emerging awareness of the ideologies driving the maker movement.

> After our first class and going through the Wark (2013) reading, the Mann (2011) video and Logan Laplante's (2013) talk, one theme kind of stood out and resonated with me. I find that they were all, in some way, touching on the ideas of freedom and openness. (Student blogpost 'Nathan', 2017).

Nathan then explains how, across all the resources, freedom played a large part in the maker culture – freedom to understand how things are made; freedom to combine work and play and the freedom to carve one's own path – in education or life in general. As these are all key components in maker culture, Nathan's emerging understanding from the various resources provided to him at the beginning of the course is made evident through these comments.

After being introduced to a variety of maker-related resources, Nathan entered the stage of analysis where he synthesized the content and analysed it for value and purpose, attempting to make meaning of the materials he encountered. In his exit interview, he shares:

> I had to pay close attention to the readings and other research related to Critical Making. In the end I developed a much deeper understanding of making and its application in learning contexts, but more importantly for me, the critical making framework we looked at in the course and informed by the research I undertook wove together and showed me the connections among many of the theories and models of education that informed my work throughout the M.Ed program (Critical pedagogy, Aboriginal and culturally responsive pedagogy, Project-based learning and assessment and authentic assessment).
>
> (Student feedback 'Nathan', 10/02/2017).

In addition to Nathan's burgeoning awareness of the theory and pedagogies associated with making, he also demonstrates awareness of maker tools and an ability to analyse them (as seen in his earlier posts).

After exploring the programme, Nathan describes 123D Circuits by AutoDesk:

> This is one of several online applications Autodesk offers related to digital design, fabrication and making. The 123D Circuits application is essentially an open-ended electronics sandbox that offers the digital equivalent of hands on experience wiring electronics and building circuits.
>
> (ibid).

He clearly articulates its features and functionalities (before the course we had no prior experience with the tool). He then provides some insightful analysis of it grounded in research: 'open-ended and constructive play for learning has identified potential value in platforms [such as AutoDesk] offering low floors, high ceilings and wide walls (Graves Petersen, Rasmussen and Jakobsen, 2015).' He connects this theory to AutoDesk by explaining it, 'allows novices easier entry points, gives experts the opportunity to work on more sophisticated projects and at the same time expands the overall diversity of outcomes'. He explains:

> Like me, you could go in with basically no knowledge of electronics and circuits and be wiring up light bulbs and LEDs in no time. For more experienced users, you can use the platform to build complex electrical devices from a homemade LED watch to stuff I can't even begin to understand the purpose of.
>
> (Student feedback 'Nathan', 10/02/2017).

This explicit connection between theory, for example the concept of low floor, high ceiling, and the tool, represent his analysis stage, 'analyzing what is already out there for quality' (Movement to Maker Framework). In this case, Nathan relates the quality of the tools to the theoretical concept of easy entry, but also notes the sophisticated possibilities in terms of usability.

Through his various reflections on the readings and the tools (and the connection between theory and practice), Nathan's awareness and analysis are evident at the outset of the course. This deeper understanding ultimately prepares him for the next more involved stages of the module: remixing and innovation.

Remixing

Nathan's remixing phase was unique because he was situated in a remote northern community while he was taking the course. As a result, he did not have the same access to the making tools as others in southern Ontario (ie. through public libraries, the university's maker lab, stores). Nathan, however, was forced to improvise and to hack traditional making by creating almost exclusively online using programs such as TinkerCAD, Scratch and online simulations of real-world maker tools, such as the Arduino. Below, in Figures 7, 8 and 9 Nathan provides screenshots of his first programming project, which involved coding an Arduino circuit board to become a 'bedside clock that signals when it is time to get up' because 'living in the far north […] in the winter we have 24-hour darkness.' (student feedback 'Nathan', 10/02/2017). For this project Nathan considered a personally relevant problem he wanted to solve through making.

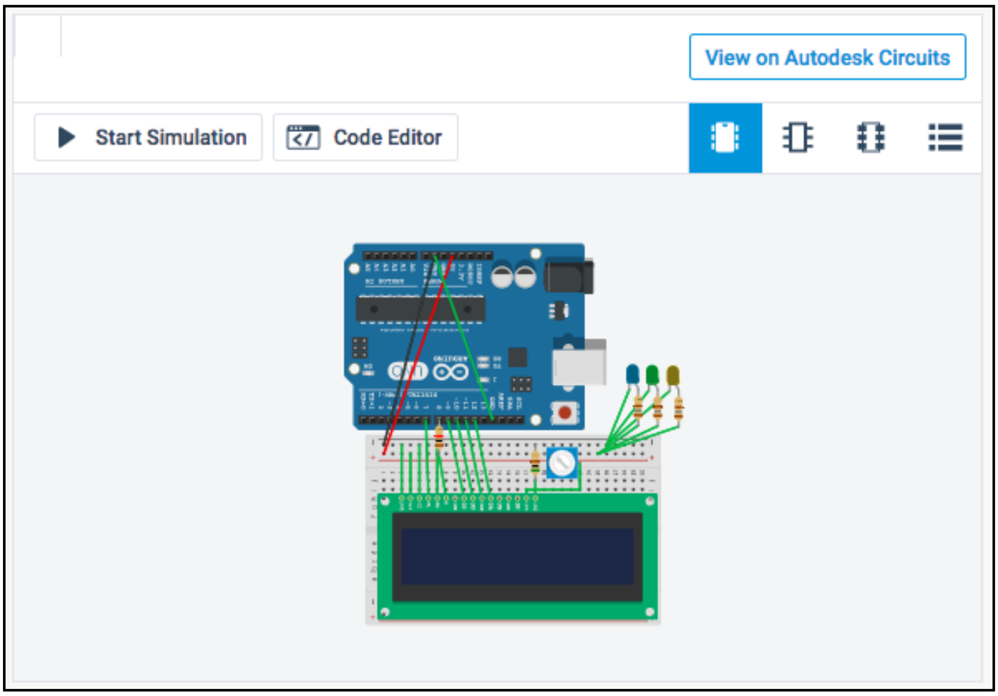

Figure 7: Screenshot, online Arduino simulator. Image: student project participant 'Nathan'.

As Nathan attempted to build this alarm clock prototype, he quickly realised he did not have enough knowledge of circuits and programming as was required for this project. In his reflection Nathan shared, 'I could copy wiring schematics and designs but as soon as something did not work (because I had made a mistake or otherwise) I had no idea how to begin problem solving the issue' (student feedback 'Nathan', 10/02/2017). Although the project in its originally-intended form did not come to fruition, Nathan had still entered the stage of remixing where he was taking established schematics and adapting them for his purposes. He scaled back his original plan with the Arduino and decided his success criteria would be 'if I could get an Arduino unit programmed to do anything' (ibid). After spending more time with the code – examining it, remixing it, trying different things – he 'finally ended up coding a string of LEDs to flash on and off. A significant achievement' (ibid).

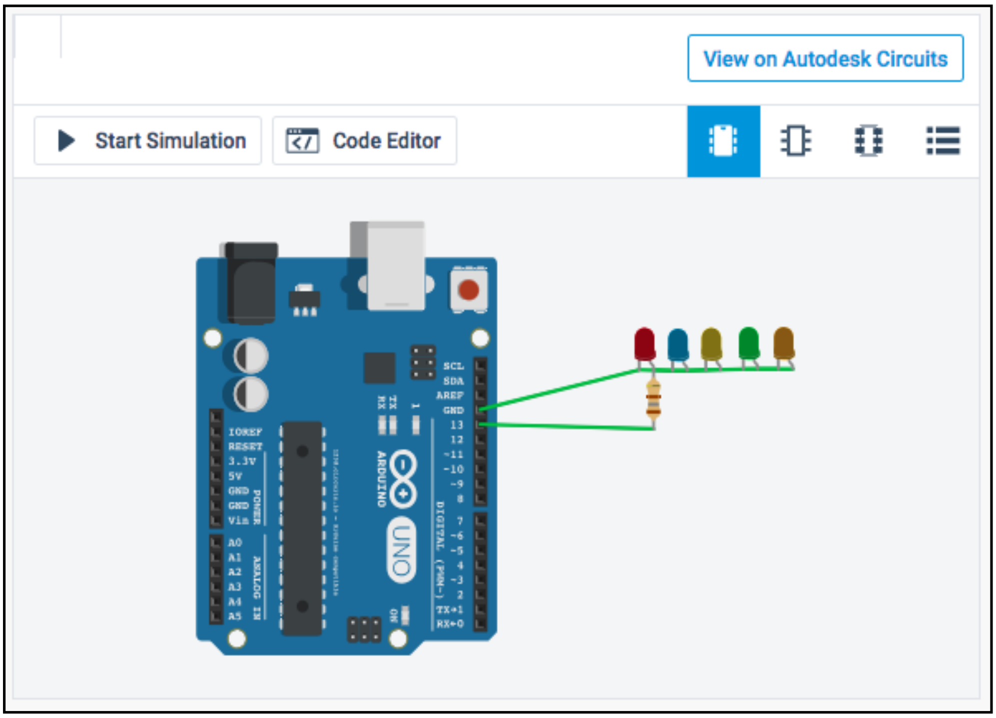

Figure 8: Screenshot, online Arduino simulator. Image: student project participant 'Nathan'

Nathan changed direction and chose code that was simple enough for him to interact with, remix and to adapt for his purposes. Nathan understood that, as his competency developed, he would eventually be able to return to his more involved alarm clock idea.

Innovation

Nathan's innovation stage was most remarkable in his final project, which was a course website where he curated all of his online making projects.

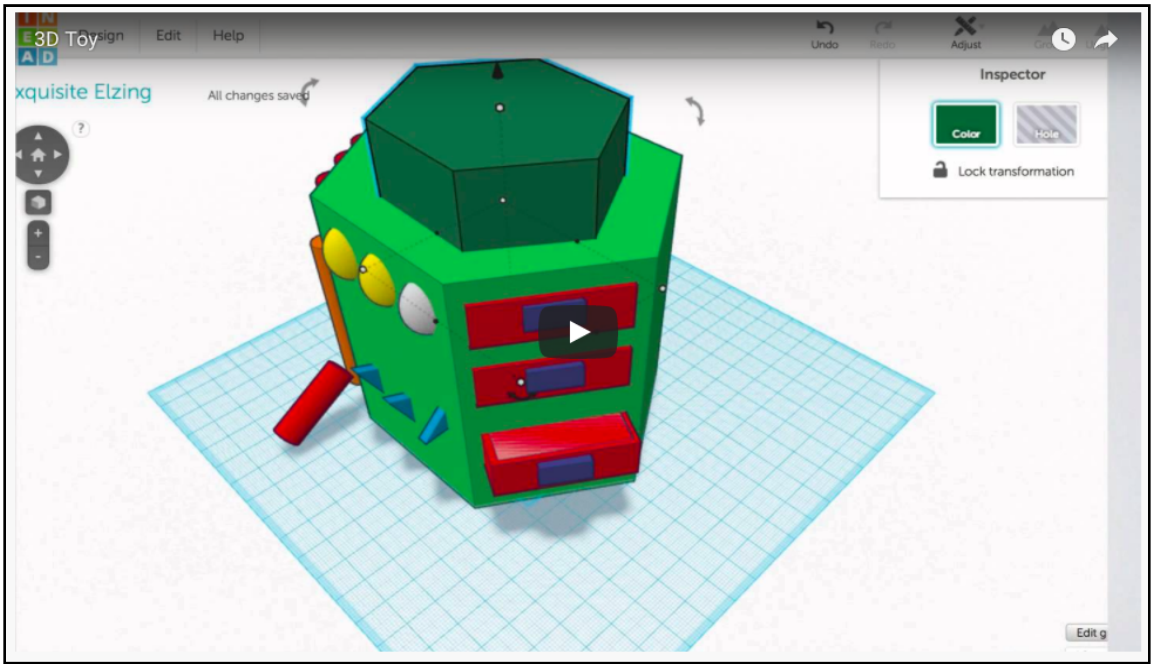

Figure 9: Screenshot, online TinkerCad 3D design. Image: student project participant 'Nathan'

This was innovative because, as Nathan explained:

> I was taking the course from a very remote location […] where access to supplies and materials is extremely limited and costly. As a result, my artifact creation focused entirely on what I could create virtually – or using online tools. Because I live and work in the Arctic, this approach was actually quite useful for me to take.
>
> (Student feedback 'Nathan', 10/02/2017).

After having an awareness of the tools available to him in this online environment and becoming more familiar with them through experimentation and remixing, Nathan decided to become a niche expert in online making and making within constraints. His innovation extended beyond the course: 'In a much more complex and professional context, my work in the course led me to connect and collaborate with a non-profit group operating in Nunavut devoted to developing coding, game-making and 21st century skills development for Inuit youth.' (ibid). Nathan explained that he was able to,

> leverage my learning in the critical making course and the research and thoughts I developed to collaborate on a proposal for the Arctic Inspiration Prize. Our submission was selected as a winner last winter and awarded $400,000 to develop a curriculum and program for sustainable skill development in a field directly linked to critical making.
>
> […]
>
> Taking the making course directly impacted my becoming involved with the group and the information, research and findings we presented in our proposal. For me, this was an extremely rewarding direct application of the knowledge and understanding I gained from the course.
>
> (ibid).

By the end of the course, Nathan had transitioned from being a novice in both his understanding of maker tools and pedagogies, to a maker equipped with the knowledge and skills to develop an innovative programme connected to critical making in his specific context.

Conclusion: Implications for practice and/or policy

This maker study sheds light on the creative process of making and innovation. Although just one case study, analysis of Nathan's progress provides 'local clarification through observation, description and interpretation' (Koehler, Mishra and Yahya, 2007, p.750) of the processes this student went through. It adopts the theoretical lens of making as learning, and provides a framework for educators to track student progress in the development of global competencies. As Ministries of Education begin to update their curricula to include these competencies, this research and framework prove timely. Curricula are becoming about more than simply assessing students' recall and content acquisition. Developing so-called 'soft' skills is being recognised as equally important to the development of content or 'hard' skills.

This skills attainment is echoed in an article released by the *Washington Post* in December 2017, which outlined Google's study that investigated the most important qualities of its top employees (Strauss, 2017). Notably, STEM expertise came in last (8th most important skill). Amongst the preceding 7 were qualities aligned with Ontario's new report card: communicating, possessing insights into others, having empathy, being a critical thinker and problem solver and being able to make connections across complex ideas. With this range of skills that are required and increasingly valued in professional practice, a shift in education is required, to help students develop transferable competencies such as innovation and creativity. Ultimately, to nurture innovation and change in our schools and communities we will need to do more than simply develop STEM knowledge.

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