Supporting Teachers' Ability to Leverage Makerspaces in the Teaching and Learning of Mathematics

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Abstract. Makerspaces are increasingly present in K-12 schools and these spaces have the potential to be transformative for mathematics education. However, this rich promise of makerspaces to be transformative for education assumes that teachers will be able to successfully integrate these spaces into their instruction. Teachers who lack the specialized knowledge for such integration, which we refer to as MakerPACK, are unlikely to use makerspaces to their full potential. This mixed-methods research project investigates teacher learning of makerspace technologies through the lens of mathematics curriculum and tasks within the context of a graduate course. Emerging results suggest that while exposing practicing teachers to these makerspace technologies through guided explorations had an overall positive impact on teachers' perceptions of the role of technology in mathematics teaching, their attitudes and beliefs about technology integration were often mediated by their beliefs about mathematics teaching and learning.

Introduction and Literature Review

While the pedagogical approach of hands-on learning has been utilized for hundreds of years, the growing presence of makerspaces provides students with novel ways of engaging in active learning (Burke & Kroski, 2018). A makerspace can be broadly defined as a physical space equipped with the materials needed to encourage creative design (Cavalcanti, 2013). Some technologies currently found in makerspaces include 3D printers and other digital fabrication tools, robotics kits, and microcontrollers (e.g., Arduino), as well as craft and circuitry tools. These spaces are increasingly present in K-12 schools and they can provide students with the opportunity to meaningfully engage with science, technology, engineering, and mathematics (STEM) concepts as they experiment, build, and tinker (Cooper, 2013).

Makerspaces have the potential to be transformative for mathematics education. As students create in a makerspace environment, they authentically and organically raise and investigate important mathematical questions (e.g., Blikstein, 2013; Martin, 2015). Computer-aided design software and 3D printing can enable students to access unique representations of mathematics concepts (e.g., Popelka & Langlois, 2018). The positive impact of coding on students' mathematical learning and thinking has been well documented, from using LOGO to teach geometric properties (e.g., Papert, 1971; Clements & Battista, 1990) to using Scratch to teach probability and problem solving

(Akpinar & Aslan, 2010; Fengfeng, 2014). Coupling students' coding work with readily available robotics kits provides students with real-world contexts to apply and extend their mathematical problem-solving skills (e.g., Ortiz, 2015).

However, this rich promise of makerspaces to be transformative for STEM education assumes that teachers will be able to successfully integrate these spaces into their instruction. Despite the enthusiasm and push for makerspace education over the past decade, as well as the increased availability of makerspace technologies, teachers remain woefully unprepared to incorporate these technologies into their practice. Teachers who lack the specialized knowledge for such integration are unlikely to use makerspaces to their full potential. As Simon Papert stated almost 30 years ago, "The phrase 'technology and education' usually means inventing new gadgets to teach the same old stuff in a thinly disguised version of the same old way" (Papert, 1980, p. 1).

Research suggests that when implementing any new technology, teachers must develop a specialized knowledge known as technological pedagogical content knowledge. Technological pedagogical content knowledge (TPACK), which builds upon Shulman's (1986) pedagogical content knowledge framework, describes an integrated body of knowledge combining technological expertise with an understanding of how technology can be used to support student learning of content (Koehler & Mishra, 2009). The TPACK framework delineates the complexity of combining content knowledge, teaching pedagogy, and incorporation of technology into classroom practice (Koehler & Mishra, 2009). It has been well documented that successful integration of technology is dependent on teacher professional development (e.g., Wenglinsky, 1998). Similarly, professional development can be an effective tool for supporting teachers' development of TPACK (e.g., Koehler & Mishra, 2005; Bos, 2011). In order to understand teachers' development of TPACK, Niess et al. (2009) suggested a developmental sequence to describe the ways in which mathematics teachers integrate technology into their instruction (Tab. 1).

Level	Teacher Knowledge and Technology Integration
Recognizing	Teachers can use a technology, but cannot yet integrate it into teaching
Accepting	Teachers see benefits of a technology and may use it for a teacher-led demonstration of a mathematical idea
Adapting	Teachers can include student use of technology in a surface or instrumental way to support previously learned mathematics ideas
Exploring	Teachers can integrate a technology for effective learning of new mathematics
Advancing	Teachers can integrate technology to expand boundaries of students' mathematical practices

Table 1. Developmental Levels for Mathematics Teachers' TPACK (Niess et al., 2009)

There is little existing research about how teachers can develop TPACK for makerspaces (which we refer to as MakerPACK). Given the emerging nature of the technology, there is a significant need for research into how teachers can learn to use makerspaces within their mathematics instruction (Halverson & Sheridan, 2014). This project investigates teacher learning of makerspace technologies through the lens of mathematics curriculum and tasks within the context of a graduate course. Particular considerations include how teachers developed MakerPACK during the course, technological barriers that arose, and how learning occurred through makerspace technologies presented in the graduate course. The specific research questions explored are:

1) How does practicing teachers' MakerPACK evolve through their engagement with makerspaces, and to what extent are they able to use their MakerPACK to develop mathematics lessons?

2) What obstacles do teachers encounter when learning makerspace technologies and designing lessons using these technologies?

Methodology

This mixed-methods research project is a work-in-progress and is being implemented in a large public university in the Mid-Atlantic region of the U.S., which offers a Master of Science in Mathematics Education. Our participants include seven graduate students in the M.S. program who completed the makerspace-focused mathematics instructional technology course in December 2019.

Course Design

The curriculum for the makerspace-focused mathematics instructional technology course was developed during the summer of 2019 by two of the authors. The course is organized into five thematic modules based on technologies commonly found in makerspaces: Paper Circuitry, 3D Design and Fabrication, Programming, Robotics, and Arduino.

The *Paper Circuitry* module focused on the combination of mathematics and origami in concert with basic elements of electronics. Guided explorations included using non-standard measurement tools to determine the volume of an origami balloon, using copper tape, LEDs, and batteries to create a light-up origami creation, and using multimeters to derive Ohm's Law. These activities required students to complete student-centered origami constructions, problem-based learning, data collection, and planning and design.

The *3D Design and Fabrication* module utilized digital fabrication to create mathematical manipulatives. Guided explorations included a probability task involving the arrangement of numbers on the sides of dice to result in certain outcomes and using computer-aided design software (TinkerCAD) and a 3D printer to fabricate the dice designed in the probability task. Having access to these physical manipulatives allows for the comparison between theoretical and empirical probabilities.

The *Programming* module allowed for guided explorations at different levels of programing, including block-based coding (Daisy the Dino and Scratch) and text-based programming (Python). In the Daisy the Dino activity, teachers learned how they could integrate coding as a formative mathematics assessment tool by assigning solutions to mathematics problems to the different movement codes for Daisy the Dino. This activity also provides students with the opportunity to self-assess their work by comparing their movement sequence with their classmates' sequences. In the Scratch activity, teachers programmed their "sprite" (avatar) to move along a number line to represent graphical solutions to various absolute value inequalities. In the Python activity, teachers programmed turtle graphics to draw various polygons and a five-point star using iterative programming methods, culminating with creating a program that can draw any star with an odd-number of points. The star challenge required knowledge of various geometric concepts, including interior and exterior angles.

The *Robotics* module incorporated different levels of makerspace robots, including the Ozobot Bit (elementary), Sphero SPRK+ (middle school), and LEGO EV3 (high school), to uncover and confirm various mathematical concepts. In the Ozobot Bit activity, teachers determined a travel path defined by operations with small integers and used color-codes to allow the Bit to navigate this path. In the Sphero SPRK+ activity, teachers measured the distance traveled by the SPRK+ at different time intervals, graphed their collected data, and determined a linear equation to model their collected data. In the LEGO EV3 activity, teachers used the EV3 to launch a ball in the air and calculated the initial velocity, final velocity, time at which velocity was zero, and the maximum height of the ball. Both the SPRK+ and EV3 robots are programmed using block-coding, allowing teachers to build upon the concepts they learned during the Programming module.

The *Arduino* module was a culmination of teachers' learning from the previous modules. This module provided teachers with an introduction to solderless circuits, digital and analog ports, and allowed them to revisit basic programming. Guided explorations include using the Arduino to perform simple tasks: making an LED blink and change colors, using a potentiometer to create a dimmer, controlling a Servo motor, and creating a binary counter. During these guided explorations, students were able to see the connection between mathematical functions and programming languages.

Data Collection and Analysis

To assess the extent to which students' MakerPACK evolved as a result of their participation in the makerspace-focused instructional technology course, we collected and analyzed students' "lesson concepts," which were developed at the conclusion of each instructional module. The lesson concepts consisted of an educational object using a specified technology, a description of how the technology could be used to teach a mathematics topic, and a reflection on the design process. A comparative case study approach was used to analyze a sample of lesson concepts using Niess et al.'s (2009) "Mathematics Teacher Development Model." The Coding module occurred at the halfway point of the semester and provided a benchmark for the teachers' MakerPACK development. Of the seven lesson concepts submitted, three lesson concepts were purposefully selected for the comparative case study because they provided opportunities for students to engage in coding

Results and Discussion

The comparative case study analysis of teachers' lesson concepts revealed diverging views regarding technology and its use in a mathematics classroom, despite having similar experiences with makerspaces prior to and during the makerspace-focused mathematics instructional technology course. Based on the analysis of codes from the "Mathematics Teacher Development Model" (Niess et al., 2009), we identified three distinct MakerPACK profiles: Accepting (Jenna), Exploring (Kyle), and Advancing (Lauren).

Jenna: Accepting

Data analysis revealed that Jenna was at an "accepting" level of MakerPACK because she was willing to use the technology in a teacher-centered lesson, but her "concerns overshadowed [her] enthusiasm for the use of [technology] in instruction" (Niess, 2013, p. 181). Jenna's lesson concept was intended for use in an eighth grade classroom and she planned an activity for students to use Scratch to create an animation of geometric transformations. Jenna was concerned that the use of technology would distract students from learning the mathematics content and as a result, her activity was teacher-directed and students had very limited autonomy. Jenna chose geometric transformations as the content topic for her lesson concept because there are already codes in the Scratch platform for rotation ("turn"), translation ("glide"), and dilation ("change size by" or "set size to"). However, coding a reflection in Scratch, while possible using costumes, is not as straightforward and when Jenna encountered this technical difficulty, she chose to change the content of her lesson rather than trying to find a workable solution. As Jenna explained in her reflection, "I struggled to justify the amount of time and effort required to not make a lot of mathematical progress."

Kyle: Exploring

Kyle was at an "exploring" level of MakerPACK because of his willingness to use technology to explore new content and to give students autonomy in the classroom; he "displayed indications of transforming [his] knowledge by more clearly integrating mathematics, pedagogy, and [technological] knowledge" (Niess, 2013, p. 188). Kyle's lesson concept was intended for use in a pre-calculus class and he planned an activity for students to use Scratch to create an animated piecewise function. Kyle's activity gave students considerable mathematical autonomy and he developed a rubric, rather than teacher-specified directions, to provide instructional guidance for his students. Like Jenna, Kyle also encountered technical difficulties when creating his own Scratch animation that required him to use mathematics beyond what he intended for this lesson concept (e.g., converting, scaling). Rather than changing the content of his lesson concept, Kyle used his own experience to anticipate students' challenges and his lesson concept included plans for how he would attend to these challenges when implementing his activity.

Lauren: Advancing

Lauren was at an "advancing" level of MakerPACK because she used the technology to "willingly explore and extend the mathematics curriculum" (Niess, 2013, p. 189). Lauren's lesson concept was intended for use in an eighth grade classroom and she planned an activity for students to use Python to create a program that would calculate the unknown side length of a right triangle. Being able to write the Python program motivated the need for a generalized application of the Pythagorean theorem, which was an extension of her curricular goals. Lauren explained in her reflection that having to troubleshoot initial errors in her program syntax gave her additional ownership over her final product. She recognized that the use of technology could also expand her students' mathematical practices, writing in her reflection, "I hope coding brings out the problem solvers in my students."

Conclusion

While Jenna, Kyle, and Lauren had similar experiences in the makerspace-focused mathematics instructional technology course, their lesson concepts highlighted variations in their MakerPACK development. Specifically, their MakerPACK varied in the following ways: (1) perceived value of integrating technology into their instruction, (2) degree of student autonomy in their activities, and (3) response to technical difficulties when using technology. These findings highlight the integrated nature of MakerPACK, aligning with previous research which suggests beliefs about technology, instructional practices, and technical expertise are closely associated. We hypothesize that developing MakerPACK is mediated by teachers' beliefs about mathematics teaching and learning. Jenna often expressed frustration with technology and a strong preference for direct instruction in her weekly reflection, whereas Kyle and Lauren both regularly wrote about their willingness to engage in productive struggle and a desire to work towards mastery of the different technologies in their weekly reflections. While this hypothesis aligns with research which suggests TPACK development is often mediated by teachers' beliefs (e.g., Smith, Kim, & McIntyre, 2016), further research is needed to better understand the relationship between teachers' beliefs and MakerPACK, as well as how teachers can develop makerspace-specific TPACK.

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Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1852846.