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EARLY CHILDHOOD EDUCATION STUDENT-TEACHERS EXPERIENCING VIRTUAL MATH MAKERSPACES: ORGANIZING PLAYFUL LEARNING ENVIRONMENTS

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Abstract

This study investigates the integration of makerspaces in early childhood education. It emphasizes the impact of play-based learning on children's cognitive development and attitudes towards learning. Quality early childhood learning encourages positive attitudes toward learning and school, fostering strength, confidence, and resilience. The study focuses on implementing makerspaces, defined as environments for creative exploration and cognitive engagement through play. Participants in a Bachelor of Early Childhood Education (BECE) program engaged in a virtual, mathematics-focused makerspace. This study aimed to understand participants' perceptions of makerspaces as effective learning environments for early learners. Participants were tasked with taking part in *making* activities like coding, beading, origami, and 3D construction, which connected mathematical concepts to real-world applications. Results indicated that makerspaces support the development of technological, pedagogical, and content knowledge (TPACK). Participants also found these environments promoted digital literacy, confidence, creativity, critical thinking, and fine motor skill development. The study further highlighted the role of makerspaces in building learning communities involving children, parents, and teachers, and the significance of incorporating technology in early childhood education.

Keywords: Math makerspace, early childhood education, TPACK.

INTRODUCTION

Ontario's Renewed Early Years and Childcare Policy Framework (2017) explains that early learning experiences have a long-lasting impact on a "child's language, literacy, and mathematics skills" (p. 9). The framework further states that quality early childhood learning experiences encourage children's positive attitudes towards learning and school and may also impact children throughout life by promoting the positive development of strength, confidence, and resiliency in the individual child (Alexander & Ignjatovic, 2012; Grieve 2012; Reynolds, Temple, & Ou et al., 2011). Furthermore, GGI Insights (2024) shares that current research indicates innovative approaches to teaching in early childhood education emphasizes learning through exploration, discovery, and play. Makerspaces are learning environments that are useful design structures for organizing these exploratory and innovative teaching and learning experiences. The nature of these quality learning experiences involves play-based, open-ended explorations that engage children in complex thinking, which occurs through play in which

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children are "making connections and testing theories as they interact with their world. Nurturing this innate curiosity through high-quality relationships and experiences is key to their health and well-being" (Ontario's Renewed Early Years and Childcare Policy Framework, 2017, p. 10). Thus, preparing teachers of early learners to design and implement playful, creative learning spaces in which children participate as contributors, creators, innovators, and makers becomes an essential and necessary part of the educational system for early learners.

Makerspaces and Early Childhood Learning

Calderon (2018) explains that "children are natural makers, and Early Childhood teachers and caregivers have been providing opportunities to create, engineer and fabricate since before [the learning environment] was officially labeled as a "makerspace" (para. 2). Early childhood classrooms often contain learning centers where children can engage in open play or role-playing, building and making, or just exploration. These foundational experiences of open-ended explorations by the child promote meaningful learning – the child initiates the inquiry and explores to an extent. Daniels (2016) suggests that, in these learning centers, play is the leading activity, and Marsh et al. (2019) further add that play is useful as a learning event that can "foreground children's needs, motives, and interest, as well as their participation in diverse social and cultural practices" (p. 222).

Similarly, makerspaces are also learning environments where the young learner can utilize play for engaging cognitive processes in creative work, specifically including problem-solving, metacognition and creative practice (Wood, 2013). These cognitive processes are especially supported when children are incorporating a blend of tinkering, making, and engineering explorations in which they are "transform[ing] everyday tools, symbols, and meanings through individual and collective activity" (Marsh et al., 2019, p. 223). The term, *making*, is used to broadly encompass all types of activities that engage the learner in the acts of building using a variety of tools and materials (Click2Science, 2022). These *making* activities may include specific tinkering explorations where the process is more valued over the product, and where "tinkering refers to the kind of open-ended, hands-on, focused exploration of a variety of different materials that often leads to new ideas and discoveries" (Good2Know Network, 2021, para. 3). *Making* activities may also specifically target the learning of engineering-related activities, with the purpose of the exploration to "put their learning to work in solving a meaningful problem" (Click2Science, 2022, para. 10). In other words, makerspaces are especially useful as learning environments that encourage the development of budding mathematicians, engineers, and scientists. Calderon (2018) even further states that "when we allow young children to have these creative, open-ended makerspace experiences, we are enabling them to develop foundational skills for future careers in hardware or software architecting and development, engineering, coding, and so many other tech fields" (para. 19).

Makerspaces and Technological, Pedagogical and Content Knowledge (TPACK)

Technological, pedagogical and content knowledge (or TPACK) is the essential educator knowledge required to design and implement learning activities that integrate technology into education effectively (Mishra & Kohler, 2006). This knowledge is developed through a series of learning experiences, such as makerspaces, that provide teachers with the skills to design and teach using technologies (Figg & Jaipal, 2009, 2012; Harris, et al., 2009; Neiss, 2005). TPACK is pivotal in equipping Early Childhood Education students (ECEs), the university students specializing in early learning for ages 3-8 (PreK – Grade 3), to seamlessly incorporate technology within their own instructional approach.

Learning how to design makerspaces, and the various innovative *making* activities that match the curricular-based theme of the makerspace, supports the development of TPACK in teachers (Figg, Khirwadkar & Welbourn, 2020). Free exploration of makerspace activities as part of learning about makerspaces, and the design of the making activities, provides ECEs with opportunities to engage in pedagogical discussions about the design process while making connections to the curriculum. These experiences promote the skills educators need to be able to design and implement environments for early learners that include problem-solving, thinking critically, taking risks, and recognizing different cultural values and diversity, thus promoting real-world and daily life applications of the abstract conceptual understandings of mathematics (Friederichs, 2016; Kafai & Proctor, 2022; Komanski & Black, 2016; Shively, 2017).

Makerspaces with a focus on math concepts provide a flexible learning space where early learners can connect math to the real world. Free-play exploration could include activities such as 3D construction, origami, beading, and coding (such as Code Your Family, Unplugged Coding, and Scratch Coding activities). All of these activities promote learning and understanding of mathematical concepts (Figg, Khirwadkar & Welbourn, 2020). Makerspaces enhance TPACK by preparing educators to meet evolving digital spaces in teaching and learning.

Makerspaces, Social Emotional Learning (SEL) Skills, and Communities of Learning

According to the Ontario Mathematics Curriculum 2020, social emotional learning (SEL) skills contribute to the overall development of a child, including their academic performance and progress. SEL skills support children's learning of mathematics by developing resilience, growth mindset, and perseverance in continuing working with a task (MOE, 2020). Halverson and Sheridan (2014) demonstrated that the creative autonomy of makerspace tasks provided stress relief and supported students in managing academic pressures, as hands-on, immersive activities allowed them to focus and cope effectively.

As well, the creative autonomy inherent in *making* provides the individual with the independence to engage in collaboration and exploration with others during the *making* process. Litts (2015) further explains that "makerspaces are places where *making* happens in community" (p. 1). Thus, *making* in an online environment within virtual makerspaces could contribute to the development of a learning community of students, parents/caregivers, and teachers, further promoting successful learning experiences (Loertscher, 2015).

The Study – Purpose and Significance

There is a need for ECEs to experience makerspaces and gain pedagogical knowledge about the design and implementation of this valuable informal learning space for early childhood learners. To address this need, *making* experiences were introduced into the math course for the ECEs in the Bachelor of Early Childhood Education (BECE) program at our university. As part of this math course, ECEs participated in a virtual, mathematics-focused structured makerspace while also serving as participants in this study, to investigate the perceptions they developed about the usefulness of makerspaces as a learning environment for early learners. With their help, we sought to answer these guiding questions about makerspaces and early childhood learning:

- In what ways do makerspace activities provide effective pedagogical practices for teaching with technology (TPACK)?
- How do makerspaces help to create positive learning experiences for early learners?
- In what ways can makerspaces support building learning communities consisting of children, parents/caregivers, and teachers?
- How do makerspaces empower children to be autonomous learners?

METHOD

The asynchronous, online nature of the BECE program courses made it necessary to organize math makerspace experiences virtually. Being the first virtual makerspace experience for early childhood teachers, the math makerspace developed skills and knowledge that can be transferred to their early childhood learning environments while collaborating with parents and caregivers. These makerspace experiences are rooted in the social constructivism of experiential learning, such as described by Dewey (1938), Piaget (1963), and Vygotsky (1981) while drawing from the TPACK framework for enhancing ECEs' beliefs about how to teach with technology (Donnelly et al., 2011; Ertmer et al., 2014). Recognizing the significance of this theoretical framework, we designed a qualitative study that honored the voice and perceptions of the participants and ensured that participants' perspectives were considered

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central components of the study (Lincoln & Guba, 1985). Themes emerged from a constant comparative textual analysis (Creswell & Creswell, 2018).

Participants

Participants are in the final semester of the BECE program, which is an online Honours degree that follows the completion of a two-year Early Childhood Education Diploma program, or equivalent. Many of the students in this program are currently working in early childhood environments, such as preschools, play centres, and daycare facilities.

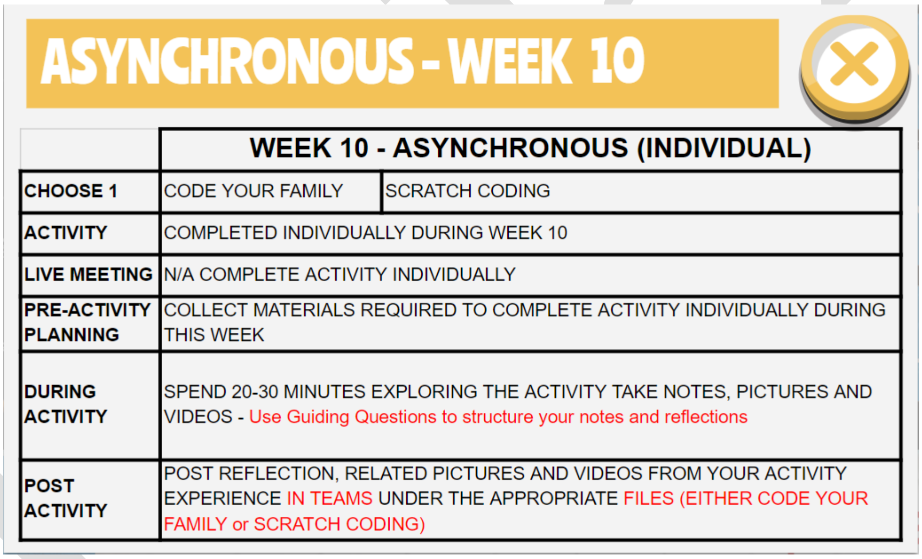
A purposive sampling technique, where the recruitment criteria drew study participants from university students enrolled in the Winter 2022-2023 BECE mathematics course, was used for recruiting the participants. There were 34 students who participated in this study.

Procedure

For the virtual makerspace experience, the procedure was replicated from the initial physical math makerspace experiences, which were studied previously (Khirwadkar & Figg, 2019). The virtual makerspaces took place in weeks 10 and 11 of the BECE mathematics course.

Week 10 Procedure

In Week 10, participants worked individually and asynchronously (see activities at http://bit.ly/BECE2223 or see Figure 1 for the slide presented to the participants of the checklist steps required for completing the makerspace activities for Week 10).


ASYNCHRONOUS - WEEK 10

	WEEK 10 - ASYNCHRONOUS (INDIVIDUAL)	
CHOOSE 1	CODE YOUR FAMILY	SCRATCH CODING
ACTIVITY	COMPLETED INDIVIDUALLY DURING WEEK 10	
LIVE MEETING	N/A COMPLETE ACTIVITY INDIVIDUALLY	
PRE-ACTIVITY PLANNING	COLLECT MATERIALS REQUIRED TO COMPLETE ACTIVITY INDIVIDUALLY DURING THIS WEEK	
DURING ACTIVITY	SPEND 20-30 MINUTES EXPLORING THE ACTIVITY TAKE NOTES, PICTURES AND VIDEOS - Use Guiding Questions to structure your notes and reflections	
POST ACTIVITY	POST REFLECTION, RELATED PICTURES AND VIDEOS FROM YOUR ACTIVITY EXPERIENCE IN TEAMS UNDER THE APPROPRIATE FILES (EITHER CODE YOUR FAMILY or SCRATCH CODING)	

Figure 1. Week 10 makerspace activities checklist.

In week 10 ECEs worked individually and asynchronously by choosing one of the coding activities: (a) *Code Your Family*, or (b) *Scratch Coding*. For the *Code Your Family* coding activity, ECEs engaged in unplugged coding where they selected topics like moving their family members from one place to another place, going for a walk around the block, or going to the shopping mall, while considering sequencing, selection, and loop. They tried out the code and debugged their programs where necessary. They took pictures, made curriculum connections, and wrote reflective notes to share with their makerspace group about the process and any curriculum connections they made through their making. They also reflected on the guiding questions during their explorations with virtual makerspaces (See Figure 2).

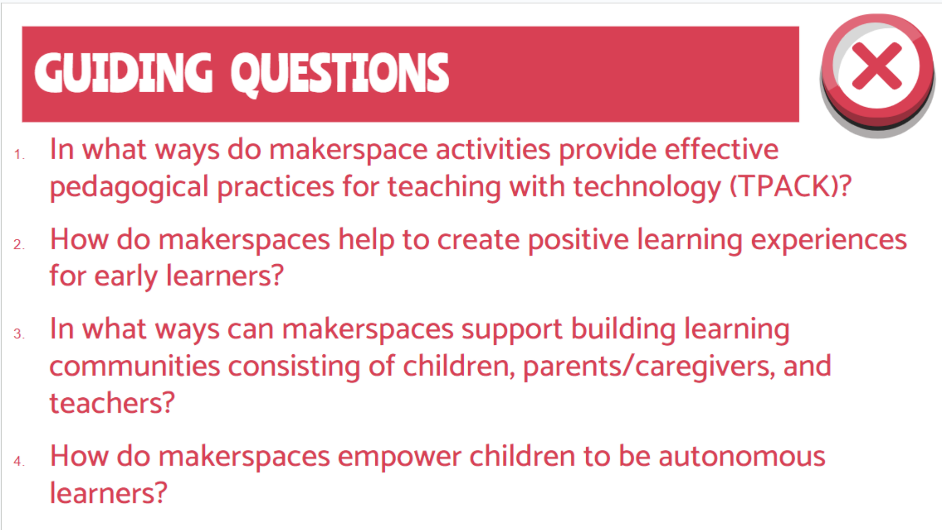
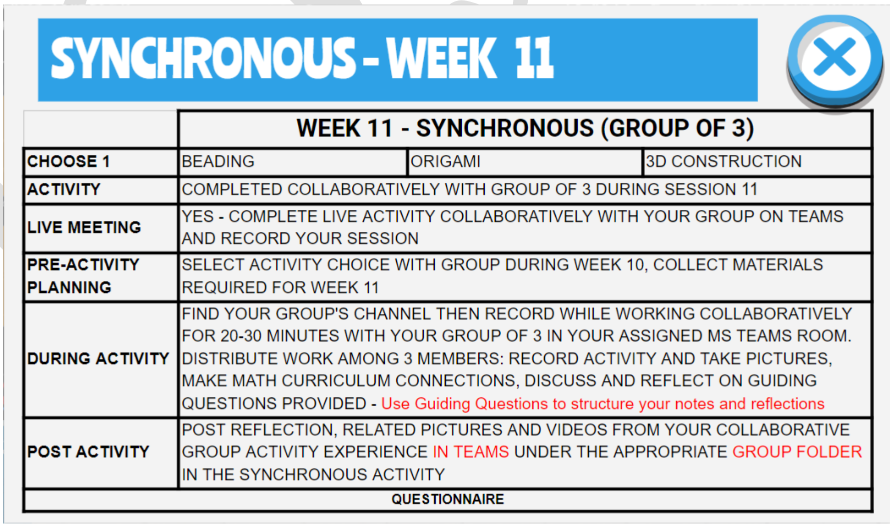


Figure 2. The guiding questions from the mathematics virtual makerspace.

These questions helped ECEs to reflect on their experiences in the asynchronous learning environment, as well as reflect upon what they had learned about engaging children with technology, thereby connecting their learning activities to coding.

Week 11 Procedure

In Week 11, ECEs worked in groups of three members and met synchronously using the MS Teams videoconferencing platform. They chose one of the station activities (Beading, Origami, and 3D Construction), gathered the materials needed for the activities, and met synchronously with their group members. They video-recorded their synchronous-making session and discussed pedagogical and curriculum connections about how they might use makerspaces in their professional practice. The ECEs reflected on their synchronous-making experiences using the guiding questions. See Figure 3 for the list of makerspace activities completed in Week 11.



SYNCHRONOUS - WEEK 11

	WEEK 11 - SYNCHRONOUS (GROUP OF 3)		
CHOOSE 1	BEADING	ORIGAMI	3D CONSTRUCTION
ACTIVITY	COMPLETED COLLABORATIVELY WITH GROUP OF 3 DURING SESSION 11		
LIVE MEETING	YES - COMPLETE LIVE ACTIVITY COLLABORATIVELY WITH YOUR GROUP ON TEAMS AND RECORD YOUR SESSION		
PRE-ACTIVITY PLANNING	SELECT ACTIVITY CHOICE WITH GROUP DURING WEEK 10, COLLECT MATERIALS REQUIRED FOR WEEK 11		
DURING ACTIVITY	FIND YOUR GROUP'S CHANNEL THEN RECORD WHILE WORKING COLLABORATIVELY FOR 20-30 MINUTES WITH YOUR GROUP OF 3 IN YOUR ASSIGNED MS TEAMS ROOM. DISTRIBUTE WORK AMONG 3 MEMBERS: RECORD ACTIVITY AND TAKE PICTURES, MAKE MATH CURRICULUM CONNECTIONS, DISCUSS AND REFLECT ON GUIDING QUESTIONS PROVIDED - Use Guiding Questions to structure your notes and reflections		
POST ACTIVITY	POST REFLECTION, RELATED PICTURES AND VIDEOS FROM YOUR COLLABORATIVE GROUP ACTIVITY EXPERIENCE IN TEAMS UNDER THE APPROPRIATE GROUP FOLDER IN THE SYNCHRONOUS ACTIVITY		
QUESTIONNAIRE			

Figure 3. Week 11 makerspace activities checklist.

After Week 11 Procedure

At the end of the Week 11 exploration, individual participants completed a final 'exit' ticket questionnaire which asked for specific examples related to the research questions.

Data Collection and Analysis

Textual qualitative data was collected from a variety of sources, including recorded conversations, reflections based on guiding questions from the ECEs working on their maker activities, and brief interviews. Participants also provided images, pictures, videos, and visual data documenting the creation of artifacts or participation in the making. Additionally, participants completed an exit questionnaire consisting of 13 questions, both open-ended and multiple-choice. These multiple sources resulted in three types of data being considered for this study: multiple-choice frequency data, textual, and images/pictures/videos/visual data documenting the creation of the artifacts. Trustworthiness of the data collection and analysis processes was ensured through three techniques (suggested by Erlandson et al., 1994; Creswell & Creswell, 2018): (a) triangulation, or the collection of data from multiple and diverse data sources, (b) purposive sampling of participants ensuring diversity and richness of the perspectives collected, and (c) the use of emergent coding of data to identify common themes from the multiple participants.

After data collection, the process of transcribing and coding data was conducted to look for emerging patterns and themes related to the research questions, as well as any common patterns that emerged from the analysis (Creswell & Creswell, 2018). An emergent coding process was used for the analysis of textual data, which began with unitizing the data or segmenting the text into codable units, a process explained by Reed et al. (2018) as representing "the smallest data component that is analyzed within interactions" (p. 208). Once the data was coded, the unitized data was sorted into categories based on similarities, patterns, or ideas, from which the themes emerged. The artifacts, images, videos, and other items shared by the participants were analyzed using a visual analysis process that Saldana and Omasta (2021) describe as the act in which researchers make "special note of items that seem to suggest particular meaning to either the researchers or the participants" (p. 74). These meanings were also categorized using emergent themes.

RESULTS

Overall, the participants in the study found value in learning about and through virtual makerspace learning environments in a similar fashion to the elementary preservice teachers in the face-to-face makerspaces of the original study (Khirwadkar & Figg, 2019). As well, four themes emerged that address the research questions.

First and foremost, the idea that mathematical concepts could be reinforced through makerspace activities and the use of technology for early learners was a common theme shared by participants throughout the data. By participating in the virtual learning environment, ECEs understood that they were building their own pedagogical knowledge for teaching with technology (TPACK). For example, participants commented, "Participating in both of the makerspace experiences made me see the value of using technology. I realize that it has a place in the classroom and can enhance children's learning" (J-9). Another stated, "I learned how to use technology to show students origami activities in a clear and concise manner. Not only could the students hear my instructions, but they could also see my steps on video" (J-14). Two others added:

> I learned that it can be extremely beneficial because, a lot of the time, you can complete it on your own time. As well it was extremely beneficial to see that we can still engage with hands-on activities with each other, but in multiple different ways. This has been extremely beneficial because now I have this knowledge for the future (J-12).

> Teaching with technology from exploring in a structured virtual makerspace has taught me that there is countless of effective possibilities to engage and support students virtual learning experience by implementing activities in a clear way utilising visuals and hands-on manipulatives; this could effectively engage children in the learning process and aid their mathematical skills (J-15).

Still, others made connections to the curriculum document mathematical standards in comments such as:

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> After I showed the students how to fold paper into the object, I would let them try to fold their own objects and share with each other. Students could think creatively, build relationships and communicate effectively, which is from Strand A: Social-Emotional Learning Skills in Mathematics and the Mathematical Processes (Ministry of Education, 2020) (N-14).

> Using makerspace activities to teach mathematics can allow students to think critically and creatively, build positive relationships with peers and use mathematical communication effectively. Teachers can integrate multiple strands into activities with students and help them develop math skills (O-14).

> Makerspace activities could be very useful in elementary mathematics instruction. The activities actually get the children involved and help them make meaning of what they are learning about through exploration. It is also a great way for children to connect mathematical concepts to real-life situations (P-3).

Secondly, the data analysis provided insights into the theme that the makerspaces could help create positive learning experiences for early learners. One participant explained, "Using makerspace activities to teach mathematics can allow students to think critically and creatively, build positive relationships with peers, and use mathematical communication effectively. Teachers can integrate multiple strands into activities with students and help them develop math skills" (O-14). Another stated, "Makerspace activities are useful for young children which they provide diversity and fun way to engage children in the class. And it also lets students expand open-mindedness and exercise fine motor skills" (P-14). Others commented on how the activities supported the development of critical and creative thinking, such as stated by one of the students (I-4), who explained that students experienced mathematical concepts where they would "not expect perfection, [and] have an open mind. Ask the children to describe what they are thinking and doing. No idea is wrong." Another participant pointed out that, "Makerspaces can be extremely beneficial. It provides a space for children to engage in an activity in multiple different ways and have meaningful conversations with their peers and adults while they are engaged in their learning" (P-12). Still, other participants described the effectiveness of the virtual aspect of the learning environment in comments such as, "The virtual aspect of the makerspaces shows they can easily be implemented with children while they are learning at home. Children can use materials found around their house and create what they want" (I-9).

A third theme that emerged from the data analysis was the perception that parents/caregivers could be engaged in the learning environment as well as teachers and students, thereby promoting a sense of community in which teachers, students, and parents/caregivers were integral parts of the learning. Participants' comments included:

> I think that makerspaces can be extremely beneficial. It provides a space for children to engage in an activity in multiple different ways and have meaningful conversations with their peers and adults [including parents] while they are engaged in their learning (P-12).

> We discussed the differences between exploring a makerspace online and in person. As well, we discussed how we would implement a makerspace within the classroom such as providing instruction for parents to help them set up activities at home for online learning (I-12).

Finally, the participants addressed the fourth theme of how makerspaces might empower children to be autonomous learners. For example, one participant explained how the activities promoted multimodal learning, "I learned how to use technology to show students origami activities in a clear and concise manner. Not only could the students hear my instructions, but they could also see my steps on video" (J-14). Another explained how the activity engaged learners in self-regulation and communication experiences:

> We worked in the origami station, and we have found many great examples on how this activity is beneficial for children in the third grade. This is because children in this age have more comprehension and previous experience throughout the math domain; also, children in third grade are able to communicate and follow instructions well (L-4).

Another participant provided an example of how the activities promoted risk-taking, open-mindedness, and opportunities for working independently:

> I will be using origami in my teaching practice with children because it allows for them to strengthen their abilities to follow directions, it enhances their trial and error understanding, and it makes their brains and hands work in the same sequence. Also, have an open-mind, not all brains compute the same way and will respond differently from their peers/acquaintance when given instruction (M-4).

Other participants connected the learning experiences to opportunities for learners to engage in creativity, critical thinking, motor skills practice, and thinking for themselves. One participant explained,

> "I think I would bring beading and origami activities into the classroom because they stimulate students to think for themselves and be creative, develop critical thinking in math, and practice fine motor skills" (M-14).

The early childhood educators found the makerspace activities to be enjoyable and engaging for learning, but also noted some challenges, such as the importance of clearly communicating instructions and procedures. Additionally, some students noted difficulties with accessing the full experience of visualization in the virtual space. However, these early child educators will be promoting math learning through makerspace activities in an in-person delivery model with their early learners.

DISCUSSION, CONCLUSION, and SUGGESTIONS

Similar to previous studies with preservice teachers (e.g., Turakhia et al., 2024), this study has revealed that virtual makerspace activities are useful to early childhood educators as effective learning environments that promote digital literacy skill development and mathematical, conceptual learning for early learners. Digital tools find a place in early education play centres to engage children with the hands-on learning enhanced by technology. The experience gained by the ECEs, as they navigated the virtual learning environment, helped them to strengthen their TPACK knowledge to utilize in their own teaching practices to benefit early learners. Other research, such as Marsh et al. (2019), has shown the use of technology devices and technology-enhanced learning activities, like robotics or AI, supports the development of knowledge and skills needed in the future society, for the economic growth of societies.

Engaging in makerspace activities helps to create positive learning experiences and allows students to experience and manage a range of emotions, particularly when confronting challenges or failures. The iterative nature of design and creation in these spaces encourages students to view setbacks as learning opportunities, promoting emotional resilience. For instance, students participating in maker projects often encountered frustration during the problem-solving process, which helps them develop coping strategies and emotional regulation skills (Lister, 2019). The findings of the study were found to be useful in engaging children in a variety of makerspace activities, meeting their needs and readiness as per the universal design for learning principles for early years. This study also indicates that educators could organize makerspaces to encourage playful, exploratory learning environments, which helps educators assess children's knowledge and skills in a holistic way (Kay & Buxton, 2023).

The study further revealed that virtual makerspaces support collaboration with parents, engaging them in their child's development in the home environment. The active play-based learning environment created through makerspaces encourages children to take an active part in exploration, investigating ideas, and thereby taking charge of their own learning, while facilitating parents in being an active support in their child's development.

The findings of the study also indicate that makerspaces empower children to be autonomous learners, helping them to make decisions that drive their own learning through hands-on, creative activities. The autonomy and engagement inherent in maker activities enable students to immerse themselves in tasks, entering into unknown terrain taking risks, thereby engaging themselves in creative exploration (Halverson & Sheridan, 2014). This supports the development of effective coping mechanisms and a growth mindset as students navigate challenges in supportive and safe environments.

Thus, investigating the views of ECEs on the usefulness of *making* learning environments in Early Childhood Education programs contributes to foundational knowledge about the types of early childhood experiences that are most effective and beneficial for early learners. Also, the findings support the limited research about the effectiveness of virtual makerspaces as a learning environment in the lived experiences of young learners (Strawhacker & Bers, 2019), and effective ways in which early childhood education encourages the collaboration of children, teachers, parents/caregivers.

Ethics and Conflict of Interest

The authors of the study acted in accordance with ethical rules in all processes of the research. There are no individuals or financial relationships that could be perceived as potential conflicts of interest related to this study.

Author Contribution

All authors contributed equally to the research.

Data availability

The data that support the findings of this study are available on request from the corresponding author.

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