Reimagining the Mathematics Curriculum Through a Cross-Curricular and Maker Education Lens

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ABSTRACT

Despite the positive impact of maker education on student learning, challenges towards its implementation in formal school settings still exist. There is limited research on maker education in teacher education programs and a lack of knowledge on how to integrate it into the mathematics classroom. To address these issues, the following research questions were examined: What is the nature of the productive design features of maker education for teacher candidates? What are the benefits and challenges of these opportunities for teacher candidates learning to teach mathematics? The methods used were a case study interlinked with design-based research. A total of 114 teacher candidates participated in the study. The research findings have implications for educators who design/implement maker education curricula into STEM courses. For educators and researchers, the maker education opportunities from this study contribute to further re-imagining learning competencies, pedagogy, and resources in teaching mathematics and other STEM disciplines.

KEYWORDS


INTRODUCTION

In the past 10 years, makerspaces have gained significant traction in K-12 schools (Sator & Bullock, 2017; Stager, 2014), and teaching through makerspaces is seen as an avenue to achieve the goals of re-imagined pedagogy in mathematics education (Bullock & Sator, 2018; Halverson &
Sheridan, 2014; Kafai et al., 2014). In the traditional classroom, young children’s problem-solving experiences have been limited to problems that follow a specific procedure (taught in class) or a defined path (English & Watters, 2004). Children are rarely provided with opportunities to interpret a problem, or to find the solution to ill-defined problems by identifying, visualizing, modelling, and evaluating possible solutions (English & Watters, 2004). English and Watters (2004) explained that “mathematical modelling takes children beyond basic problem solving where meaning must be made from symbolically described word problems, to authentic situations that need to be interpreted and described in mathematical ways” (p. 336). The adoption of makerspace learning and teaching within formal education “is the deliberate positioning of student learning in contexts that require the drawing together of skills and knowledge from the areas of science, technology, engineering, and mathematics (STEM) to create, construct, [model, solve a problem] and critique a product or artefact” (Blackley et al., 2017, p. 23).

**Maker Education in Schools**

Halverson and Sheridan (2014) argued that the theoretical roots of the maker movement are in education reformists’ ideologies such as Papert’s constructionism (Cohen et al., 2017; Corbat & Quinn, 2018; Papert & Harel, 1991), Piaget’s constructivism (Corbat & Quinn, 2018), Dewey’s notions of learning by doing (Bullock & Sator, 2018; Stevenson et al., 2019), and Vygotsky’s theories of development (Cantelon, 2018; Martin, 2015). Whereas it is agreed that the maker movement became more prevalent over the last decade (Corbat & Quinn, 2018; Sator & Bullock, 2017; Stager, 2014), it also widely agreed on that “the culture of the maker movement embraces creativity, tinkering, hacking, repurposing, collaboration, and fun” (Cantelon, 2018, p. 1).

The engagement of “making” in formal school settings is known as “maker education”, or the use of “makerspaces” (Hughes et al., 2016). Maker education engages students in learning through making and producing, often in designated spaces or communities, in schools or out, on specific days, or during specific events. Through maker education, students and their teachers, regardless of their age or experience, learn multidisciplinary ways of knowing and approaching problems (Cohen et al., 2017; Halverson & Sheridan, 2014; Martin, 2015; Peppler & Bender, 2013; Sheridan et al., 2014; Somerville, 2016). In schools, maker education aims to enhance competencies that allow learners to cope with “contemporary technical and infrastructural developments” (Papavlasopoulou et al., 2017, p. 57) and learn processes and approaches to solving problems using simulations, experiments, and the creation of objects (Cohen et al., 2017; Halverson & Sheridan, 2014; Peppler & Bender, 2013). During maker education activities students and teachers practise thinking, designing, creating, experimenting, and building with materials (Anderson, 2012; Freeman et al., 2017; Halverson & Sheridan, 2014). Further, when engaged in making in classrooms, students learn to utilize materials and construct tangible products (Freeman et al., 2017; Hughes & Morrison, 2018) with sensibilities such as those of prototyping, open sourcing, upcycling, digitizing, documenting, sharing work, and using materials critically to meet individual and community needs (Corbat & Quinn, 2018; Halverson & Sheridan, 2014).

Traditionally, the implementation of makerspaces within schools has been limited to school disciplines that involve hands-on materials, and many of these subjects have been increasingly separated from an academic focus. Researchers have identified a need to consider incorporating maker experiences and pedagogies in K-12 classrooms (Blikstein & Krannich, 2013; Hughes et al., 2017). Cohen et al. (2017) maintained that makerspaces connect components of informal maker culture to “purposeful instructional design” (p. 227).

Makerspace research, through its study of the integration of engineering, design, technology, and creativity (Bullock & Sator, 2018; Hughes et al., 2019), promises to address the inequitable representation of mathematics in STEM (English, 2016), and the shortage of STEM research that focuses on enhancing mathematics competencies and pedagogies. In re-imagined mathematics education, efforts have focused on, and taken the form of, learning competencies (Anghileri, 2006),
pedagogy (Herrera & Owens, 2001), curriculum (Atweh & Goos, 2011), resources (Remillard & Jackson, 2006), and assessment reform practices (Suurtamm et al., 2010).

Maker Education in Teacher Training

Despite the widely acknowledged positive impact of maker education on students’ learning, challenges towards its implementation in formal school settings still exist. One significant challenge is the limited amount of research on maker education in teacher education programs (Cohen et al., 2017; Sator & Bullock, 2017). To support best practices and shift the culture in instructional practices for teachers early in their careers, there is a need to incorporate maker education within teacher education programs. Løkken and Moser (2012) stated that many educators are not familiar with the role of makerspaces in curriculum-based teaching. Moreover, Doorman et al. (2019) highlighted that “more expertise is needed for designing … [makerspaces] for students that are both motivated and contribute to learning mathematics” (p. 151). Sarason (1996), Somerville (2016), and Bullock and Sator (2018) discussed how teachers and educators need to explore *making* in training and workshops before they can teach the concepts and approaches themselves; teachers are unlikely to enact practices that they have not yet experienced or are unfamiliar with. Without a clear integration of specific pedagogies that prepare and support educators in successfully implementing *making* in classrooms (Bullock & Sator, 2018), maker education will remain technocentric (i.e., centred on technology), sporadic rather than mainstream, and only evident in select courses (e.g., art, music, engineering education, design studies, and health science). Corbat and Quinn (2018) saw that the diffusion of maker knowledge in teacher education courses will meet a broader goal of “refining the enterprise of teaching future teachers in and through makerspace” (p. 2). Cohen et al. (2017), maintained that if practices of maker education are properly leveraged, they “hold promise for transforming formal education in a variety of contexts” (p. 217).

The purpose of this study was to investigate the nature and impact of preparing teacher candidates to use makerspace tools, activities, and approaches to teaching mathematics. The study aimed to explore the nature of the learning opportunities, benefits, and challenges of implementing maker education experiences with sustainable “productive design features” (Darling-Hammond et al., 2007, p. 5) within mathematics methods courses in teacher education programs in a university in southwestern Ontario. Darling-Hammond et al. (2007) found that many “pre- and in-service programs share many common features . . . [which they called] productive design features” (p. 5). For example, Darling-Hammond et al. (2007) found that all the preservice programs had the following elements/productive design features: a “comprehensive and coherent curriculum aligned with state and professional standards . . . [and] active, student-centered instruction that integrates theory and practice and stimulates reflection” (p. 6). Similarly, the authors of this study wanted to explore the productive design features of the maker education workshops in teacher education programs. To better understand this phenomenon and the aim of the study, the authors asked the following research questions: What was the nature of the productive design features of maker education for teacher candidates? What were the benefits and challenges of these opportunities from the perspective of teacher candidates learning to teach mathematics?

Theoretical Frameworks for Maker Pedagogy

Sarason (1996) argued that teachers are unlikely to enact practices that they have not yet experienced or are unfamiliar with, which is echoed by Bullock and Sator’s (2018) research. In this study, the researchers introduce maker education to teacher candidates through different makerspace tools, activities, and approaches to teaching mathematics. The researchers use the principles of Maker Pedagogy (Bullock & Sator, 2015, 2018) as a theoretical framework and critical lens to examine the learning opportunities of maker education and the impacts of these opportunities from the perspective of teacher candidates in a faculty of education. Bullock and Sator’s (2018) principles of Maker Pedagogy include:
1. Maker education “can offer novel opportunities for problem-solving in multi-disciplinary ways” (p. 59).

2. Making “can emphasize process over product, particularly given that the processes of making require learners to encounter, and work through, mistakes and problems” (p. 59).

3. Maker education activities can promote “collaboration among groups of learners from a variety of disciplinary backgrounds; these collaborations feature a commitment to the sharing of knowledge, a spirit of inclusiveness, and openness of learning” (p. 59).

METHODOLOGY

Context in a Canadian Faculty of Education

The maker education research was carried out within the Faculty of Education at a large Canadian university in Southwestern Ontario. The teacher education program at the time of the study was a two-year program that consisted of 27 weeks of pedagogical learning, 20 weeks of experience as a student-teacher under the supervision of a certified teacher, 7 weeks of alternative field experience, and a total of 28 days of professional development events (Bertrand et al., 2022). A research team, consisting of one researcher and several graduate and undergraduate students, offered professional development opportunities in the form of sessions and workshops to teacher candidates with the goal of sharing knowledge to create communities of practice.

In the Faculty of Education, maker education opportunities are currently taught in integrated contexts within existing courses and workshops (Bertrand et al., 2022). In Ontario, and various other provinces in Canada, coding has recently become a part of the mathematics curricula. This was not the case at the beginning of this study. Other components that are central to maker education, such as designing and modelling, are not currently in any of the curriculum documents in the province where this study took place.

Design–Based Research and Case Study

The methods used were a “case study . . . interlinked with Design-Based Research (DBR)” (Bertrand et al., 2022, p. 5). A case study is an “approach to research that facilitates exploration of a phenomenon within its context using a variety of data sources . . . [and] lenses which allow for multiple facets of the phenomenon to be revealed and understood” (Baxter & Jack, 2008, p. 544). DBR, like the case study method, is conducted in a natural setting. The researchers define “design-based research as a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in the real-world setting” (Wang & Hannafin, 2005, p. 6). The researchers adopted the following features of DBR (Bertrand et al., 2022): (a) co-designing the model features (of selecting tools, designing tasks, and teaching approaches) of maker education workshops for teacher candidates; (b) analysing classroom data in collaboration with teacher candidates (Hoyles & Noss, 2015) participating as Students as Partners (SaPs) (Cook-Sather et al., 2014); and (c) over time, refining of the model in the iteration cycle (diSessa & Cobb, 2004). Coupling the case study method with DBR was necessary to implement and redesign the curriculum. In contrast to case studies, however, DBR uses a cycle of designing, trying out, better understanding, and refining a solution in a setting where it will be implemented (Cobb et al., 2003). Earlier iterations (from 2016 to 2020) of the designed activities had been planned and taught to teacher candidates in their methods courses, in elementary schools, and through the engagement of the participants.

Digital Tools and Curriculum Design

The researchers adapted tools that are easily accessible and versatile to use in faculties of education and school settings. They designed learning tasks that use maker education materials (e.g., of
programming and crafting). The researchers facilitated participants’ engagement (e.g., when modifying or creating simulations) and teaching practices (e.g., introducing the tools and guiding exploration). They identified how the tools, tasks, engagement modes, and practices adopted were (a) affected by the overall environment of the classroom (i.e., necessary and sufficient conditions), and (b) sufficient for implementing successful maker education experiences (Brown, 1992) in the faculty of education.

As reported by Bertrand et al. (2022), the workshops focused on investigating a variety of maker education tools (i.e., plugged and unplugged coding tools), maker education methods (i.e., creating digital simulations of concepts or objects), and exploring maker education instructional approaches (i.e., why is this important and how to teach it). To support learning in the maker education workshops, the researchers provided teacher candidates with direct instruction, discussion, reflection prompts, and opportunities to share their feedback with the researchers. All teacher candidates who participated in the maker education workshops were invited to participate and share their reflections with the researchers via survey questions.

Research Sites and Participants

The research sites were: i) a mathematics methods course as part of the teacher education program, and ii) professional development opportunities developed and implemented within the local community (e.g., local libraries and maker labs). The researchers recruited two sets of participants: (a) teacher candidates who participated in a maker education workshop “during their regular class time in a formal learning environment” (Bertrand et al., 2022, p. 5), and (b) teacher candidates and SaPs, who contributed to creating, developing, and implementing (i.e., collecting and analyzing the data) maker education workshops in the Faculty of Education and the local community. In addition, SaPs collaborated with instructors, library staff, and personnel at community maker labs to support maker education learning sessions. In this paper, the authors refer to the role of SaPs in the curriculum development and research component of the study, but they do not include specific data in the form of quotes from the SaPs. Besides the survey, the researchers took field notes and pictures of teacher candidates’ work and the making process. For privacy issues, such as recording those who did not consent to participate in the study, the researchers chose not to record the maker education workshops. The researchers also conducted a focus group with the SaPs which was audio recorded but the results were not reported in this paper.

In addition to participating in the maker education workshops, the SaPs and the researchers co-designed digital and non-digital content and lesson plans in the form of modules for use in the workshops, as well as K-12 teaching resources, to share with other educators. The SaPs were engaged in “a reciprocal process to enhance [their] teaching and learning; curricula and pedagogy; and to engage in research” (Coombe et al., 2018, p. 85).

A total of 114 teacher candidates participated in the survey. This number excludes teacher candidates who participated in the workshops but did not consent to participate in the study. In the first two years, all workshops were developed for in-person maker education activities. During the third and fourth years, all workshops were online (synchronous and asynchronous) due to the Covid 19 pandemic. The online sessions were not audio recorded because the teacher candidates did not consent to participate in the study until after they attended the synchronous session. The researchers labelled the participants by their sequential number based on when the surveys were completed and the year the data was collected (see Table 1). For example, participant number one in year 1 is represented by P001. Fewer teacher candidates consented to participate during the third and fourth years of the study (see Table 1). This might have been because the workshops were conducted during the pandemic, which directly impacted teacher candidates’ participation in the study when they were dealing with external stress, grief, and/or mental health issues.

Data Collection

The researchers observed, interacted with, and asked teacher candidates survey questions to seek responses on the nature and impacts of maker education on learning to teach mathematics. As reported...
by Bertrand et al. (2022), the “survey included 20 questions with reflection prompts soliciting feedback and comments on learning, knowledge, efficacy, attitude, perspectives, and surprises experienced during the session” (p. 6). The survey questions were organized under the following categories: maker education experiences; “learning(s)—content, concepts and processes”; “planned maker education experiences”; “maker tools of preference”; “pedagogy applicable to maker education activities and sessions”; “perceived usefulness of integrating maker education activities”; and a final category requesting “feedback on any other aspects” (Bertrand et al., 2022, p. 6). Three of the questions required rank order, and one was multiple-choice. The rest were short answer questions to elicit detailed responses. When designing tasks, SaPs and researchers implemented a design-as-implementation model. For example, this model provided an opportunity for SaPs to observe how the first-year teacher candidates in a classroom setting were engaging with mathematics curricula in the context of maker education. The SaPs reflected and contributed feedback based on the teacher candidates’ experiences, observations, and reflections. Further, feedback from teacher candidates was used to inform further revisions and later iterations of the research activities, such as the suggestions for extended workshop sessions, more activities, and more explicit connections to the provincial mathematics curriculum.

**Data Analysis**

The researchers collected and analyzed data in five stages (see Figure 1).

- **Raw Data**: The researchers identified some overarching themes based on the keywords in the survey questions, such as the benefits and challenges of maker education.
- **Organizing and Preparing Data**: The teacher candidates’ answers to the survey questions were organized in an Excel spreadsheet based on the survey questions, participant number,
course section, and year of the study. Similarly, photos of the teacher candidates’ work and the curriculum documents were organized based on the digital tool (e.g., Makey Makey, Micro:bit, Sphero, Cubetto, and Osmo).

- **Colour Coding the Data:** For the thematic analysis, “colour codes were initially used for each question to assign codes and then the data were read and reread as they were hand-coded to identify themes across questions” (Bertrand et al., 2022, p. 6). Then the rank-ordering questions were analysed using descriptive statistics, and the open-response questions were analysed using thematic analysis. New themes emerged from the pre-existing themes and were interpreted through the literature and theoretical framework.

- **Triangulating the Data:** Overarching themes such as cross-curricular connections were used to triangulate the data and make connections between the different data sources such as the survey responses, curriculum documents, and the Ontario mathematics curriculum (OME, 2020). During this phase, the quotes from the teacher candidates were reanalyzed simultaneously with the curriculum documents and the photos of the teacher candidates’ work.

- **Relating and Interpreting Themes:** The data analysis focused on the learning outcomes related to teaching practices, identities, self-efficacy, pedagogies, and interactions during the activities. The themes were determined when the researchers started to notice keywords that were repeated throughout the responses, such as *learning by doing, interactive, hands-on, and experimenting*. These words were used to develop the theme of hands-on experiences. In “interpreting the meaning of the themes, researchers and SaPs further reframed the research questions in relation to the data, literature review, and theoretical frameworks” (Bertrand et al., 2022, p. 6).

**RESULTS**

In this section, the researchers report the findings from the descriptive statistics, preferred instructional practices, and maker education tools of the teacher candidates. The researchers include examples of the mathematics curriculum content embedded into the maker education workshops and modules (e.g., screenshots of the slides). The researchers also report the benefits and challenges of the maker education activities shared with us from the teacher candidates’ responses to the survey questions.

**Demographics of Study Participants**

On the survey, which followed the guest lecture, 62 out of 114 teacher candidates indicated that the guest lectures provided by the researchers were their first maker education experience. Specifically, 54% of the teacher candidates stated that they had no prior experience and 36% indicated that they had some exposure to makerspaces or maker activities during their teacher training. Participants with prior maker education experiences stated that they had previously used tools such as particular block-based coding software (e.g., Scratch), learning robots (e.g., Sphero), and microcontrollers (e.g., Micro:bit). On the other hand, only two participants noted that they had a deeper understanding and knowledge of coding, with one teacher candidate highlighting that they were a “program coordinator and summer student at [a] STEAM [science, technology, engineering, arts, and mathematics] centre” (P082, year 2) and another identifying that they “went to elementary schools teaching coding” (P066, year 2).

**Productive Design Features of the Workshops**

Researchers and SaPs designed maker Education workshops with specific design features. These features included digital tools (e.g., physical manipulatives, virtual manipulatives, and dynamic mathematics software) and instructional practices (e.g., hands-on, inquiry-based, and project-based learning). According to Darling-Hammond et al. (2007), these productive design features “had strong enabling influences on what the programs could accomplish” (p. 6). The participants identified the design features of the maker education workshop in terms of ranking the most useful features, instructional practices, and makerspace materials/tools. Teacher candidates said they saw maker
education as useful for learning (83%), teaching (79%), knowing (76%), professional practice (74%), and academic studies (70%). On the list of instructional practices, teacher candidates ranked inquiry-based learning first, exploration centres second, and experimentation third as the most applicable; these were followed by project-based learning ranked fourth, design thinking fifth, use of problem solving sixth, and physical materials seventh as the most applicable to maker education. Discussions/brainstorming eighth, outdoor fieldwork ninth, and laboratories tenth were ranked as the least applicable instructional practices to maker education activities. Teacher candidates also ranked their interest in the makerspace materials and tools used as shown in Table 2. In the survey, the researchers asked, “Please rank, by a check mark, the Ed lab tools below in terms of your interest to use them for knowing, learning, teaching, academic and professional work” (Teacher Candidate Survey). Thus, the tools of most interest from the perspective of teacher candidates were programmable tangibles and hands-on manipulatives and craft materials, followed by the other four categories—digital tangibles, learning apps, 3D printing, and studio recording (see Table 2). Another participant went as far as saying they wanted “another course like this [workshop]” (P008, year 1). Eighteen participants identified specific activities they would like to learn about in future maker education sessions, such as 3D printing or cutting, a micro-controller—Makey Makey, robots—Sphero, Cubetto, and robotics in general. On the other hand, 5 out of 114 participants stated that they would not be interested in further maker education activities or sessions, with no additional comments.

**Mathematics Curriculum Content**

Although the researchers did not directly ask the teacher candidates about the teaching and learning of mathematics, they, however, asked questions that highlight the connection between teachers’ education, maker education activities, and the Ontario mathematics curriculum. For example, the researchers asked, “What maker Ed activities do you see applicable in your own learning (for knowing, teaching, learning, professional work, academic studies)?” (Teacher Candidate Survey). In the first and second years of the study, teacher candidates explored digital tools and maker education activities in centres. Some teacher candidates asked: “How can it be used in and out of the classroom?” (P040, year 1); “How do you connect the Micro:bit to math?” (P056, year 2); and How can “the connection to learning math . . . be made more clear [?]” (P019, year 1). Based on the feedback from these participants, the researchers modified the maker education workshop in the third and fourth years of the study to include more explicit connections to the new Provincial Mathematics Curriculum (OME, 2020) as seen in Figures 2-6. During the Micro:bit module, the teacher candidates had the opportunity to connect their knowledge gained from the maker education workshop to computational thinking (i.e., coding) and mathematics concepts and processes. For example, the teacher candidates had the opportunity to make specific connections to the new Mathematics Curriculum (OME, 2020) during the asynchronous sessions (i.e., they worked on this task independently by following the learning module

| Table 2. Maker education tools of interest to teacher candidates listed in ranking order |
|-----------------------------------------------|----------------|----------------|
| **Maker Ed Tools**                             | **Ranked**     | **Participants**|
| Programmable tangibles, e.g., robots           | Most and moderately interested | 92% |
| Hands-on manipulatives and craft materials e.g., conductible materials | Most and moderately interested | 92% |
| Digital tangibles, e.g., conductible, hybrid or upcycle materials | Most and moderately interested | 82% |
| Learning apps, e.g., math and coding apps      | Most and moderately interested | 78% |
| 3D Printing                                   | Most and moderately interested | 77% |
| Studio recording of videos, animations, etc.   | Most and moderately interested | 75% |
slides) on the Micro:bit (see Figure 2). The teacher candidates learned about loops and conditional statements (see Figure 3) and then modelled this mathematically by writing the code using the forever loop on the http://makecode.com website (see Figure 4). The teacher candidates explored simulations and learned through the hands-on maker education activity. They wrote the code for the animation, downloaded the code, and tested it out on Micro:bit (Figures 4 and 5). One participant noted that “this is a great exercise for students who don’t necessarily enjoy math or lack confidence . . . because their
mistakes are displayed in the code, which allows them to identify what needs to be improved" (P106, year 3/4). The teacher candidates learned the importance of coding and how to “introduce kids to coding and math from a different perspective” (P053, year 2) through hands-on activities. The purpose of the modifications was to provide the teacher candidates with deeper and more meaningful mathematical content. For example, the teacher candidates learned about abstract concepts such as loops, conditional if-then statements, and variables, and applied that knowledge when they designed and created a virtual die (Figure 4) and thermometer (Figure 5). During the asynchronous modules, the teacher candidates solved mathematical problems using physical and programmable tangibles.

Figure 4. The teacher candidates engaged in activities that applied the knowledge of loops and conditional statements when making a virtual die

**WRITING THE CODE FOR A VIRTUAL DICE**

9. Here is the entire completed program!

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<td><img src="image1" alt="Virtual Dice Code" /></td>
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Figure 5. The teacher candidates created more complex code when they made a digital thermometer

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<tr>
<td><img src="image2" alt="Thermometer Code" /></td>
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(concrete materials such as Lego and Micro:bit), modelling (graphs were used to represent the data), and coding and computational thinking (abstract concepts were represented with Javascript coding blocks), as outlined in Figure 6. These mathematics curriculum connections mentioned above, were reinforced during the synchronous online session.

Benefits and Challenges of Maker Education

Besides the connections to the mathematics curriculum, the teacher candidates also identified the benefits of maker education and thinking in terms of the learning experience (hands-on, comfort with the technology, and efficacy) and type of skills attained (transferable and cross-curricular). The teacher candidates also reflected upon the challenges of implementing and integrating maker education into the curriculum in terms of the time, resources, and access limitations as well as difficulties with the technology and tools.

Benefits

The researchers asked, “What do you see as the benefits of maker Ed activities?” (Teacher Candidate Survey). The teacher candidates mentioned the hands-on experiences, transferable skills (communication, collaboration, problem solving, and coding/technology skills), and cross-curricular connections among academic and non-academic disciplines that were embedded in these maker education activities.

- **Hands-On Experiences:** Overall, 30 of 114 teacher candidates saw hands-on experiences as the most beneficial aspect of teaching mathematics in the context of maker education. During these maker education activities, “teacher candidates can learn first-hand how fun and interesting learning by ‘doing’ can be, and how creativity can be a part of math and science class” (P109, year 3/4). The participants expressed that these maker education activities “make math fun and interactive” (P024, year 1) and “can make math more hands-on for students” (P018, year 1). One participant stated that hands-on learning opportunities can create “higher engagement in
Another said that they “thoroughly enjoyed the opportunity to learn about math through hands-on experience. It made math fun!” (P095, year 2). Similarly, one teacher candidate stated that the “hands-on approach to coding was engaging and enjoyable” (P109, year 3/4). Another stated that “incorporating hands-on practices to teaching subjects are bringing feelings of excitement and real-world connections to topics and lessons” (P025, year 1). Other teacher candidates specified that they favoured coding tools and justified the reasons for their selection in the following statements: hands-on way to learn, able to experiment and discover with it, fun to watch, hands-on activity, coding by moving the blocks, and find out what each coding piece did (see Table 3).

- **Transferable Skills:** One participant stated that the Micro:bit was “approachable/transferable” (P080, year 2). Others explained that these maker activities “could foster skills such as problem solving, critical thinking, resilience” (P102, year 3/4) as well as “encourage creativity, perseverance, extending, exploring, [and] inquiry” (P105, year 3/4). The teacher candidates seemed to see the potential to transfer their learning beyond the confines of the maker education workshop through the application of coding and technology, problem solving and collaboration skills, in another context.

- **Coding and Technology:** One participant explained that “getting students comfortable with technology and coding . . . is important for future careers” (P009, year 1). These makerspace activities “motivate kids to explore and develop a better understanding of technical skills” (P030, year 1) and provide opportunities for “students . . . [to find] a passion to use technology and coding that they want to continue outside of school” (P032, year 1). In addition, “coding can be used in many subjects” (P099, year 3/4). One participant noted that “so many jobs now rely on computer science and coding technology and knowledge, I believe this [is a] fun and engaging way to introduce coding [that] will only benefit students” (P110, year 3/4).

- **Problem-Solving:** The teacher candidates seemed to associate the problem-solving aspect of making with perseverance (struggle) and troubleshooting (figuring things out, trial and error). One participant mentioned that “allowing students to struggle and figure things out on their own can be beneficial” (P010, year 1). Another stated that “these [activities] are great for student problem solving and [learning] through trial/error” (P051, year 2).

- **Community and Collaboration:** Participants noted that maker education “can allow students to collaborate and make discoveries together” (P074, year 2) and through these collaborative practices provide them with “a sense of team or community” (P102, year 3/4). Similarly, another noted that the maker education workshop was “fun and [that] it was great to collaborate with others. It helped with confidence and social relationships” (P004, year 1).

- **Cross-Curricular Connections:** Some participants noted the cross-curricular connections between coding tools and subject areas. For example, one participant’s observation of a

<table>
<thead>
<tr>
<th>Coding Tool</th>
<th>Example Quote</th>
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<tbody>
<tr>
<td>Makey Makey</td>
<td>“Makey Makey because it allowed a fun and <strong>hands-on way to learn</strong> how to use it, while providing a variety of ways to enjoy for all” (P077, year 2).</td>
</tr>
<tr>
<td>Micro:bit</td>
<td>“Micro:bit [was] accessible and fun. … I enjoyed being able to <strong>experiment and discover</strong>” (P074, year 2).</td>
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<tr>
<td>Sphero</td>
<td>“Sphero [was] the most <strong>hands-on and fun to watch!</strong>” (P056, year 2).</td>
</tr>
<tr>
<td>Cubetto</td>
<td>“Cubetto … [was the] most <strong>hands-on activity</strong> I explored. [I was] able to problem solve to find out what each coding piece did…” (P064, year 2).</td>
</tr>
<tr>
<td>Osmo</td>
<td>“Osmo. It was cool to see <strong>coding by moving the blocks ourselves</strong>” (P070, year 2).</td>
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specific activity that used “Makey Makey to make interactive poster(s) … [noticed that it] could [be] incorporate[d] [into] many subject areas” (P042, year 1). Other participants noted that “Micro:bit was the] most approachable/transferable” (P080, year 2) and that the “Micro:bit was cross-curricular” (P084, year 2). Another teacher candidate said that “it was great to have cross-subject learning (e.g., music, patterns, shapes, etc.)” (P004, year 1). Teacher candidates highlighted an appreciation of the multidisciplinary approaches of maker education activities, with one participant stating that they were “surprised about how many ways this translated into the classroom/real life” (P036, year 1). Another participant noted that they “can see the cross-curricular connections, which will make for more interesting learning” (P056, year 2). Similarly, a teacher candidate described the learning experience as “engaging, inspiring, student-driven, cross-curricular, [and] hands-on” (P042, year 1). Another said, “this is knowledge that can be applied to cross-curricular material, which is very exciting as a new teacher in training” (P097, year 3/4).

• **Comfort and Efficacy:** The teacher candidates expressed feelings of nervousness, intimidation, confidence, and excitement: “I was very nervous at the beginning because I had very little experience with coding” (P097, year 3/4); “I was very intimidated at first but was pleasantly surprised how achievable it was!” (P107, year 3/4); “I felt an increase in confidence after completing the activities” (P102, year 3/4); “[I was] excited to discover these [tools] and explore on my own” (P001, year 1); “I was so excited to take part in the coding Maker Ed activity. . . I believe that my students will get the same joy and confidence from this activity” (P108, year 3/4); “I enjoyed the activities . . . because I am not comfortable with math [but] this made me more excited in the future [to teach math]” (P061, year 2); and the “activities brought a sense of excitement by connecting math to a fun activity” (P025, year 1). One participant expressed “I absolutely loved this experience and as a future teacher, I felt that it gave me more confidence in teaching math, especially in an online setting” (P106, year 3/4). Another participant explained, “I was worried about learning this because I don’t like math at all, but this was a very cool and insightful experience that I would love to use in a classroom” (P036, year 1). This increase in confidence appears to be associated with their overall comfort level and efficacy with the coding and maker education tools (Bertrand et al., 2022). The maker education workshops provided teacher candidates with “efficacy after knowing how to do it” (P009, year 1).

• **Other Benefits:** One participant expressed “I love how interactive and creative the programs were. They were exciting and engaging and I think students would love them” (P006, year 1). Another explained “I am really liking the student-led inquiry process that Maker Ed uses. It puts the student in control of their learning by using various assessment tools and reflections” (P111, year 3/4).

**Challenges**

The researchers asked, “What do you see as the challenges of maker Ed activities?” (Teacher Candidate Survey). Participants identified a variety of challenges associated with the maker education activities, including a lack of opportunities, lack of time, cost and access limitations in schools, technical difficulties, possible accessibility barriers for students, and barriers for teachers. Other participants expressed feelings of frustration when the technology or maker education tool did not work. Participants offered suggestions for improving the design of the maker education workshops including extended sessions, more activities, and more explicit connections to the Ontario curriculum.

• **Lack of Opportunities:** The data indicate that prior to attending workshops at the Faculty of Education, most teacher candidates had few experiences with maker education (see Descriptive Statistics).
Lack of Time: Fifteen participants noted that time was limited to try all of the activities at the maker education workshop. Other participants pondered “How do we as educators gain more practice and resources to use maker education activities with our students?” (P078, year 2). Although 37 participants indicated an interest in learning more about maker education in future workshops, some teacher candidates (e.g., nine participants) said that they would be interested in more opportunities, but they were not aware of what was available. Additionally, nine teacher candidates stated that time constraints could be challenging in the classroom. One teacher candidate wondered “how to put all activities and [a] sufficient [amount] of time for [the activities], in a small amount of time” (P027, year 1). Another said that it might be “time-consuming [in terms of] planning” (P065, year 2).

Resource Cost and Access Limitations: When asked about their perceptions of the challenges of maker education, 22 out of 114 teacher candidates identified cost and access limitations. Participants asked, “Can schools afford the technology?” (P020, year 1), and “How do I acquire these resources?” (P078, year 2). Another teacher candidate noted that a challenge might be that there is “not enough to give students their own piece of technology and that the most learning happens from doing rather than observing, which is what happens when students work in groups” (P057, year 2). Another teacher candidate expressed “I can see it may be difficult to obtain all desired materials for Maker Ed activities (such as more expensive technology)” (P102, year 3/4).

Technical Difficulties: Nineteen participants identified technical difficulties as a challenge for the maker education activities. Participants noted that “when things don’t work as you wanted it can be frustrating and at times defeating” (P006, year 1), while others noted that you could “break/lose material” (P031, year 1) and “that sometimes technology can be hard to rely on” (P017, year 1).

Despite the challenges identified after the maker education workshop, 41 participants indicated that they plan to engage in these types of maker activities in some capacity (e.g., in class, during their practicum, and through professional development). One teacher candidate explained: they “plan on developing a cross-curricular coding lesson/activity between math and language arts” where students “use code to tell a story” (P109, year 3/4). Forty-five participants stated that they would be interested in further opportunities to learn more about and engage with maker education tools (e.g., more in-depth maker education sessions, having more time to explore and tinker with the robots, and more curricular connections). One participant stated that they were “very interested in learning more in any way possible” (P064, year 2). Another expressed their interest in “workshops that guide you through the uses of the activities … in-depth” (P068, year 2). Similarly, another participant suggested: “maybe more detailed ones on how to use it in a classroom” (P024, year 1) and another, “how to integrate into the classroom” (P091, year 2). For example, some participants were interested in learning about “math art, making artwork with code” (P063, year 2) and “music-based tools!” (P076, year 2). Similarly, another participant would be interested in “more cross-curricular content, i.e., how could we apply these activities in a language arts setting, music, [and] social studies?” (P105, year 3/4). Two participants were interested in maker education sessions that “would contribute to [their] competencies as a future French teacher” (P102, year 3/4) or access to maker activities that were translated into French (P111, year 3/4). Another candidate “would also love to see how these activities are adapted and complexified for [older kids or] high school students” (P112, year 3/4).

DISCUSSION

The maker education experiences and pedagogical practices of teacher candidates in this study potentially lead them to ask questions that may disrupt their core beliefs about teaching. They experienced the central components of maker education such as hands-on learning, transferrable skills, community and collaboration, and cross-curricular connections while critically reflecting on the use of maker activities in teaching.
Hughes et al. (2019) saw promise in integrating makerspaces and maker pedagogies into classroom practices, whereby students learn through hands-on experiences and *making*, thus reinforcing the benefit for teacher candidates to learn, explore, and get familiar with these techniques. Teacher candidates ranked inquiry-based learning, exploration centres, and experimentation as the top three ways to approach maker education, which corresponds to the literature and other findings from the data. A teacher candidate described maker education as a “student-led inquiry process [that] ... puts the student in control of their learning” (P111, year 3/4). Other teacher candidates explained that maker education is a “hands-on way to learn” (P077, year 2), which encourages students to “experiment and discover” (P074, year 2) and promotes “higher engagement in math for students” (P020, year 1). The teacher candidates also identified programmable tangibles (e.g., Sphero robot) and hands-on manipulatives (e.g., Makey Makey) as the most interesting and engaging maker education tools. For example, one participant said, “Sphero [was] the most hands-on and fun to watch!” (P056, year 2), and another explained that the “Makey Makey . . . allowed a fun and hands-on way to learn” (P077, year 2). They also described the maker education activities as *interactive, creative, fun, exciting,* and *engaging* as they learned through *problem solving* and *trial and error*. This echoes Bullock and Sator’s (2018) statement that maker education “can offer novel opportunities for problem solving in multidisciplinary ways” (p. 59). Another participant expressed: “This is a great exercise for students . . . because their mistakes are [displayed in] . . . the code, which allows them to [problem solve on the spot and] identify what needs to be improved” (P106, year 3/4). This is in line with Bullock and Sator’s (2018) findings that *making* “can emphasize process over product, . . . and [provide students with the opportunity to] work through mistakes and problems” (p. 59).

In this study, participants spoke about how the workshop engaged them in transferable skills such as *problem-solving, coding,* and *making* with digital technology, and community and *collaboration*. This pedagogical approach of *making* reflects learners’ lived experiences and enables them to learn transferable skills (Hughes et al., 2016, 2017, 2019). The teacher candidates valued these skills that students can learn from utilising coding and technology in maker education activities, and then use this knowledge outside of school. For example, the maker education activities can be “important for future careers” (P009, year 1), help students develop a “passion to use technology and coding . . . outside of school” (P032, year 1), and increase their “confidence and social relationships” (P004, year 1). The teacher candidates saw the connection between the maker education activities and their future teaching practices in the classroom. They were “surprised about how many ways this translated into the classroom/real life” (P036, year 1). This is in line with Somerville’s (2016) finding that maker education bridges the gap between classroom knowledge and real problem-solving.

Teacher candidates learned both individually and in a collaborative environment when they worked in groups. Similarly, Bullock and Sator (2018) found that maker education activities can promote “collaboration among groups of learners from a variety of different backgrounds” (p. 59). In makerspaces, learners are able to rely on individual and collective knowledge to create, design (Bullock & Sator, 2015), and make conclusions, while constructing a new understanding and appreciation of the learning process (Ratto, 2011). In this study, many opportunities were provided for teacher candidates to make cross-curricular connections. This is in line with Bullock and Sator’s (2015) findings on ways in which maker experiences provide opportunities to break down traditional barriers to computing and create connections between school subjects. For example, teacher candidates described the maker experience as “cross-subject learning (e.g., music, patterns, shapes, etc.)” (P004, year 1) that can develop these “*cross-curricular connections*” (P056, year 2). Other scholars explain that makerspaces surpass disciplinary boundaries to enable processes, practices, and learning opportunities to experience, create, and innovate (Sheridan et al., 2014; Somerville, 2016).

In addition to the cross-curricular connections, most teacher candidates observed how these experiences highlighted the importance of deep mathematics learning. During the maker education workshops, the teacher candidates had the opportunities to use physical materials, programmable tangibles, modelling, and coding to learn mathematical concepts as seen in Figures 4-6. These
workshops appeared to encourage teacher candidates to go “beyond basic problem solving . . . to authentic situations that need to be interpreted and described in mathematical ways” (English & Watters, 2004, p. 336), using terms like variables, loops, and conditional statements. By re-imagining mathematics education, students can learn by modelling, experimenting, designing, creating, and building with materials (Anderson, 2012; Cohen et al., 2017; Freeman et al., 2017; Halverson & Sheridan, 2014; Peppler & Bender, 2013). For example, the teacher candidates learned mathematics concepts when creating an animation (loops and patterns), virtual dice (variables, conditional if-then statement, probability when selecting a random number from 1 to 6), and a thermometer (variables, conditional if-then statements, and inequalities when the temperature is >25 or £ 0), as seen in Figures 4 and 5 respectively.

The maker education opportunities which the authors researched in this study took place within the institutional constraints of resources, space, and time. These findings corroborate those by Somerville (2016) who described educators’ ongoing concerns about the lack of time and space for the implementation of maker pedagogy related activities and practices. In their study on engaging teacher candidates in the makerspace, Corbat and Quinn (2018) described their participants’ concerns about funding and issues related to access limitations. Further, Cohen et al. (2017) argued that the lack of funding is a barrier to the maker movement and makerspaces in teacher education. In this study, some teacher candidates felt frustrated when the technology did not work. Bullock and Sator (2015) asserted that “specialized technical knowledge” (p. 19) is needed to participate in the maker movement, otherwise the process can be intimidating for those who lack this knowledge. The research team members, including the principal investigator and SaPs, collaborated during the curriculum design process. The SaPs used the responses from the participants on the benefits/challenges to analyse and reflect on the teacher candidates’ feedback and revised the maker education workshops and modules. The process of curriculum design can be described as iterative: the cycle repeats continuously, design-revise-share, then reflect-revise and repeat again.

LIMITATION

The findings need to be interpreted in light of the study’s limitations. A major limitation is that the opportunities researched were limited for the first set of teacher candidates, who participated during their regular class time in a formal learning environment with no out-of-class maker education opportunities. To model best practices for makerspaces in classrooms, the researchers additionally provided teacher candidates with extended tinkering time to explore materials and reduce any frustration that would have occurred (Corbat & Quinn, 2018). The researchers did this at a makerspace gallery walk, by providing materials (e.g., individual kits and class sets) through the library which teacher candidates could take on loan, and through creating other participation opportunities in the broader maker community, including in their practicum in schools. This out-of-class, hands-on session workshop (i.e., gallery walk) focussed on further play, exploration, and tinkering experiences. It was attended by a range of 35 (first year of the study) to 160 (second year of the study) to about 100 (third year of study the numbers were not recorded) to 104 (fourth year of the study) teacher candidates, and depending on the year of the study featured six or seven different booths (or modules in the third and fourth year of online-only learning) of activities. During the online sessions, the researchers focused on one maker education tool (i.e., Micro:bit) rather than many to accommodate different levels, abilities, and comfortability with coding. All teacher candidates were exposed to many different maker education activities and tools during the makerspace gallery walk (second, third, and fourth year) and their mathematics method course (first and second year). With wider integration of maker education at different school levels and in more post-secondary courses, over time this limitation and the need for more opportunities will be reduced.
IMPLICATIONS AND FUTURE RESEARCH

The research findings have implications for educators and researchers who integrate maker education in their teaching practices and design curricula in STEM education. The findings on maker pedagogy emphasize the benefits for teacher candidates engaging in maker education; they are broad and extend from knowledge of curriculum to teaching practices, social-emotional responses, and self-efficacy. Cohen et al. (2017) argued that if maker education approaches are effectively harnessed, they offer the potential to reform formal education. To achieve these benefits, however, materials, spaces, forums, and teams are needed to support instructors in learning about, adopting, and implementing maker pedagogies. Also, there could be a correlation between interest in using maker materials and teaching methods, and which pedagogies are perceived as most applicable.

The barriers that teacher candidates identified in terms of knowledge, resources, support, and perceived barriers in classrooms require further research. To address these challenges, universities and colleges may consider partnerships with local makerspaces or businesses and apply for STEM grants. This would allow them to secure funding which can be invested in training and professional development opportunities and resources/tools. Considering the importance of and need for preparing teacher candidates to integrate maker education into the curriculum, universities should allow more time within their schedules to learn about makerspaces in the context of mathematics and STEM education. As a result, future teachers would be prepared to create maker spaces and teach maker education at their schools. Further investigations are needed to study data in settings where more opportunities to learn about maker education activities and pedagogies exist. As well, further analysis (e.g., quantitative and mix-method studies), follow-up interviews, and revised survey questions will help clarify the findings of this study in subsequent years.

CONCLUSION

The authors have reported findings from this study on teaching maker pedagogy to teacher candidates through in-course workshops and out-of-course design workshops for SaPs. The goal was to better understand the designing of opportunities for and the benefits and obstacles of doing so within the context of mathematical methods courses from the perspective of teacher candidates. The findings from this paper demonstrate the importance of teacher candidates’ (a) collaboration with the researchers towards implementing the workshop’s “productive design features” (Darling-Hammond et al., 2007, p. 5) and “purposeful instructional design” (Cohen et al., 2017, p. 227); (b) exploration of maker education pedagogy as a hands-on, immersive approach that involves learning experiences with the tools, tasks, and personal engagement; and (c) reflection on maker education teaching practices. It is essential for them to engage in this learning experience and the processes associated with it in the same way that their future students would experience it. The researchers offered teacher candidates an opportunity to engage with maker education activities that helped them make relevant connections among teaching mathematics and using hands-on experiences, engaging learners in transferable skills, utilizing coding and technology, learning through trial/error and problem solving, seeing cross-curricular connections, collaborating, and making discoveries. This in turn reinforced for the teacher candidates the benefits and challenges of skill development, and the technology available to design productive maker education opportunities as teachers in their own practice. The research in this study contributes to the discourse that is needed to support the goal of teacher candidates learning and implementing pedagogies such as maker education, and, as Somerville (2016) put it, modelling curricular programming, professional education, and collaboration as a way to connect innovative pedagogies to the broader understandings of teaching.

Doorman et al. (2019) stated that “more expertise is needed for designing … [makerspaces] for students that are both motivating and contribute to learning mathematics” (p. 151). To address this issue, the researchers used participants’ feedback and SaPs’ contributions in order to enhance the design
of the makerspace sessions and fortify the learning experience by including more time for teacher candidates to tinker with and explore the new technology, as well as providing more opportunities to make connections to the Provincial Mathematics Curriculum (OME, 2020). During the sessions, teacher candidates reflected upon student motivation and their own efficacy in teaching with maker tools and technology. They observed that teaching mathematics in maker education has the potential to motivate students to learn through fun, interactive, and engaging activities. Recognizing the benefits of maker pedagogies, Halverson and Sheridan (2014) and Hughes et al. (2017, 2019) maintained that scholars are required to define best practices and describe ways to use making for learning and teaching purposes. In this study, making involved creating opportunities for teacher candidates to gain experiences of learning to make, extending this learning, and exploring learning to teach maker education in a variety of contexts. For mathematics teaching and learning, maker education opportunities contribute to further re-imagining learning competencies, pedagogy, and resources to use when teaching mathematics in ways that promise to engage more learners.

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