STEAM-3D Makerspace

Ontario

CODE
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UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

Science 3D: Discovery, Design & Development through Makerspaces

Introduction

Community makerspaces have become a widespread phenomenon; however, these Do-It-Yourself (DIY) models, rooted in design thinking and innovation, are beginning to move into the realm of formal education.

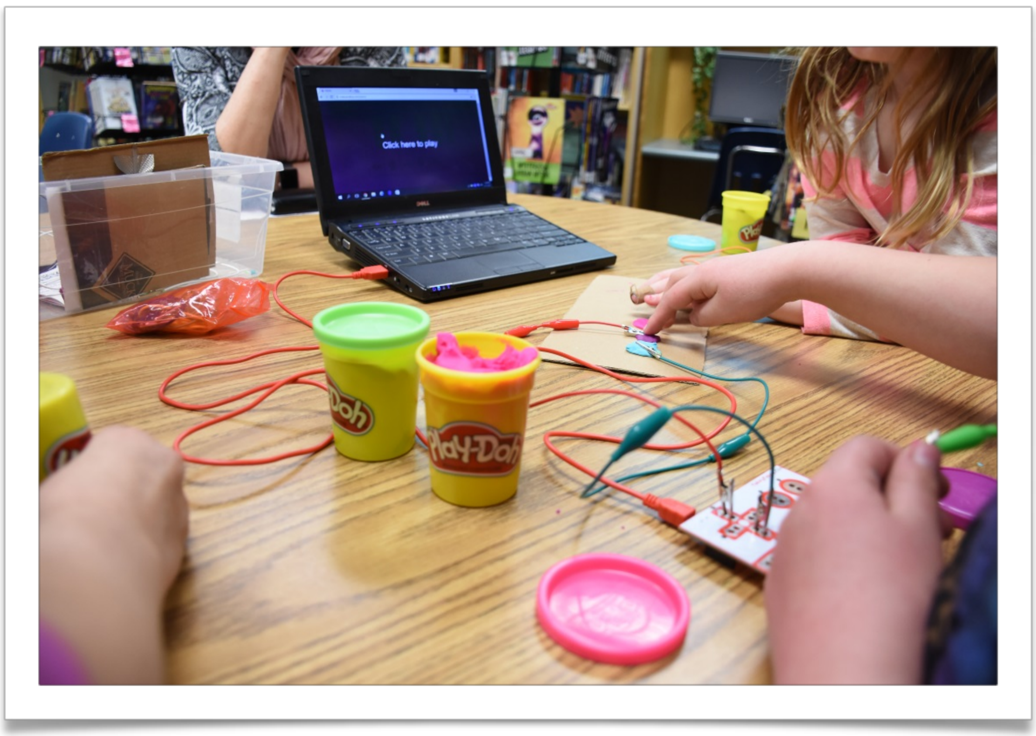

Figure 1. Students working with MaKey MaKey at Evergreen Public School, Keewatin-Patricia District School Board

The maker movement was borne out of the increasing number of people who creatively engage in both physical (or tangible) and digital fabrication to solve an existing problem or need, and to share their design and making with a community of like-minded innovators (Halverson & Sheridan, 2014). The maker movement has been associated primarily with Science, Technology, Engineering, and Math (STEM) or STEAM education (where there is a focus on embedding the Arts into science, technology, engineering and math); however, maker pedagogies more generally, promote important principles including inquiry, play, imagination, innovation, critical and creative thinking, problem solving, collaboration, and personalized learning. As MAKE magazine founder Dale Dougherty argues in his 2011 TED Talk, we are all makers. Maker pedagogies build on project and problem based learning, design thinking and remixing practices often highlighted in media literacy programs. A current need in this area is to define best practices and to better understand how to utilize making for the purpose of learning (Halverson & Sheridan, 2014; Cohen, Jones, Smith & Calandra, 2016).

What distinguishes a makerspace from a place where people make 'stuff' is the inherent culture. A makerspace is much more than the equipment that is housed there. A makerspace should be committed to a culture of innovation, while at the same time, provide the skills and foundation that students will need to succeed in that kind of learning environment (Fleming, 2015). A maker culture promotes risk-taking, learning from mistakes, problem-solving and the development of perseverance when tasks are difficult. A maker culture fosters higher-order thinking skills and opportunities to share learning at local and global community levels through Maker Faires and websites such as www.instructables.com, www.thingiverse.com and www.DIY.org.

Overview of Study

The focus of this research is on developing and observing constructionist "production pedagogies" that work to build capacity for investigating and affecting change and innovation in formal and informal education settings. The research investigates the impact of "makerspace" pedagogies that facilitate the discovery, design and development (3Ds) of digital and tangible products for teachers, their students and the school community. Teachers with knowledge and skill in science and technology collaboratively are exploring new avenues of thought in their practice. The research questions focus on how educators can use makerspace pedagogies to promote inquiry, play, imagination, innovation and design thinking, critical and creative thinking, problem solving and collaboration. With the infusion of resources and custom-designed professional development, teachers are being introduced to innovative ideas and practices in maker or "critical making" pedagogies. They are gaining the knowledge, skills and confidence to establish and implement a makerspace/maker culture in their classrooms/schools, where learners can congregate to design, engineer, and fabricate digitally enhanced products of all kinds, both digital and tangible, and explore the uses of digital technologies in general, including mobile devices, social media, apps and games, digital circuits, 3D printing, e-textiles, programmable robots and virtual/augmented reality.

Figure 2. MaKey MaKey attached to Bongos at Burkevale Protestant Separate School, Penetanguishene Protestant Separate School Board

Research Questions

How might educators use makerspace pedagogies to promote 21st Century skills such as inquiry, imagination, innovation and design thinking, critical thinking, problem solving and collaboration?

What challenges exist for teachers/schools in establishing a makerspace/using maker pedagogies with students?

What are some best practices associated with maker pedagogy approach?

What supports are necessary for teachers shifting to an inquiry based, maker pedagogy approach?

- What impact, if any, does a maker pedagogy approach have on student achievement and well-being?

Relevant Literature

The research activities draw on the concept of critical making as a vehicle for deep learning through digital technology. Situated within a constructionist approach to education, critical making assumes that learning is most effective when learners are active in making tangible objects in the real world and draw their own conclusions through experimentation across multiple media, where learners construct new relationships with knowledge in the process (Kafai, 2006; Ratto, 2011). Unlike more traditional instructionist approaches to learning (where the knowledge to be received by students is already embedded in objects delivered by teachers), constructionist learning encourages learners to learn from their own active engagement with raw materials. In this project, "raw materials" include both tangible and virtual materials. Seymour Papert (1980), an early proponent of constructionism, proposed a “low floor, high ceiling” learning environment, where students engage in digital coding in a form that has minimal prerequisite knowledge yet offers opportunities to explore and to build concepts and relationships well beyond students’ formal grade levels. Resnick et al. (2009) added to that early model the dimension of "wide walls" that support "many different types of projects so people with many different interests and learning styles can all become engaged" (p. 63). It is this approach to learning that is offered in child-friendly coding environments such as Scratch and digital circuit making products such as MaKey MaKey (see Figures 1 and 2); this project engages teachers and their students with these “low floor, high ceiling” computing and manufacturing tools. Creating interactive stories, simulations, games, and both physical and wearable technologies entails using digital tools to identify, access, manage, integrate, evaluate, critically analyze, synthesize, create, communicate, collaborate, and code.

Beyond simply creating objects for the sake of creating objects (e.g., creating 3D keychains), critical making concerns itself with the relationship between technologies and social life, with emphasis on their liberatory and emancipatory potential. Thus, it connects two practices that are often considered separate: critical thinking and creative expression (Ratto, 2011). The term critical making is associated with the Do-It-Yourself (DIY) movement, and emphasizes critique and expression over technical sophistication: shared acts of making are more important than the resultant object. Do-it-yourself (DIY) paradigms have recently re-emerged and have gained popularity as a medium for creative expression (Buechley et al., 2008; Buechley & Perner Wilson, 2012; Kuznetsov & Paulos, 2010; Tanenbaum et al., 2013) and self-directed learning (Martinez, 2013; Qiu et al., 2013; Kafai et al., 2014). The maker movement for education has broadened the level of participation in DIY activities across several demographics leading to increased activity in terms of creation of new makerspaces for practising hands on learning, encouraging girls to participate in STEM activities, and generally placing emphasis on the idea that every child can become an innovator (Halverson & Sheridan, 2014; Education, 2015).

Figure 3. Virtual Reality at St. Ambrose Catholic School, Huron Perth Catholic District School Board

In the context of the research, “makerspaces” were established at eleven schools to promote, observe and evaluate the impact of this kind of critical building/making using digital tools, including digital text making, 3D printing, robotics, virtual/augmented reality (see Figure 3) and e-textiles.

To avoid the “dangers of trivialization” or “keychain syndrome” of “making stuff” that will end up in landfill sites, Blikstein (2013) cautions educators to shy away from the kind of quick demonstration projects typically associated with makerspaces, and move toward STEM learning that is more meaningful and contextualized. It is for this reason we are exploring makerspace pedagogies in close connection to the Ontario Ministry of Education Grade 1-8 Science and Technology Curriculum.

Methodology and Methods

The first year of this research involved 11 elementary schools in 11 school boards in Ontario including schools with Eng/Fr/FNMI students, in public and Catholic boards:

School/Board	School Location	Principal	No. of Students	Grades
Brookview Middle School Toronto DSB	Toronto (Urban)	Anton Walcott	400	T/L 6 7
Burkevale Protestant Separate School Protestant Separate School Board of the Town of Penetanguishene	Penetanguishene (Rural)	Julia McLaren	236	8 5 6
École élémentaire catholique Ste-Catherine CSCProvidence	Pain Court (Rural)	Lucie Crête	214	5 7
École Ronald Marion CSViamonde	Pickering (Suburban)	Sylvie Roy-Hollingsworth	450	5/6 5/6 1
Evergreen Public School Keewatin-Patricia DSB	Kenora (Rural)	Shannon Bailey	170	4/5 2/3 5/6
Northeastern Elementary School Rainbow DSB	Garson (Rural)	Randy Wallingford	500	8 1 7/8
Ridpath Junior Public School Kawartha Pine Ridge DSB	Lakefield (Rural)	Penny Hope	435	4/5 TL 6
Rockwood Public School Renfrew County DSB	Pembroke (Rural)	Terry Burwell	400	7 4 3
St. Ambrose Catholic School Huron Perth Catholic DSB	Stratford (Rural)	Judy Merkel	198	8 SERT 3
St. Elizabeth Catholic School St. Clair Catholic DSB	Wallaceburg (Rural)	Liz Gibson	196	8 3/4 2
St. Joseph Catholic School Durham Catholic DSB	Uxbridge (Rural)	Phyllis Pereira	330	SERT 2 6

Three teachers per school worked in cross-curricular inquiry teams. Each school received support and guidance from the research team in the UOIT STEAM-3D Maker Lab to collaboratively identify and then develop an intensive Science 3D: Discovery, Design and Development school-based inquiry project. Teachers worked in teams to integrate critical making and the Ontario Curriculum expectations in science and technology. The work was to draw on and align with the Ontario Ministry of Education's Science and Technology curriculum document as well as the Growing Success document in order to provide a foundation for the implementation of assessment and evaluation and the Achieving Excellence and 21st Century Competencies documents. For a more detailed timeline of research activities, please see:

https://www.sutori.com/story/science-3d-discovery-design-development-through-makerspaces

Qualitative, ethnographic case study methods probed teacher participants' experiences and learning in both classroom and lab settings. The research team at the UOIT STEAM-3D Maker Lab provided customized professional development sessions, resources and face-to-face as well as on-line dialogue to help teachers discover ways to create Science 3D inquiry projects that make important connections and teach the skills and knowledge in precise and integrated ways. Many of the individual projects lasted for several months in each school and a great deal of student learning in each of the schools was expressed in artistic and technologically enhanced ways. (e.g. design and construction of eco-friendly homes, robotics, green screen documentaries, e-textiles, stop-motion animation (see Figure 4) three-dimensional collages, social justice-themed quilts, etc.). It is expected that there has been and will continue to be significant and sustainable on-going benefits in teacher practice when the imaginative, integrated and innovative inquiry-based projects are developed, implemented and shared throughout Ontario and when the project is expanded to include another nine school boards in year 2.

The empirical approach to understanding learning in the STEAM-3D lab was supplemented with in-depth interviews, allowing participants to describe their experience in their own words, encouraging metacognition about their thought processes and affective states before, during and after instruction and work. This approach allows researchers to understand the private world of the learner. Qualitative research documentation includes digital video and audio recordings, on-the-ground field notes and observational notes, and pre and post interviews with participants. Interviews asked participants about their attitudes, dispositions and experiences with making and technologies, as well as other media production practices. The qualitative data is enhanced by pre-project surveys completed by all participants.

Findings/Results

After a preliminary analysis of the data, many sub-themes emerged that could be aligned under our five overarching research questions. However, upon closer examination, we recognized that the sub-themes and research questions could be further divided into four main themes. These themes can be categorized as: 1) Challenges; 2) Supports; 3) Best Practices; and, 4) Benefits. Each theme is presented below with quotes from teachers and administrators, combined with brief discussion to both illustrate these main points and to add context.

1) What challenges exist for teachers/schools in establishing a makerspace/using maker pedagogies with students?

i.) Deciding on a focus. Deciding on a focus for the makerspaces was a challenge for many of the schools at the beginning of the project. For some, it was difficult to decide on the technological focus (i.e., mainly robotics or a cross-section of different tools) and for others, it was difficult to determine the exact purpose of the space — for example, what are the needs of the community and how can the makerspace respond to those needs?. In the teacher interviews, one participant shared that some difficulties included “trying…to decide what we wanted our direction to be with the makerspace as to what items to pick or what directions to go.” They settled on a programming focus: robots and computerized sewing, as they felt these two types of tools would speak to their students’ interests (ie. coding and textiles). Echoing similar challenges, Northeastern shared, “…it’s great to have the money, but we want to be using it for stuff the school really needs.” It took Northeastern a while to narrow in on their focus, however, the final direction for it — a woodshop—suited the learning needs of the community. The school wanted a hands-on space where students could build and tinker with tangible materials.

ii.) Managing materials & technologies. Managing materials and technologies was another sizeable concern for most of the schools. One school provided the following anecdote to reflect the challenges they faced in terms of not always having enough materials for the class:

> The issue with the students probably would be do you have enough materials, and what size are the groups. Now we have 4 in a group, because we don't have enough materials. Would it have been better with fewer kids? Absolutely. Would

> there be more learning? For sure. Day to day there are sometimes members of the group who don't do much. That would be the big thing. Same with the 3D printing, so many people get to work at it and there's only two printers.

This was echoed at other schools, too; however, sharing materials was not always seen as a detriment to learning:

> We don't have enough materials for one for everybody, so that's the real goal -- how do you work together as a group to achieve the task in the required amount of time? Sharing the glue, the materials --that's been the real eye opener for me. It's made them better people because they've had to work together to achieve the tasks because they've not had enough stuff. It's been a really rewarding experience to watch.

When students need to share materials, there is also an inherent need to learn to get along with one another and to develop positive communication and interpersonal skills.

iii.) Monitoring student progress. Monitoring student progress became a double-edged sword for many of the teachers involved. On the one hand, the teachers found it easier to be able to see the students' learning through the physical creation of an artefact — i.e., what the students did or did not understand and how they problem-solved and worked through challenges. Unfortunately, on the other hand, when it came to quantifying the progress within a traditional education setting, this became more difficult. One teacher captured this dichotomy when she shared:

> In terms of assessment we're used to having some kind of artifact or some kind of final assessment. I was in the 6/7 classroom yesterday and the teacher was using Dash 'n Dots and students were programming them and doing different triangles on the floor. There's an example where the observation and the conversations with students is the assessment. But I think for so many teachers it's hard to be comfortable developing that assessment and saying I know the child mastered that skill because I observed them create that triangle and have conversations with their peers and myself. I think that that's kind of new age assessment which has been in Growing Success for years, but I think that we need to develop a stronger comfort level with that to say I know that child mastered that skill because I saw it. We don't necessarily need the child to then answer some kind of paper and pencil activity to confirm that, so trusting our observations is going to be an ongoing challenge.

So, the focus now needs to be on how do we revise traditional assessment tools, so that teachers can feel both comfortable and confident in all forms of assessment (for, as and of) when using the maker pedagogy approach in the classroom.

iv.) Motivating frustrated students. While many of the schools reported increased motivation for their students (in those who were both previously engaged or previously disengaged in the traditional setting), some teachers reported difficulty in motivating students who were easily frustrated by the constructionist, student-centered and problem-solving-based model of learning. One teacher explained: “That’s what I noticed most, in the beginning they were nervous if things would work, so they wanted me to help them all the time.” However, once the students realized that their teacher either was not going to intervene (or due to a lack of knowledge in the area actually could not provide them with the answers), the students got to work. Another teacher explained that she would allow the students to struggle to a point and then after 10-15 minutes, she would provide them with some piece of guiding advice. She did this in order to help keep the learning momentum going and to avoid task abandonment or disengagement.

v.) How much scaffolding? The issue of scaffolding was another challenge that teachers at the various schools experimented with throughout the project. Oftentimes, the teachers noticed that very little scaffolding was needed: “…you can set the kids free with [the makerspace tools] and they're going to learn on their own”. At other times, the teachers noticed that a more structured, or focused, approach to the making activities was a requirement. One educator explained: “Another thing we're really thinking hard about as a staff is making sure as much as possible is we're making meaningful connections to the curriculum because there's a lot of learning skills happening in there, that's never an issue, but to make it most connected to the curriculum is more challenging”. These teachers felt more purposeful scaffolding was necessary when it came to determining specific learning objectives and making direct curriculum connections.

vi.) Initial distraction of new technology. The initial distraction of the new technology was a challenge for many of the teachers at the beginning of the project; however, most came to recognize that this was a normal part of the technology integration and adoption process. The novelty and entertainment factor of the tools became less acute after the initial introductions, which made way for the shift to the adoption of the tools for more purposeful educational purposes.

vii.) Connecting to the curriculum. Some of the teachers at the beginning of the project found making connections to the curriculum a seamless process: “I found it pretty simple, sometimes I have a hard time getting in all the ideas and fitting them into the year, it takes some thinking maybe a little research but it's not very hard”. However, many found it a challenge: “Just connecting everything they're doing to the curriculum specifically sometimes I have a problem with that. So I ask myself if my time spent on this is justified, and by the end of the year I have to get their report cards done, and so the expectations might be stretched in some ways to do with makerspace…" While it may certainly be possible to make countless curriculum connections with activities related to the maker tools, it has also become apparent that teachers need more explicit support in this area.

viii.) Finding an appropriate space. For many schools, deciding where the makerspace would go was an issue at the beginning. Some schools wondered if the library was the best choice (or if it would limit how the makerspace was used, i.e., an add-on as

Figure 4. Four different makerspaces (top left: Northeastern; top right: St. Elizabeth's; bottom left: St. Ambrose; bottom right: Burkevale)

opposed to integrated into the curriculum). Some schools felt many of the more collaborative spaces would not be able to adequately store the technologies and making materials (issues of security, cupboard space, etc.). To navigate these perceived challenges, two of the schools opted for mobile maker bins that could be easily wheeled to classrooms and the tools integrated into daily lessons. Nine schools opted to retro-fit a previously unused space or the learning commons. Whatever was eventually decided upon, each school chose what made the most sense for their purposes (see Figure 5).

2) What supports are necessary for teachers shifting to an inquiry-based, maker pedagogy approach?

i.) Professional development. Professional development was a large factor for the schools when it came to adopting the maker tools and pedagogy. Many teachers commented on the value they saw in attending the professional development session at UOIT at the beginning of the project:

> The days that we spent in Oshawa at the camp we really enjoyed. We got to see a lot of different technologies that we had not delved into at all at our school. The presenters, who I believe were a lot of faculty of education students, were really well prepared and very confident in the technologies they presented to us and really made us want to get on board. When they were presenting we could really see our students enjoying the technologies presented to us.

> Having that time on the Friday afternoon to create that list [of equipment to be purchased] I would say was very valuable before we left Oshawa, because then as you said everything was very fresh in our heads.

Despite this initial session, several participants felt that additional professional development was necessary. The research team modified its plans for the second school visits and incorporated more advanced PD in May and June, 2017. Decisions about what to focus these PD sessions on were made collaboratively between the participants, the school administration and the research team.

ii.) Permission to make mistakes. The teachers also shared they found that working in an environment with a failure-positive mindset encouraged them to experiment with the tools and activities and to learn alongside their students:

> I find that this year has been a lot of learning for me, and I find that like when I first went down for the training I was like oh my gosh I don't know what I can do, I'm not sure if you picked the right person, but I picked one thing and tried to get good at it…

For the teachers, being positioned as a learner alongside their students freed them to take risks with the technology. At times, the technology did not work or the class had to troubleshoot together, but these things were viewed as part of the learning process and not something negative.

iii.) Collaborative planning time. Many of the teachers and administrators talked about the value they found in having collaborative planning time. The time allowed for rich discussion, technical and emotional support, knowledge and idea sharing and the creation of a positive and innovative learning culture. One administrator shared: "What I try and do is be supportive and remove the barriers that may be in their way. Bring our librarian into it so there's that shared ownership, because there really does need to be teamwork for it to be successful." None of the teachers in the project worked in isolation or silos. The collaboration created a solid support network and foundation for these core teachers to learn about the maker approach and tools and to successfully plan and create rich learning opportunities for their students. Unfortunately, attempts made by the research team to provide a professional learning network via TeachOntario were not as successful. The majority of the participants found the addition of another online space to be too onerous and time-consuming. They reported that their time was better spent learning the new tools and working within their school teams.

iv.) Quality leadership. Support from the administration, the technology lead teachers and other teachers who came forward in leadership roles had a positive impact on how successful the schools were in the makerspace set-up, adopting the maker pedagogies and developing the skills of other educators:

For me, I know that now that a lot of teachers see my role and see the makerspace, I know that I'll probably have a lot more demand next year. I think the teachers will have a lot more needs. They see the potential and see what we can do with this stuff so I think it's going to be a busy year next year.

One other area of leadership that stood out in terms of having a significant impact on the project's success was how involved the principals were and in what capacity. Being at the UOIT training session was one significant factor:

> 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 deep understanding—I would have been following their lead instead of trying to lead with them.

These principals ended up well-versed in the pedagogy and tools and returned to their schools with their teachers, sharing the same vision. Additionally, there were principals who helped redefine and distribute leadership roles:

> In my role as principal, I've been actually taking a shared leadership role. I've been allowing my staff who are very good at seeing the vision of our school, how we can incorporate this into our school improvement plan, and making use of the funds that have been so generously afforded to us through this project to say how does this fit what we're doing, where do we want to see our students go with this? And then together as a team we've been working to see what is a

> good fit for the needs of our school and the planning process of just sitting and allowing them to lead.

This approach proved successful in creating a collaborative, agentive and functioning innovation team.

v.) Flexibility/creativity. Finally, teachers found that being afforded flexibility and creativity in their planning and lessons was necessary when adopting a maker pedagogical approach in their classrooms:

> Some students [who] have kind of connected what we're learning with makerspace culture as well. I think we're creating a culture in the class where they know that I value what they want to do - what they want to make and the connections that they have to different themes and topics that we're studying in the class. It's really neat that they have the freedom and the time and the support from me to make connections.

The freedom the teachers felt in their planning had a trickle-down affect on the students and their work. For a true maker culture to be developed, flexibility and creativity needed to be fostered and encouraged at every level.

3) What are some best practices associated with a maker pedagogy approach?

i.) Inquiry-based learning. When making a shift to a maker pedagogy approach, a number of items emerged, in terms of best practice, for the successful and effective adoption of this approach and its implementation in the classroom. First, teachers found they needed time to play with the maker tools — to know what they are and generally how they work. While it's not necessary to be an expert in the technology before using it in the classroom, having some sort of base idea of what the tool is and how to begin using it emerged as a positive factor when it came to best practice. One school shared the way in which they used an inquiry approach to start learning the tools themselves, "...we literally took a half day and unpacked the goodies, and we just got in there to see what they do. The first instinct as teachers is to teach ourselves first, but we weren't going to do that. We just got in there and figured it out, we would have to google things and maybe that person's an expert that person knows what to do." Other schools took a slightly different approach as is reflected in the following anecdote: "Some teachers [didn't] understand it, so we let the three teachers try it out first and they kept coming back and they started to share and see the excitement from the students." These teachers jumped in and began exploring the tools alongside their students. Those teachers who were less comfortable doing this were then able to see how effective and engaging that strategy can be, which ultimately led to adoption, the development of new skills and competencies and “scaling up” at the school level.

In terms of inquiry in the classroom, many of the teachers in the project realized that inquiry really does mean taking a step back from that traditional ‘teacher’ role and becoming a facilitator:

> Sometimes it gets to the point where I'm not teaching, and I hate this word but facilitating, but that is what it kind of is. The kids start to kind of be more self motivating and become self directed and that took a while, a number of months before we had the necessary rapport and they were comfortable with the materials and what they were doing.

From this anecdote and others, it became obvious that there was a period of transition for many of the teachers and their students to the more inquiry-based approach. It took time to accept and settle into the new dynamic in the classroom — the teachers were no longer the holders of knowledge and answers. The students also needed to develop the skills aligned with self-learning: “[Problem-solving] is a skill that they get from using tech a lot, they learn how to problem solve while using it — like try something else and if there's an issue they come up with I often can't solve it either and they end up figuring it out, it's a different mindset using it in the classroom.”

ii.) Passion-based and personalized learning. In adopting the maker approach to learning, many of the schools have also adopted a passion-based learning approach. This is an approach similar to Genius Hour where students choose a topic they would like to explore, research the topic in-depth and usually create something in response to the question driving their inquiry. Of his shift to a passion-based approach, one teacher explained:

> I’m trying to move toward forward teaching...We’ve started doing passion projects this year...Passion to me is that you’re excited about something and then you’re going to do something with it...I have a student right now -- we have a bunch of bikes in our basement...what he wants to do is rebuild [a bike] and then have a raffle at school so that a needy student at our school can take it home. And he’s a needy student himself, so it was quite a leap for him to come up with that completely on his own. It’s something that interests him -- he likes working with his hands...they’re getting into some really interesting things.

Although the teachers found time and curriculum constraints challenging, they also found creating a space for this type of passion-based learning, which draws on a student's internal locus of control, highly motivating and engaging for the students in their learning process.

iv.) Pedagogical documentation: Reflecting, sharing, connecting. Pedagogical documentation has played a large role in shifting control of the learning into the hands of the learners and also helping them develop the meta-cognitive skills associated with learning to learn. Reflection has been a major component in the making process at all of the schools. The use of "Maker Journals" or other written/oral reflections, where students record their challenges, successes and final products, have been instrumental in making the learning process visible to both the students and teachers.

Sharing. The students also constantly shared their work with others — they put their making "out there" and reached an audience greater than just the teacher. This occurred through MakerFaires, parent nights and when the students shared their work with the class, other classes and in some cases the whole school. Peer-to-peer knowledge sharing was also prevalent alongside intergenerational learning (older students teaching younger students and vice-versa; students teaching teachers and vice-versa):

> The kids, they love teaching. I've noticed so many positive things with my kids in that role. They're supportive of each other, they'll say 'that was a really good thing that you did!' and you don't usually see that if they're at your desk writing right, but they see them making these things, they're able to voice what they're doing, they have increased stamina and persistence, it's amazing.

Their work was also shared with the community on social media such as Facebook, Instagram, Twitter, YouTube.

Connections. Subject integration became common place with the introduction of the maker pedagogy approach. One teacher explained:

> It fits in nicely. I know for our one project we fit in science, math, and art, so it was really easy to tie a bunch of things together. They really enjoyed it because it's part of forces and structures in science and usually they made bridges so it's really repetitive, so it's good they could learn about structures and durability and forces in a different way, and it fits nicely into the curriculum and we touched on everything they had to learn in one project. They have a second project on a natural disaster and they can easily transfer all their knowledge into that project too.

The making activities usually hit many strands of the curriculum at once, so subject integration became a seamless process for many of the teachers involved.

4) Benefits: What impact, if any, does a maker pedagogy approach have on student achievement and well-being?

i.) Engagement and motivation. Overall, every school reported a significant increase in student engagement and motivation. To illustrate the levels of engagement, one school shared:

When we work in the learning space, there are no discipline problems to worry about; the kids are almost all engaged. There is a lot of higher level thinking and problem solving that is required so we do have some students who would struggle with that. The collaboration helps, but I would say almost every student is engaged at their highest level possible, almost everyone is loving it.

Figure 5. Students engaged in an Ozobot exploration session at St. Ambrose's MakerFaire

Another school echoed this in sharing:

[There is] a lot of student engagement. We were talking about this yesterday that when we go down there and we do centers and have the whiteboards and different activities the kids can do, we never have any problems because they're so engaged. They're more willing to help each other and maybe this one is good

> at coding and this one is having trouble. They have different skills and they don't come to me, they go to each other because they know I'm at the same level they are. I like that, it's more about what can this person give to this child and it's not always the same children so in the classroom it might be this person's really good at math, this person's really good at reading. Everybody goes to each other for those talents and I love that. Some of the kids who don't normally shine get to shine.

Students' strengths and knowledge are recognized and leveraged in the maker framework, which has proven to encourage investment in the learning process and ultimately, as a result, engagement.

ii.) Academic Achievement. Many schools also reported an increase in academic achievement — especially for students who may have previously had difficulties in the traditional classroom due to various exceptionalities. One teacher explained:

> In a grade 8 room working with S, she was showing me how a student with a learning disability was able to show his peers how to use complex VR software and apps and had developed his own VR and this is a child who can give a really good presentation and dive into complex themes in a book, and if that child just used paper and pencil, 2 things. 1, we may not get that level of thinking out of that child, and 2, he wouldn't be in a position where he is the expert in front of his peers and so all of a sudden there are multiple themes showing the impact it has.

Similarly, in special education settings in general:

> That whole perseverance piece is showing up with the makerspace and with kids that you don't maybe expect, like some of my Special Ed kids are just eating this up. They love it and they're having success. They're proud of themselves, and we had a little tower competition in our classroom, and some of the Special Ed kids were the most successful, using their logic to figure things out and they succeeded which was great to see.

In this way, the maker approach has provided the space for a more personalized and inclusive learning experience for all students.

In addition to providing an opportunity for many different types of students to achieve, another teacher explained that the sense of achievement that comes from the process of creating has influenced students' dedication to learning in general:

> I certainly think there's a direct link to the achievement in making things and academic achievement. The different qualities that they're achieving in making things is something you have to value. For example, we were doing inquiries about our footprints on the world, and we were making some social studies connections to that with biodiversity, and one of our groups did a presentation on what happens to plastic and other materials--after it leaves us, where does it go? So after a few makerspace activities they took water bottles, plastic grocery bags, and they made all these beautiful pieces of art with them, and it was really cool that they took it upon themselves. It wasn't part of the project that they had to make anything, they did a PowerPoint presentation with some information, but they also created all the really cool things to go along with it.

The students have moved beyond working for the sake of marks and have instead elevated the learning process to something more personal and connected to the real-world.

iv.) Improvements in Behaviour. The maker tools have also had a positive impact on behaviour — not only because the students are engaged in their learning, but because the tools have provided the students with a multitude of options for communication. One teacher provided this anecdote to illustrate the communication affordances of students learning to code:

> Ever since we started doing Scratch and Scratch Jr., [a student] had an incident with another teacher where he didn't use kind words, so he, as his own idea, grabbed the scratch junior iPad and made an apology letter. So it was like 'I'm sorry for yelling at you', and not only did he just have that, he had it interchanging seasons and this animated whole thing and showed it to her. Someone with low engagement, struggles with reading, fine motor skills etc., he made this on his own and was so excited about it.

In providing the students with more ways to communicate — beyond the verbal or with pen and paper — many have begun to flourish.

5) Benefits: How might educators use makerspace pedagogies to promote 21st Century skills such as inquiry, imagination, innovation and design thinking, critical thinking, problem solving and collaboration?

A variety of 21st Century skills and competencies were developed as a result of the makerspaces (the pedagogies and technologies). Across the board, problem-solving collaboration and the development of perseverance were consistently cited as major outcomes of involvement in the project. Teachers shared things like: “It's really cool to teach them to be thinkers and problem-solvers, instead of having them ask how we want them to solve it.” With regards collaboration, many teachers shared observations such as this one: “The collaboration in the classroom when the kids have to work together to solve a problem, that whole piece too with that learning skill is coming up very evident in the things they do. Collaboration is something I wasn't expecting to come out of the makerspace” and “…we’ve seen a lot of great collaboration among students.” With regards perseverance, another teacher shared:

> That’s what I noticed most, in the beginning they were nervous if things would work, so they wanted me to help them all the time, but once they got the hang of just trying it, figuring it out, knowing that I'm not going to fix the problem for them, then they would persevere. Then they would work the whole time. We set it up kind of like a genius hour, once a week that's what we would do, and they would all decide what they wanted to do and they would go get their materials and get started.

Perseverance was a skill with which many students were not as familiar at the beginning of the project:

> ...they want something that's produced immediately that's gonna be great, and when it doesn't it's harder on them, and so we have to work through that and that's persevering also. I read them the book Rosie Revere Engineer and we talk about the first try all the time. No reason to be upset, just try something different and carry on. Maybe it won't work in the end and that's ok, just try something different, something new and that's ok. Like I said with some of my students who aren't as strong academically, this is their chance to shine. I have a couple of students who have a little bit of difficulty with academics, and they're putting those little bits together and figuring it out, and it's amazing and they're so proud of themselves. It's really good for that whole motivational aspect of school. So that carries over to the academics when we talk about how we persevere with the makerspace and we need to do that in language and math also.

The students’ work in the makerspaces and the shift in mindset that is required, created an environment where the students could begin to develop important skills such as perseverance.

Project Impact

The project had wide-reaching impact. The impact included:

(1) enhanced understanding of how maker pedagogies may be integrated into school contexts;

(2) enhanced understanding of the materialities and modalities afforded to learners through digital design and production;

(3) development and communication of best practices for the use of maker pedagogies in educational contexts, including how these will inform teacher preparation programs;

(4) development and communication of models for school-home and school-community connections where students engage in digital making for wider audiences, i.e. Maker Faires and exhibitions;

(5) contribution to the development of Ministry of Education and school district policy at a time when digital making is in its infancy in education;

(6) development of the research capacity of graduate students in this field, to encourage future research as digital making pedagogies and technologies continue to evolve; and,

(7) increased student capacity in STEAM education, which may lead to increased future participation in the digital and knowledge economies.

Project Outcomes

The benefits of the research include: 1) enhanced understanding of how critical making may be integrated into school contexts; 2) enhanced understanding of the materialities and modalities afforded to learners through digital design and production; 3) development and communication of best practices for the use of critical making in educational contexts, including how these will inform teacher preparation programs; 4) development and communication of models for school-home and school-community connections where students engage in digital making for wider audiences, i.e. Maker Faires and exhibitions; 5) contribution to the development of Ministry of Education and school district policy at a time when digital making is in its infancy in education; 6) development of the research capacity of graduate students in this field, to encourage future research as digital making pedagogies and technologies continue to evolve; and, 7) increased student capacity in STEAM education, which may lead to increased future participation in the digital and knowledge economies.

The project also had a variety of different outcomes ranging from participant reach to dissemination to the creation of resources. These include:

- Teachers involved 33+
- Students reached (potentially) 3529
- Best practices disseminated
  (1) STAO, November 2016
  (2) YCDSB admin, November 2016
  (3) HEIT keynote, November 2016
  (4) NERA, March 2017
  (5) CONNECT
  (6) OPC/ etc. Webinars, Feb 2017 & April 2017
  (7) CSSE, May 2017
  (8) OPC Summer Institute, August 2017
  (9) Ottawa Digital Literacies Conference Keynote, July 2017
  (10) ICDE World Conference, Toronto, October 2017

UOIT B.Ed. Maker Day, October 2017

Development of teacher professional resource guide (110 lesson plans in French & English) and curated online at: http://janettehughes.ca/lab/science-3d-discovery-design-development-through-makerspaces-2/lesson-plans/

- Production of project documentary to disseminate widely
- Development of open source website resource: http://janettehughes.ca/lab
- Increased capacity in STEAM education, in the STEAM 3D Maker Lab (TCs, grad students, MITACS student)
- Creation of a UOIT Mobile Maker Lab (15 school visits to date plus several upcoming bookings)

News articles (St Joe’s, UOIT, Metroland) http://janettehughes.ca/lab/lab-news-2/press/

In Sum

Although it can be a challenge to find a suitable and dedicated space to house a school makerspace and to properly outfit that space with the most current tools and technologies, the benefits of a makerspace are certainly worth the effort and cost, especially when issues of sustainability are foregrounded so that students can participate in recycling and upcycling programs. A designated place, whether that is a room in the school learning commons or library, or whether that is a centre or station in the classroom that changes its focus regularly, students benefit from playing, tinkering, discovering, designing and developing through Makerspaces.

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