DEVELOPING TPACK FOR MAKERSPACES TO SUPPORT MATHEMATICS TEACHING AND LEARNING

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In this project, we investigate how teachers develop the skills and knowledge to integrate makerspace technologies into mathematics lessons. Makerspaces are physical spaces that encourage creative design that often include emerging technologies such as 3D fabrication, coding, and robotics, and are being increasingly used to enhance mathematics instruction. Research suggests that for teachers to integrate any new technology into instruction, they must develop a specialized technological pedagogical content knowledge (TPACK), but little is known about how teachers develop TPACK for makerspace technology. We present emerging findings investigating how practicing mathematics teachers developed TPACK for makerspaces during a graduate technology course. Results suggest that despite similar experiences in the course, teachers varied significantly in their development of TPACK and integration of technology.

Keywords: STEM/STEAM; Teacher Education – Inservice/Professional Development; Teacher Knowledge; Technology

The issue of how teachers can integrate technology into their instruction in order to improve student learning of mathematics has been a focus of research for decades (Weglinsky, 1998), but continues to be a source of new questions (Cullen, Hertel, & Nickels, 2020). As new technologies are developed, researchers continue to wonder how these new technologies might impact students' mathematical thinking and learning. One emerging category of technologies which have the potential to transform student learning are those that are found in makerspaces.

Broadly considered, a makerspace is a physical space equipped with materials and technologies to encourage creative design (Cavalcanti, 2013). Some technologies currently found in makerspaces include 3D printers and other digital fabrication tools, robotics, microcontrollers (e.g., Arduino), as well as craft and circuitry tools. In this project, we investigate how teachers can develop technological and pedagogical content knowledge of makerspaces. This work looks "across cultures" as we investigate whether teachers can successfully integrate the "playful, growth- and asset-oriented, failure-positive, and collaborative" culture of makerspaces (Martin, 2015) into the context of their mathematics classrooms.

Introduction and Literature Review

Although makerspaces are relatively new, there is an emerging body of knowledge which suggests that they can be effective in improving student learning of mathematics. The use of makerspaces in mathematics instruction is informed by the cognitive theory of constructionism (Papert, 1980), which proposes that learning occurs by "actively constructing knowledge through the act of making something shareable" (Martinez & Stager, 2013, p. 21). Digital fabrication tools can expand constructionism to the creation of physical items. For example, students in a calculus class used 3D printers to create solids of revolution to create visual representations of integration (Propelka & Langlois, 2018). Some research has also suggested that makerspaces can be useful in developing

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teachers' pedagogical content knowledge (Corum & Garofalo, 2019; Greenstein, Fernandez, & Davidson, 2019). However, little is currently known about how teachers can build on these experiences in makerspace to inform their own instruction.

A long-standing body of research suggests that teacher professional development is critical to the successful integration of technology (e.g., Weglinsky, 1998). Building on Shulman's (1986) description of pedagogical content knowledge, researchers have described an integrated technological pedagogical content knowledge (TPACK) which combines expertise in technology with understanding of how it can be purposefully used to enhance student thinking of content ideas (Koehler & Mishra, 2009). Previous research suggests that professional development can be effective in developing teachers' TPACK (e.g., Bos, 2011), but that this specialized knowledge can develop in uneven or unexpected ways (Polly, 2011). In particular, Niess et al. (2009) proposed a set of developmental levels for TPACK to describe teachers' integration of a new technology into their mathematics instruction (Table 1).

Table 1. Developmental levels for mathematics teachers' TPACK (Niess et al., 2009)

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

Niess et al. (2009) emphasize that teachers must go through these developmental stages separately for different technologies, and that particular features of each technology might impact teachers' learning. However, no research has specifically investigated the development of teachers' TPACK for makerspaces (which we refer to as MakerPACK). In order to address this gap in the literature, we investigated how professional development (in the form of a graduate-level, makerspace-augmented mathematics instructional technology course) can impact teachers' MakerPACK. In particular, we explored the following research question:

> How does practicing teachers' MakerPACK develop through their engagement with makerspaces, and to what extent are they able to use their MakerPACK to develop makerspace-augmented mathematics lessons?

Methodology

To understand how teachers' MakerPACK develops, we designed a makerspace-augmented mathematics instructional technology course. Our goal in course design and implementation was both to develop teachers' MakerPACK and to investigate that development, including how teachers demonstrated their MakerPACK through the creation of mathematics lessons.

Course Development and Structure

Informed by current trends in makerspace technologies, five modules were created to develop students' technological knowledge of emerging technologies. These technologies included paper circuits, 3D fabrication, coding, robotics, and microcontrollers. The primary instructional method was open-ended guided exploration to model best practices when integrating makerspace-augmented lessons into a classroom. Examples of guided explorations include determining the volume of an origami balloon using non-standard measurement tools, deriving Ohm's Law, using iterative programming to draw various polygons, and creating a binary counter. Each module included open make time for teachers to explore the technology on their own and to develop their own mathematics lesson to highlight how this work could be incorporated into their own classroom contexts. Two of the authors with extensive experience in makerspace technology and mathematics education were lead curriculum writers.

Participants and Implementation

The makerspace-augmented mathematics instructional technology course was offered at a large public university in the Mid-Atlantic region of the U.S. A total of eight graduate students, all of whom were experienced mathematics teachers, completed the course in the Fall 2019 semester, with seven students agreeing to participate in the study.

Data Collection and Analysis

In order to assess the extent to which the makerspace-augmented mathematics instructional technology course supported students' development of MakerPACK, we collected the "lesson concepts" students developed throughout the course. These 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. We used a comparative case study approach to examine similarities and differences among teachers' development of MakerPACK. A sample of teachers' lesson concepts (each using coding to teach a mathematical idea) were analyzed using the components of the "Mathematics Teacher Development Model" as described by Niess et al. (2009). Two of the authors assessed the lesson concepts independently and then compared their assessments. When the authors' individually assessments were not aligned, they reviewed the lesson concept together in order to come to a consensus. Three lesson concepts were purposefully selected to illustrate the different levels of MakerPACK as observed during the makerspace-augmented mathematics instructional technology course.

Results and Discussion

Data analysis of the codes from the "Mathematics Teacher Development Model" (Niess et al., 2009) revealed that these three participants varied significantly in their MakerPACK development. None of these teachers had prior experience with makerspaces, and all three had similar experiences in the makerspace-augmented mathematics instructional technology course, yet their lesson concepts revealed quite different views and uses of technology. Looking across the components, we noticed three distinct profiles of MakerPACK: Accepting (Jenna), Exploring (Kyle), and Advancing (Lauren).

Jenna: Accepting

Jenna created a Scratch animation and activity to demonstrate geometric transformations for use in an eighth grade class. Her lesson included tightly teacher-directed instructions and little student autonomy. Jenna struggled with identifying an application for coding within her curriculum, and she expressed concern that the use of technology would divert students' attention from learning mathematics. When Jenna encountered technical difficulties, she changed the content of her lesson rather than persevering to find a solution, and stated in her reflection, "I struggled to justify the amount of time and effort required to not make a lot of mathematical progress." Across multiple components, analysis revealed that Jenna was at an accepting level of MakerPACK since she was willing to use the technology in a teacher-centered lesson, but similar to participants described by Niess (2013), her "concerns overshadowed [her] enthusiasm for the use of [technology] in instruction" (p. 181).

Kyle: Exploring

Kyle created a Scratch animation and student project to learn about piecewise function for use in a precalculus class. His reflection expressed enthusiasm about a strong fit with his curriculum, and his project gave students multiple options and significant mathematical autonomy, using a rubric rather than specific instructions to provide guidance. We also note that Kyle's view of the challenges of using new technologies was different than Jenna's. Kyle identified his own difficulties in creating a Scratch animation that required him to use mathematics beyond the specified topic (e.g., converting, scaling), and he planned for how he would attend to these challenges when implementing the lesson concept with students. Data suggests that Kyle was at an exploring level of MakerPACK since he intended to give students autonomy in the classroom to explore new mathematical content; he "displayed indications of transforming [his] knowledge by more clearly integrating mathematics, pedagogy, and [technological] knowledge" (Niess, 2013, p. 188).

Lauren: Advancing

Lauren created a Python program and a programming experience related to the Pythagorean Theorem for use in an eighth grade class. Lauren intended to use technology to expand students' mathematical practices, as the technology provided motivation for determining a generalized solution method for determining the unknown side length of a right triangle. Lauren recognized that the value of incorporating technology into this lesson extended beyond the identified instructional goals. She reflected that her initial errors and the trouble-shooting process gave her additional interest and ownership of her program, writing, "I hope coding brings out the problem solvers in my students." Lauren's lesson concept suggests she was at the advancing level of MakerPACK, in that she used her integrated technological pedagogical content knowledge to "willingly explore and extend the mathematics curriculum" (Niess, 2013, p. 189).

These specific findings indicate that these three teachers' development of MakerPACK varied in terms of the value they perceived in using technology, the level of student autonomy in their lessons, and their response to technical difficulties in using the technology. These findings reflect the integrated nature of TPACK, aligning with previous research suggesting that technical expertise, pedagogical practices, and beliefs about technology are closely linked.

Conclusion

Despite these three teachers having similar experiences in the makerspace-augmented mathematics instructional technology course, our analysis of their lesson concepts revealed wide variation in their development of MakerPACK. We hypothesize that their development of MakerPACK was mediated by their beliefs about mathematics teaching and learning. In weekly reflections, Jenna often revealed frustration with the technology and a desire for more explicit direction. Kyle and Lauren, however, revealed a willingness to engage in productive struggle and a desire for mastery of the technology. This hypothesis aligns with research suggesting that development of TPACK is often mediated by teachers' beliefs (e.g., Smith, Kim, & McIntyre, 2016). Future research is needed to more closely understand the relationship between teachers' beliefs and TPACK, as well as how TPACK for makerspaces can develop.

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