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Making STEAM-Based Professional Learning: A Four-Year Design-Based Research Study

Création d'un apprentissage professionnel basé sur les STIAM : Une étude de recherche de quatre ans orientés par la conception

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Abstract

This article reports on the evolution of a STEAM-based teacher professional learning program designed to focus on maker pedagogies. Design-Based Research methodology was used to frame three iterations of professional learning sessions, which collectively involved more than 85 teachers in Ontario, Canada. The article describes the three iterations of teacher professional learning related to a maker approach, reports on what we learned from each iteration and how we modified the pedagogical approach based on the findings, and includes discussion on the implications for future professional learning in maker education.

Keywords: Teacher professional learning; Makerspaces; Maker pedagogies; Design-Based Research; STEAM

Résumé

Cet article rapporte l'évolution d'un programme d'apprentissage professionnel des enseignants basé sur les STIAM et conçu pour se concentrer sur les pédagogies maker. La méthodologie de recherche orientée par la conception a été utilisée pour encadrer trois itérations de sessions d'apprentissage professionnel, qui ont impliqué collectivement plus de 85 personnes enseignantes en Ontario, Canada. L'article décrit les trois itérations de l'apprentissage professionnel des enseignants liées à une approche maker, rend compte de ce que nous avons appris de chaque itération et de la façon dont nous avons modifié l'approche pédagogique en fonction des résultats, et comprend une discussion sur les implications pour l'apprentissage professionnel futur dans l'enseignement maker.

Mots-clés : Apprentissage professionnel des enseignants ; Makerspaces ; pédagogies maker ; recherche orientée par la conception ; STIAM.

Introduction

Making and maker culture promote the development of important global competencies that are valued in today's classrooms, job markets, and in society in general, such as creativity, critical thinking, communication, and problem-solving (Hughes, 2017; Hughes, Morrison et al., 2019; Hughes, Morrison, Kajamaa et al., 2019; Ontario Ministry of Education, 2016). Making is inherently subject-integrated, drawing on many skills and competencies that include the knowledge and application of science, technology, engineering, the arts (including literacy), and math (STEAM). As a tool for learning, a maker approach can be characterized as student-centered, inquiry-based, grounded in constructionism, and connected to the real world (Kafai, 2006; Noss & Clayson, 2015; Papert & Harel, 1991). Makerspaces are becoming increasingly common in Canadian schools, and they are often used as sites both for informal making and for formal STEAM teaching and learning. Therefore, it is important for teachers to be familiar with promising practices associated with making as a pedagogical approach to STEAM education.

Focused and intentional teacher professional learning is essential to facilitate widespread uptake of new initiatives and to encourage the effective implementation of new teaching and learning paradigms (Avalos, 2011; Darling-Hammond et al., 2017; Kennedy, 2016). We use the term Professional Learning (PL) instead of the more traditional Professional Development (PD) because PL emphasizes active learning practices, engaged in by teachers in an agentive way, which will be used in the classroom with students (Calvert, 2016b). Professional learning is also ongoing, embedded in context, and collaborative (Calvert, 2016b; Campbell et al., 2016). Within the PL model, sustained, context-based support is necessary for effective application of knowledge and skills gained during any offsite PL to practice in the classroom with students. As Little (1994) stated almost three decades ago "... the dominant 'training' model of teachers' professional development—a model focused primarily on expanding an individual repertoire of well-defined and skillful classroom practice—is not adequate to the ambitious visions of teaching and schooling embedded in present reform initiatives" (n.p.). Unfortunately, this training model still seems prevalent in today's context. With a shift toward making as a pedagogical approach in formal education contexts and, taking into consideration that for sustained change teachers need to engage in personally driven learning tied to conceptual understandings, knowledge of curriculum, pedagogies and subjects (Calvert, 2016b; Hulten & Bjorkholm, 2016), our study sought to address the question: What are some promising practices for professional learning to support teachers in the effective use of maker pedagogies and their associated tools for STEAM learning in the classroom?

Teacher Professional Learning

Although the quality of innovation in classrooms is not entirely dependent on teacher PD, high quality PD can make a difference in whether, and how much, teachers shift their practice. Little (1994) suggests that "one test of teachers' professional development is its capacity to equip teachers individually and collectively to act as shapers, promoters, and well-informed critics of reforms" (p. 1). To this end, the effectiveness of PL may be maximized if: (a) the teaching and learning methods are active, collaborative, and follow a transformation-based model (Campbell et al., 2016; Kennedy, 2014; Stewart, 2014); (b) teachers are understood as autonomous learners with agency (Campbell et al., 2016); and (c) teachers' values and school contexts and cultures are taken into consideration (Calvert, 2016b; Campbell et al., 2016).

Collaborative and Continuing Professional Learning

Recommendations for a shift in the structure of PD toward PL can be found frequently in the literature. For example, Stewart (2014) describes the need for a "shift from passive and intermittent PD to that which is active, consistent, based in the teaching environment, and supported by peers in a professional learning community (PLC)" (p. 28). Research by Campbell et al. (2016) and Kennedy (2005; 2014) affirms this focus on context-based, collaborative continuing professional development. Specifically, Kennedy (2005; 2014) explains that transformation-based continuing professional development (CPD) includes educators working together in both informal and formal ways (i.e., structured collaboration) through communities of inquiry. Transformation-based pedagogies result in greater teacher agency, which is an important element related to buy-in and application of new pedagogies, skills, and tools in the classroom. Collaborative and continuing PD are markers of high-quality PL (Campbell et al., 2016; Stewart, 2014) and studies have found that high-quality PL translates into higher quality teaching, which ultimately has a positive impact on student learning (Darling-Hammond et al., 2010; King, 2016).

Teacher Agency

To encourage investment in PL with the goal of effective and sustained change, teachers need to be positioned as active agents. Teacher agency is the motivation and confidence teachers feel that leads them to become agents in their own professional learning (Calvert, 2016a; Liao et al., 2017; Tao & Gao, 2017; Wallen & Tormey, 2019). Supporting agency requires giving teachers the space to take ownership over their practice in meaningful and valuable ways (Campbell et al., 2016; Rozenszajn & Yarden, 2014). In the context of PL, agency-building begins with voluntary engagement, allowing teachers the opportunity to select PL sessions that align with their professional goals (Blackley et al., 2017; Buxton et al., 2015; King, 2016). Moreover, encouraging teachers to implement learned strategies as they are deemed workable and necessary (Buxton et al., 2015; Insulander et al., 2019), rather than being mandated, contributes to a context in which teacher agency is respected. Transformative models of PL encourage participants to work in a collaborative learning community to develop their own knowledge and understanding and to push past the *what* and *how* to the *why* to change their practices (Kennedy, 2005; 2014; King, 2016). Professional learning that recognizes teachers as agentive actors and reflects their values, interests, and needs is critical for the sustained implementation of innovative pedagogies and initiatives (Buxton et al., 2015; Riveros et al., 2012).

Teachers' Values and School Contexts

Facilitating the transfer of knowledge, skills, and strategies from PL sessions into the classroom necessitates careful consideration of teachers' individual and collective values, as well as the overarching school context. While alignment of professional learning with school- and district-wide goals ensures relevance and continuity (Calvert, 2016a), organizing teacher-driven learning that directly connects to daily practice recognizes the value of educators' experiences and can promote active engagement (Calvert, 2016a; Hughes & Burke, 2014). However, as the practice of teaching is embedded within a school's sociocultural and sociohistorical context, effective PL must consider the various conditions that have shaped the culture in the first place and that may affect teachers' ability and willingness to explore new tools and pedagogies (Buxton et al., 2015; Calvert, 2016a; Riveros et al., 2012).

As Cuban (2013) and others point out, school reform is not easy and despite many attempts at innovation, classroom practices remain largely unchanged (Goodlad, 1984; Sidorkin & Warford, 2017). Understanding and reshaping school culture is a crucial first step towards the adoption and diffusion of transformative PL.

Contexts that embrace innovation and critical engagement cultivate a supportive environment for teachers' agency and ongoing professional growth (Insulander et al., 2019). Although innovation initiatives are often defined and set by government policy and senior administrative personnel at the school district level, school administrators can play an important role in facilitating this transition through their attendance and involvement in teachers' PL activities (Hughes & Burke, 2014), and their commitment to providing an environment that is conducive to continuous teacher-driven learning (Calvert, 2016a). This includes positioning teachers at the centre of PL initiatives, drawing upon their concerns and observations to guide the planning and utilizing their expertise to assist with delivery, improve buy-in, and build leadership capacity within the school (King, 2016). Agentive PL warrants a shift in organizational structure that engages teachers directly involved in processes of identifying and resolving problems; collecting, analyzing, and reporting on student data related to PL goals; observing, coaching, and mentoring others within the context of personal learning networks (PLNs); and other activities pertinent to supporting continuous professional growth (Hughes & Burke, 2014; King, 2016). Furthermore, effective and sustained PL depends on a context that enables teachers to voice, deconstruct, and overcome challenges and concerns. This is particularly relevant when teachers are exploring unfamiliar pedagogies and tools for learning. As an administrator, modelling educational risk-taking and creating an environment that reframes failure as both valuable and necessary to the learning process can alleviate teachers' apprehension toward experimenting with their practice (Hughes & Burke, 2014). While a prescribed approach to balancing continuous agentic PL with school board mandates may not exist, moving toward a system that positions teachers and administrators as allies in transformative professional growth can only benefit students and schools (Calvert, 2016a).

Teacher Professional Learning and Maker Education

We know from the literature that new, innovative pedagogies and the skills students need for work and post-secondary education today (Stewart, 2014, p. 28) require a new approach to professional learning. New pedagogies, which often involve the use of new technologies, change the teaching and learning dynamic in the classroom from teacher-centered to learner-centered (Hughes & Burke, 2014; Hughes & Morrison, 2018). Some of these learner-centered pedagogies include inquiry-based, collaborative, and constructivist learning—pedagogies associated with maker education. For effective use, it is necessary for the PL to mirror the type of teaching and learning that will be done in the classroom with students. This is important to encourage teacher engagement and to facilitate knowledge-building related to how and why the pedagogies work. By structuring the PL in the same way classroom learning would occur, teachers may also gain a better understanding of where, how, and why the maker tools fit into the learning process and the knowledge, skills, and competencies developed as a result (Fazio & Gallagher, 2018).

Research Design

This study used a Design-Based Research (DBR) approach to explore, develop, and refine promising practices for maker-inspired STEAM teacher professional learning. DBR was suitable for this study as it (a) involved an interventionist approach; (b) took place in naturalistic settings; (c) was iterative, allowing for refinement; and (d) resulted in guiding principles related to maker/STEAM professional learning for teachers (Barab & Squire, 2004; Bell, 2004; Design-Based Research Collective [DBRC], 2003). We conducted three related studies over the course of four years. Each iteration built upon lessons learned from the previous iteration. The first year of our study (Iteration One) included two sub-iterations, which each lasted a year (September - June). We took this more in-depth approach with the first study to refine the intervention tool (the maker/STEAM PL). In the third and fourth years of the study (Iterations 2 and 3) we expanded across two additional research sites to understand if the preliminary guiding principles uncovered in the first iteration were transferable across other contexts (DBRC, 2003; diSessa & Cobb, 2004). Table 1 provides an overview of the participant demographics in each iteration.

Table 1

Demographics of Participants Across Iterations

Demographics/ Iteration	Iteration One (Year 1)	Iteration One (Year 2)	Iteration Two (Year 3)	Iteration Three (Year 4)
Gender	20 Women 13 Men	18 Women 9 Men	14 Women 6 Men	4 Women 2 Men
Urban/Suburban/Rural	1 Urban 1 Suburban 9 Rural	6 Urban 3 Rural	9 Suburban 1 Rural	6 Suburban

Demographics/ Iteration	Iteration One (Year 1)	Iteration One (Year 2)	Iteration Two (Year 3)	Iteration Three (Year 4)
Public/Catholic/French/ Protestant	5 Public 3 Catholic 2 French 1 Protestant	4 Public 3 Catholic 2 French	5 Public 5 Catholic	6 Public
Division	K-8	K-8	K-8	6-8

Iteration One (Years One and Two)

The first iteration spanned a two-year period and involved two sub-iterations where additional schools and participants were added after the year one pilot. Figure 1 provides a visual overview of this iteration's breakdown and the other two, as well.

Sub-iteration One

In year one, three teachers from 11 Ontario school district boards (33 teachers total) were selected to participate in our study. The schools were selected based on a representative cross-section of the types of public schools found in Ontario: There was a mix of French, English, Catholic, and Protestant along with a mix of rural, urban and suburban, low-, medium- and high-socioeconomic status (SES), and multi- and predominantly mono-ethnic and First Nations Metis Inuit. The teachers were asked by their principals if they would like to participate in the PL research. The principals made it clear that the teachers' participation was entirely optional and that there would be no negative repercussions for not participating in the project. The teachers (and any administrators that opted to attend) were invited to our two-day research makerlab to participate in maker PL sessions. During these sessions, participants learned about maker culture, pedagogies, and tools through inquiry-based, hands-on learning, including thematic sessions based on several maker technologies (e.g., circuits, robotics, augmented and virtual reality, and additive and subtractive printing). Using Kennedy's (2014) notion that PL is more effective when it includes collaboration with peers, the participants rotated through each session in school teams.

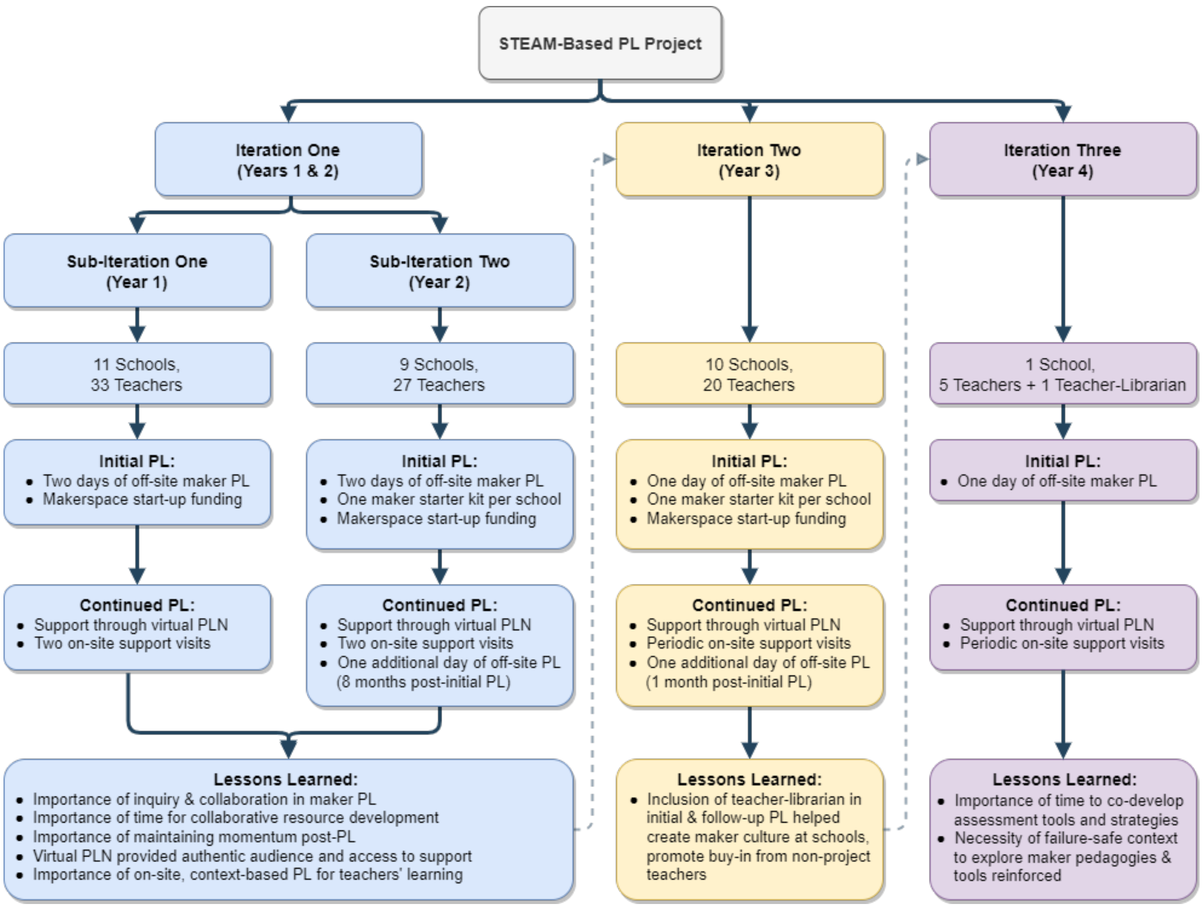
The teachers returned to their schools to set-up their unique makerspaces and to purchase the maker tools they felt would be best suited to their school community needs. Research funding in the amount of $30,000[1] was provided to each of the 11 schools to subsidize their initial makerspace purchases, totaling $330,000. Purchasing decisions were made by each school's community, reflecting desired areas of curricular integration, cross-curricular potential, and applications by grade level, among other factors. During the school year, our research team maintained regular contact with participants and followed their progress via Twitter and a common hashtag (#makeON), created specifically for the project. Members of the research team visited each school twice throughout the year to observe, consult, and provide additional context-based PL. Exit interviews were conducted at the end of the year regarding the teachers' observations, experiences, and feedback on the PL structure. Areas for

[1] All dollar amounts listed in Canadian currency.

improvement of the next iteration included: (a) the addition of a small starter kit comprised of select maker tools used during the initial PL to get the teachers started upon return to their schools (some schools reported a lag between their PL and the sourcing, delivery, and eventual set-up of the makerspace, which negatively impacted momentum); and (b) additional time to collaborate with peers on ideas for maker activities and lesson plans.

Figure 1

Overview of Project Iterations



Sub-iteration Two (Year Two)

In year two, three teachers from nine additional school boards (27 teachers in total) were selected to participate, using the same process as in iteration one. Our research team applied the feedback from the previous year and compiled maker starter kits for the two-day PL sessions. The teachers could take these kits back to their schools to avoid any delay in beginning their work with students. In addition to these kits, research funding in the amount of $25,000 was provided to each of the nine school boards to subsidize the cost of additional makerspace equipment and supplies. Regional professional learning and collaboration time was also built into an additional day of PL in our makerlab in the spring (approximately eight months after the initial two-day PL). This third PL session was a new feature in this second sub-iteration, added in response to our reflections on sub-iteration one that additional time to collaborate with peers on ideas for maker activities and lesson plans could enhance the teachers' professional learning. For this day, teacher participants were grouped based on their geographical locations to promote school district collaboration in the different regions. These sessions focused on introducing additional and emerging technologies (such as artificial intelligence), as well as creating STEAM activities and lesson plans based on the curriculum.

From these two sub-iterations, we learned that the inquiry-based, collaborative sessions and the time spent creating maker/STEAM activities were helpful for teachers in terms of learning the new technology (and feeling comfortable with it) and understanding the associated maker/STEAM pedagogies (i.e., inquiry, student-centered) and maker culture (i.e., permission to fail, emphasis on distributed knowledge). We also learned that maintaining momentum following the PL is key, and therefore having tools and ideas to bring back and to get started with right away is important. We also realized that establishing a virtual professional learning network (VPLN) and staying connected on social media was important for support. The VPLN (via Twitter) provided an authentic audience for the schools to share their successes, challenges, and innovative ideas. Finally, we realized that context-based PL (i.e., visiting the teachers at their schools and doing additional PL in the teachers' unique settings) was important for the teachers to take risks and to expand their repertoire of maker tools and activities.

Iteration Two (Year Three)

Our second study, which took place the following year, incorporated these key findings. This iteration involved two teachers from 10 schools (20 teachers total) located in two local school districts. In contrast with the two days of initial PL during the first iteration (years one and two), this study began with one PL day where participants learned about the maker tools and pedagogies and participated in thematic technology sessions for learning. The initial PL for this second iteration was able to be condensed into a single day by shifting the collaborative resource development and supplementary presentations to a second session to be hosted approximately one month later. Drawing on lessons learned in our first iteration of maker PL, participants were sent away with a small maker starter kit (valued at $1,000) and a common hashtag to share ideas, successes, and challenges. Participants were periodically visited by the research team throughout the year for observation and context-based PL, and additional collaborative time was offered at our lab during a second PL session one month after the first. After this iteration (and taken together with the first two sub-iterations), we learned that when teacher-librarians (TL) were involved in the establishment of a school makerspace, there was a greater chance for the maker tools to be used by more than just the teachers in the project, as the TLs could collaborate with other teachers during library time. Consequently, for our last iteration of the project, we made sure to include the teacher-librarian at each school.

Iteration Three (Year Four)

The third and final study was conducted with a local school that took part in our second iteration and included six participants: five teachers (grades six through eight) and one teacher-librarian. Building upon lessons learned from the previous iterations, participants were invited into our lab for a PL day that had been codesigned with the school's TL to include maker technologies that had been underutilized at their school over the past year. Given that only two of the participants had been present during the previous iteration, this expanded study served to extend the distribution of maker/STEAM knowledge within this site.

Following previous iterations, the PL session focused on maker pedagogies and cultures, connections to STEAM subject areas, and hands-on, inquiry-driven technology sessions in which participants explored the functionality and applications of the tools that had been previously identified by the teacher-librarian. This iteration reinforced the importance of involving the TL and other key figures in the planning and experience of the PL to support the developing maker culture in their schools. Moreover, we learned that time to collaboratively develop assessment strategies that captured the complexities of making with their grade-level colleagues was valuable to the teachers.

Data Collection and Analysis

Data collection within each iteration included pre-surveys that asked the teachers about their understanding of and prior experiences with maker tools, pedagogies, and STEAM-based learning. The pre-surveys also asked teachers about the challenges or concerns they anticipated in this project and what role they saw the makerspace playing in the next five years in education. These questions were asked to gain an understanding of the teachers' comfort levels and familiarity with making and STEAM-based learning, to gain an understanding of teacher concerns and challenges to best address these in the project, and to help the teachers adequately plan for long-term adoption of the maker tools and pedagogies for the purpose of STEAM-based learning. Researcher field notes, as well as photo and video recordings of the PL and in-class sessions were used to capture teachers' learning and development and major aha moments or turning points (Bruner, 1994). Social media posts by the participants using the hashtag #makeON were also collected. These social media posts served to keep the community of teachers informed of one another's work and progress in the project and it also allowed the researchers to observe the teachers' work with making and STEAM-based learning when the teachers were back at their schools. Emails and informal conversations with the teachers during the PL and in their classrooms were also collected as data (these were recorded using either a voice recorder app or as field notes). The emails and informal conversations helped the researchers develop a deeper understanding of those events either directly witnessed by the researchers or relayed to the researchers by the teachers. Finally, exit interviews and focus groups were conducted at the end of each iteration to gain further insight into the teachers' development (i.e., changes in perspectives, experiences, and understandings related to makerspace tools and pedagogies and STEAM-based learning).

Miles et al.'s (2020) process of thematic analysis was used to analyze the data. A preliminary analysis was completed in year one of iteration one and general codes were developed. A second wave of analysis occurred where sub-themes were developed, and the main and sub-themes were then applied to all the data. Examples of main themes included: (a) maker culture; (b) inquiry; (c) role of key figures (administration, teacher-librarian, technology lead); and (d) challenges establishing the makerspace. In year two of iteration one, we applied a similar process and looked for the emergence of new trends, themes, and sub-themes. When this next set of themes and sub-themes were solidified, the themes from years one and two were then applied to all the data collected in year two. This same coding procedure was also applied to iteration two (year three) and iteration three (year four).

Findings

Importance of the Learning Sessions (Pedagogies and Tools) for Transfer to Classroom

Using an inquiry-based approach with the teachers in the PL sessions was important for them to experience, and therefore better understand the exploratory, collaborative, and student-centered learning process their students were to undergo. One teacher explained how seamless this made the transfer from PL to classroom:

> I think coming to your makerlab was a great way for us to very concretely see how this could be implemented in the school, so I really enjoyed those days. When we came back to the school, it was easy for us, we kind of just piggybacked right on to those experiences, and then extended from there .... through my experience at [your lab], [I] developed a robotics club here … and each student got to decide on their own little project. (*Teacher from Iteration One, Year One*)

This teacher was able to learn alongside her students and to encourage personalized projects, which emerged from her own collaborative and learner-centered experience in the PL.

Another teacher from iteration two shared that she used one of the inquiry-based activities from the session—creating a Rube Goldberg machine—with her students. When questioned if she chose this activity because of her own PL experience, she said: “100%...I’m kind of taking the resources that were provided for me. I was exposed to a ton of different resources out there that are all related to it and that’s one of my centres that I’m currently building.” After experiencing the trial-and-error learning process embedded in the Rube Goldberg activity in the PL, this teacher was able to begin creating similar learning sessions as soon as she returned to her own school context.

Drawing upon different levels of inquiry within the PL helped to mitigate teachers’ fears that inquiry-based learning would manifest as chaos in the makerspace. Inquiry is often mischaracterized as unstructured free time, when in reality, the term represents a continuum of learning approaches oriented around a question or problem of interest (Bunterm et al., 2014; MacKenzie & Bathurst-Hunt, 2019). Free, open inquiry sits at one end of this continuum, enabling students to identify the questions to be addressed, the methods of investigation, and the resulting product. Structured inquiry sits at the other end, in which educators direct the inquiry questions, available resources, methods of analysis, and form of the results. Although these contrasting approaches may be appropriate for various classroom activities, inquiry-based learning typically takes the more moderate form of guided inquiry, blending teachers’ support and facilitation with student-driven learning and research (Bunterm et al., 2014; Watt & Colyer, 2014). Several teachers in iteration three observed that, while open inquiry was not always appropriate or even practical, it was still possible to leverage the benefits of this approach to learning by varying the level of inquiry to respond to students' dispositions, motivations, and expertise, as well as the learning objectives for a given session.

Providing time to play with the new tools and to become familiar with them prior to introducing them in the classroom was also important for the teachers. One teacher explained:

> I'd never had any experience with Ozobots at all so from the last session I got to play with them...and I realized how easy it was for all the kids to use, so I was really excited when that was in our package because that was the first time for me to use it and then to be able to come back and build on that and introduce it to the kids. *(Teacher from Iteration Two)*

As teachers normally have limited time to explore and troubleshoot new equipment, providing teachers with the time and space to become comfortable with the new technology tools led to increased confidence levels and an understanding that the tools were relatively accessible. The resulting familiarity and confidence also inspired unique ideas for the application of these tools in the classroom. One teacher remarked on the ease of manipulating shapes and text in Tinkercad, which led to the development of a geometry lesson in which students were asked to use the web-based software to transform (i.e., rotate, reflect, and translate) two-dimensional shapes. Although Tinkercad is most often used to design and create three-dimensional objects for print, providing time and space to play with the tool enabled this teacher to find alternative applications that promoted both digital literacies and curricular concepts. Another teacher reflected: "The professional learning was great. Having teachers create learning is the best PD." For this teacher, having the hands-on time to learn and create together led to a meaningful professional learning experience.

Inviting a diverse team of educators from each school to explore the tools and experience the pedagogies also proved effective for facilitating transfer, not only to the participants' classrooms, but throughout their respective schools. As highlighted in Figure 2, one school utilized the STEAM knowledge and experiences gained by their teachers who had attended the PL sessions to evaluate and refine their school improvement plan.

This school elected to send one teacher from the primary division, one from junior, and a program support specialist, as well as their principal, to participate in the PL sessions. Having such broad representation across divisions and levels of support created a network of expertise from which STEAM and the maker movement were able to spread within their school community. In each of the three iterations of our study, providing active and collaborative PL, mirroring the types of learning their students would experience, was essential in promoting the transfer of STEAM and maker pedagogies to our participants' classrooms.

Figure 2

Highlighting School's Integration of Maker PL through Twitter

Permission to Fail was an Important Message in the Professional Learning

Encouraging risk-taking and embracing a *permission to fail* philosophy was also important, both for the PL sessions and once the teachers returned to their classrooms to experiment with the maker pedagogies and tools. Of this experience one teacher explained:

> Honestly, the project for me kind of took the pressure off because I was exposed. We've gone from ground zero last year to now having all of this stuff. So, I'd never been exposed to any of that so when you gave us that opportunity to go through the centres and to play and to try different things it kind of opened my eyes to -- it's not so scary and that I don't have to be the expert. (*Teacher from Iteration Two*)

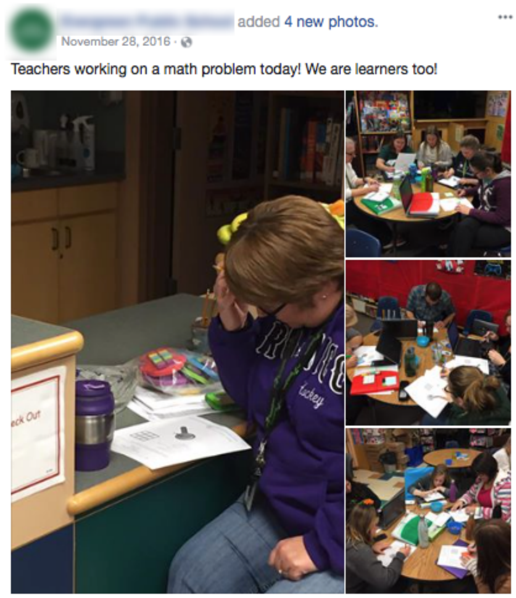
For many of the teachers, being granted the permission to be a co-learner and not the expert in the room was a turning point in terms of willingness to engage with the technologies. When questioned about their key takeaways from the study that have been applied in the classroom, another teacher similarly explained:

> I think I developed a bit more of a comfort level for myself. I was a little hesitant at first, but I felt very comfortable. I think with technology, especially in the education field, teachers are expected to be in the know so this gives us an opportunity to become the learners and to once again experience how it feels when you're learning something from the beginning. (*Teacher from Iteration Two)*

This level of comfort in learning alongside their students remained evident even after the PL sessions had concluded. As illustrated in Figure 3, some teachers were not only comfortable with co-learning, but also willing to showcase their challenges on the school's social media accounts, normalizing processes of failure and problem-solving for their students.

Figure 3

Participant Tweet Showcasing Teachers as Co-Learners in STEAM



Given that many of our participants had initially described the feeling of not being the expert in their classrooms as scary, this willingness to share their ongoing learning on a public platform represented a substantial shift in their perspective while also paving the way for their students to feel safe taking risks with their own learning.

Similarly, one of the administrators (Figure 4) attending our PL sessions reflected on the results of a failure-affirming atmosphere, emphasizing the importance of perseverance, particularly while experimenting with new tools and technologies.

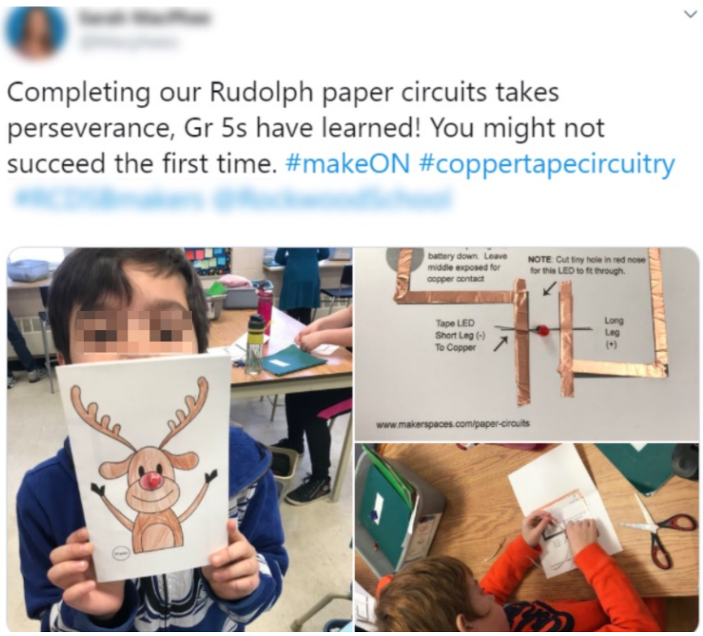
Having initially explored paper circuits (creations typically made from paper, copper or other metallic tapes, LED lights, and coin cell batteries) and other technologies within the failure-positive context fostered at our PL sessions, this Grade 5 teacher felt empowered to create a similarly safe environment in which students were supported to take the same risks.

Another group of teachers from a school in an underserved community (Iteration Three) acknowledged the importance of reframing failure, particularly with a population of risk- and failure-averse students. During their PL session, they seized the opportunity to workshop specific strategies for creating a classroom context in which failure was not only accepted but viewed as an important part of the learning process. These strategies included drawing upon literature (e.g., King & Johnston, 2012) and real-world examples of iteration leading to success, as well as highlighting favourite *mistakes of the day* and the resultant learning.

It was in modeling a permission-to-fail atmosphere in the PL and encouraging the teachers to take this approach in their own classrooms that they began to understand its important relationship to technology learning. They also came to understand that it was not necessary nor realistic for them to always be the expert in the room.

Figure 4

Participant's Tweet Commending Students' Perseverance through Technical Challenges



Importance of Key Figures at the Professional Learning Session Meant a More Seamless Transfer to School

We noticed that those schools who had an administrator, teacher-librarian, or technology lead present at the PL sessions had comparatively greater success in getting their makerspaces up and running soon after the PL and in encouraging school-wide adoption of the maker tools and pedagogies. One administrator shared her insights from being involved in the maker PL alongside her teachers:

> When I went to the training, it was myself and one other administrator there. I can't help but wonder if...having the administrator there at the training moved things along. I can only imagine staff coming back telling me about it. I wouldn't have had a deeper understanding instead of trying to lead with them. (*Principal from Iteration One, Year One)*

It was important for this administrator to understand and personally experience the new initiative to be fully onboard and "to lead with" the teachers. As seen in Figure 5, this administrator's support was demonstrated prolifically on Twitter as she shared messages with the school about important maker culture character traits like perseverance, resilience, and growth mindset.

This administrator also shared the work being done in the maker teachers' classrooms. This helped showcase the innovative activities that were coming out of these classrooms and that the administration supported the new focus, culture, technologies, and pedagogies, which provided further weight, legitimacy, and support to the new initiatives.

Figure 5

Participating Administrator's Tweets Regarding Maker Culture Characteristics

A teacher-librarian at another school in iteration one, year two noted that her unique, central position in the school's library/makerspace was a major factor in encouraging the extensive use of the makerspace by both teachers and students. This TL specifically encouraged outside-class time, student use of the makerspace through extra-curricular clubs. She also encouraged teacher use of the space by collaborating with teacher-colleagues in the development of maker lessons and activities. Of this unique position she held in the school as TL, she shared: "I teach every single class in the school but one. So, every class that comes has had some experience with making...". Not only did the attendance of key figures at the PL sessions indicate administrative and TL support of the maker project initiative, it also provided valuable insight into the various tools, pedagogies, and mindsets necessary to support PLCs and ongoing professional growth in their schools (Hughes & Burke, 2014; King, 2016).

Importance of Virtual Professional Learning Networks

The creation of VPLNs was important for sustained teacher PL, building connections across the school, district, and wider community, and encouraging the spread of the maker pedagogies beyond the classrooms of the teachers officially involved in the project.

The tools within the teachers' VPLNs (Twitter, Facebook, websites) provided platforms for teachers to make their students' successes visible, connect with the community (i.e., parents), and provide inspiration and ideas to other educators. One teacher explained that she began using Twitter to share with the school community and parents what her students were making in her class: "[T]o remind me for my assessment and to show the parents what we were doing. We put things on Twitter and…we were doing cool activities." By posting her students' work on Twitter, she invited parents into her classroom virtually to see the types of creative projects her students were engaging in with the new STEAM focus.

Regarding spread within the school board, one principal shared a story about a Grade 4 student who shared his learning about a robot (Dash and Dot) with her while she was talking to another principal:

> The student had interrupted our conversation. So, she [the principal] was intrigued and started asking him [the student] questions and then asking me questions about these Dash and Dots. And that was that…Then a short time later, I saw on Twitter that she posted about the Dash and Dots arriving at her school. I thought that was pretty cool because I knew that my student had sparked that. So, I started looking to see what kinds of adventures [the other school] was having with their Dash and Dots and got ideas. From there, I started to notice posts from teachers at other schools in our board so I started looking to see what ideas they had. (*Principal from Iteration One, Year One*)

In this case, the PLN began offline; however, it was Twitter that kept these principals and schools connected and sharing ideas. VPLNs extend the network beyond physical time and space constraints, facilitating sustained connection, continuity, and idea sharing. This principal also touched on another important feature of VPLNs in that they easily facilitate a snowball effect where an idea, resource, or individual opens one or multiple channels to other ideas, resources, and knowledgeable individuals.

Resource sharing was seen most prolifically at one of our northern schools in iteration one, year one where the technology leads were very active in their VPLNs and encouraged resource and idea sharing within the school and across the board. The tweet in Figure 6 reflects the different types of resources that were shared, tagged with key people and hashtags to promote online spread and further sharing. In this instance, a board lead retweeted a ministry lead sharing maker resources. Two maker teachers are tagged, along with the school board.

Figure 6

School Board Participant Retweeting Ministry-Shared Maker Resources

This example highlights the way VPLNs easily connect various stakeholders within a stratified education system: ministry-level personnel, board-level personnel, and teachers. Before VPLNs, this type of fluid idea sharing and immediate connection between teachers and key stakeholders who were previously disconnected in the traditional hierarchy was not possible.

Importance of Continued, Embedded, and On-site Professional Learning

Following participants' engagement in the initial off-site PL sessions, access to on-site PL throughout the year was important to provide a safety net for teachers nervous about experimenting with new tools in the absence of just-in-time, classroom-based support. Once participants had returned to their schools and began implementing the tools and pedagogies learned during the PL, the research team re-established contact with each school to determine additional learning and support needs. These differed among institutions, reflecting differences in the equipment that schools had purchased and in the curricular subjects where they had trouble with integration. One teacher shared that the on-site PL helped solidify additional curriculum connections he had not previously considered:

> The PL was great at the school. The language link was a great way to show the connection between STEM and Language. The visit made the learning authentic, especially for the host school. The extra PL last year was another way to solidify the positive relationship between STEM and its benefits when adding to the curriculum (*Teacher from Iteration One, Year Two*).

This highlights the importance of continuity when it comes to a professional learning initiative. Allowing teachers the time to learn and work with certain tools and activities incrementally over the year helped sustain interest, while infusing new ideas, strategies, and tools at key points throughout the year built on the teachers' previous experience, skills, and knowledge. Our subsequent on-site visits also enabled the research team to introduce tools that were more challenging than participants' initial purchases, but afforded greater opportunities for sophistication, deep learning, and the development of industry-adjacent digital skills. This allowed us to provide more focused PL with smaller groups as the tools became more complex.

A minimum of two embedded follow-up PL sessions were helpful to support teachers in their unique contexts. Based on the positive outcomes of the classroom-based support, we predict that additional embedded PL (i.e., once per month) would only enhance teachers' professional growth in a similar study. However, more research is needed to determine what the correct amount of embedded support might be as we also predict the need would vary from school to school depending on a variety of factors. These factors include the dispositions of teachers and administration, school infrastructure, culture, and more.

Considerations

In each iteration, the teachers were encouraged to integrate the maker pedagogies, tools, and STEAM-based learning into their practice as much as they felt comfortable. As a result, the application of knowledge from the PL sessions and the maker tools varied from school to school and teacher to teacher. For example, one suburban site in iteration one, year one adopted a maker approach to teaching and learning throughout their school as maker culture spread and the upskilling of all teachers was of primary importance to this school's principal. At another school in iteration one, year one, the three participating teachers incorporated making and maker tools to different degrees. For example, due to one teacher's self-reported feelings of low-confidence with many of the digital tools, she opted to focus exclusively on greenscreen and video-editing in her classroom. She explained that her approach was to select one tool and to learn it thoroughly alongside her students. The other two teachers at this school experimented more widely with the digital tools. These teachers used Sphero robots, woodworking tools, greenscreen, and more in their classrooms.

In one rural school in iteration two, we received feedback from a teacher that he experienced some difficulty both planning curricular connections and juggling the various initiatives at his school after the initial maker PL sessions. In his post-project interview, he explained:

> ...[I]n the first two weeks when I came back from the sessions, I was very gung-ho and started implementing, got out everything and everyone was engaging, but then something else comes along and when it's not a part of our routine, and it's not built into our program, it's easy to lose focus and you move into the next and so...And again it goes back to that planning piece, it's hard to look at those experiences as a cross curricular approach because at the end of the day I have a report card to write, I have to assess in specific skills and when I haven't really planned ahead or figured out how all of this ties into what we're doing and how I'm assessing it, it's difficult and so we treat all of these things as individual tasks.

While this was an outlier comment in the teacher interviews (i.e., most teachers did not mention the stresses of multiple initiatives or difficulties making curriculum connections), we felt it was important to recognize that this can be a reality for some teachers. From the outset of the project, we made a concerted effort to model explicit curriculum connections and subject-integrated maker activities, so the teachers could see how the maker pedagogies and tools did not need to be an added burden, but rather a shift in thinking about the teaching and learning process. Some teachers needed a bit more time, however, to get to this place in planning where curriculum connections and the maker pedagogical approaches and tools were more easily integrated. Time and support appeared to be key factors for those more hesitant teachers.

For some schools, the maker tools that were provided or ordered were completely new resources and required a significant shift in thinking and learning. For other schools, the maker tools extended some of the learning resources that were already in the schools. For example, at least four schools already had wood-working or design and technology tools and spaces. These schools were able to supplement existing resources and order other tools to extend project possibilities, like circuit-building kits that could be incorporated into designs. However, regardless of whether the tools were completely new or extensions, the schools that appeared to make the most gains in terms of the integration of the maker pedagogies and tools had teachers who were open-minded and principals who were supportive.

Discussion and Conclusions

As King (2016) states, "certain factors have been identified in the literature as supporting sustainability of practices over time: deep learning, professional learning communities and school culture" (p. 579). Based on our own multi-year research, for PL to be effective, it must be layered, like King (2016) describes. Our findings echo previous research indicating that PL must be: (a) active, involving teachers in the planning and direct experience of STEAM activities appropriate for their contexts (Buxton et al., 2015; Campbell et al., 2016; Stewart, 2014); (b) collaborative, providing opportunities for teachers to experience, reflect on, and implement the PL with the support of their colleagues and administrative staff (Campbell et al., 2016; Kennedy et al., 2014; Stewart, 2014); and (c) supported in various ways over an extended period of time (Hughes & Burke, 2014; Insulander et al., 2019; King, 2016). Maker PL, specifically, benefits from a structure similar to what students would experience in the classroom (Oliver, 2016), including the thoughtful integration of different levels of inquiry (Little, 1994; Watt & Coyler, 2014), adequate time to explore unfamiliar technologies (Hughes & Burke, 2014; Stevenson et al., 2019), and an environment in which teachers feel comfortable exploring and collaboratively developing their understanding of new pedagogies (Easton, 2008; Little, 1994; Oliver, 2016).

It also became clear in our study that creating a failure-positive environment in the PL was of utmost importance (Harron & Hughes, 2018; Hughes & Burke, 2014; Kim et al., 2018). Tinkering and iteration are fundamental components of making (Marshall & Harron, 2018; Martin, 2015; Thumlert et al., 2015) and mistakes are inevitable. The failure-positive PL context provided space for teachers to not only engage with the new tools without fear of judgment, but also to understand some of the key tenets of maker pedagogies, including the creation of a democratic learning environment based on distributed knowledge and expertise. This, in turn, encouraged the development of a similarly supportive learning culture in their own classrooms and, in many cases, the wider school community. Those schools with strategic personnel present at the PL off-site session had the most success in terms of spreading the maker culture, tools, and pedagogies within their schools, which seems at least partly due to the teachers' abilities to support the work and make it visible. VPLNs served to support teachers by expanding their resource base and connecting them with key stakeholders and other like-minded individuals. The on-site PL also supported teachers in providing context-based and ongoing focused support. Future research could include a longitudinal study of the implementation of this PL model as more research is needed on the sustainability of new initiatives and practices over time.

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