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Learning to teach mathematics with robots: Developing the 'T' in technological pedagogical content knowledge

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A multiple case study was conducted to investigate how Lego robotics instruction incorporated into a middle grades mathematics methods course could inform pre-service teachers' (PSTs) TPACK through the lens of Social Constructivist Theory. The qualitative data analysis revealed that when instruction on Lego robotics technology is integrated into semester long mathematics methods courses, PSTs are able to improve their TPACK knowledge in regard to the robotics. Overall, the findings suggest instruction of educational technology tools should be incorporated into methods courses over a longer duration of time, and in depth, to better support the development of PSTs' TPACK. To meet the demands of the teacher shortages while simultaneously supporting the needs of school districts, this research provides preliminary evidence of the need to incorporate content-specific technology into all methods courses.

Keywords: mathematics, teacher education, Lego robotics, middle grades education, TPACK

The current generation of pre-service teachers (PSTs) have seldom had to function without some form of technology in their lives. It is our job as teacher educators to provide PSTs instruction that builds upon students' innate abilities to function with technology in a meaningful, and even playful, manner. We need to teach our PSTs how to teach *with* technology, not *in addition to* technology (Carbonaro, Rex, and Chambers 2004). That is, we need to help PSTs learn how to implement technology in a meaningful way that enhances learning and engagement while simultaneously creating tasks that support the development of higher order thinking skills. Although modelling has been shown to be an effective strategy for supporting PSTs' understanding of technology integration (Howland and Wedman 2004), I propose the learning should be a hands-on, constructivist experience in the methods courses; PSTs need to begin as students learning with instructional technology before they can meaningfully integrate the technology into their curricula.

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One form of technology that has been shown to be beneficial to the learning of mathematics is Lego robotics, namely EV3 Mindstorms (e.g. Casler-Failing 2018a, 2018b; Martinez-Ortiz 2015). Select children and educators have had access to Lego robotics for the past 20 years; however, robotics has not experienced widespread use in the mathematics classroom. I posit that providing PSTs the opportunity to learn about robotics through hands-on, engaging tasks in their mathematics methods course will increase the use of robotics as a means to develop, and support, pedagogical practices. That is, this type of opportunity could support the development of PSTs' technological pedagogical content knowledge (TPACK) in regard to robotics and will better support their ability to engage their own students in similar activities in their future classrooms.

My experiences and prior research (Casler-Failing 2018a, 2018b) in a middle-school mathematics classroom working with Lego robotics demonstrated that robotics could provide richer learning and engagement than traditional 'I do, we do, you do' instruction. It was those experiences that prompted me to use them with PSTs and helped to formulate the research reported in this paper. This research was designed to investigate how PSTs' experiences with the Lego robots impacts their understanding of teaching with the robots. The research question driving this study was *How does the incorporation of Lego robotics instruction in a middle grades mathematics methods course inform pre-service teachers' technological pedagogical content knowledge (TPACK) in regard to the robotics?*

Theoretical framework

The TPACK framework has been the focus of much research over the past 15 years. Mishra and Koehler (2006) devised this framework to integrate technological knowledge into Shulman's (1986) pedagogical content knowledge (PCK) framework. The new framework is based on the premise that technology cannot be meaningfully integrated into one's instructional practices as a silo separate from learning about pedagogy in their content area. Educators need to learn about, and with, technology in parallel to learning how to integrate pedagogy and content knowledge.

Shulman (1986) developed the notion of PCK as crucial for teachers. Shulman (1986) believed teachers can possess pedagogical knowledge (PK) – the knowledge of practices and methods required for teaching – and content knowledge (CK) – the knowledge of one's content area required for teaching. However, the teaching is seldom successful unless one has intertwined the two knowledge bases to develop PCK – the knowledge, methods and skills required to teach in a specific content area and/or grade band. For example, successful teaching in a 6th grade mathematics classroom would look extremely different than successful teaching in a 11th grade history classroom.

Mishra and Koehler (2006) added technological knowledge (TK) to this framework as another important component of successful teaching. TK refers to the knowledge and skills required to incorporate any technology into instructional practices that can assist in the learning of the content (Koehler and Mishra 2009; Mishra and Koehler 2006). Examples of the types of technologies can range from whiteboards and dry erase markers to videos or podcasts. However, this research will focus on only one form of technology, Lego robotics, and the development of PSTs' understanding of how to use robotics as an instructional tool. Just as Shulman's (1986) framework

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allowed for each skill to be independent of the other, so too does the TPACK framework (Koehler and Mishra 2009; Mishra and Koehler 2006). For example, teachers could possess PK, CK, TK, technological content knowledge (TCK), or technological pedagogical knowledge (TPK); however, the goal is for the integration of all three knowledge bases – TPACK.

When new technologies are learned in concert with the development of pedagogical and content knowledge, I posit the connections among the three domains are stronger; each of the domains build upon and support the other two. Additionally, it has been my experience that learning about, and with, technology it is often easier to learn by applying it to the instructional strategies and content areas it will be used in; robotics is not any different. When an individual possesses TPACK in regard to robotics, I suggest they are able to make sound pedagogical decisions on when, and how, to use robotics to teach or apply mathematical concepts. For example, choosing to use robotics to predict, measure and evaluate the accurateness of a proportional relationship as opposed to showing a video or using a whiteboard would not only create engagement in the activity but also allow students to *see* and *experience* the reasonableness of their mathematical work (Casler-Failing 2018b).

Learning robotics is a very hands-on, engaging activity that incorporates many aspects of Vygotsky's (1978) Social Constructivist Theory. Vygotsky's theory is based on the idea that children learn best through playful, social interactions that allow learners the opportunity to support one another through discourse. It is through the discourse with peers and teachers that learners are able to expand their Zone of Proximal Development (ZPD) to achieve understanding at deeper levels (Vygotsky 1978). Allowing PSTs this experience as they work with unfamiliar technology can be beneficial to the development of their pedagogical practices in regard to learning about content-specific technology. Although robotics and its application to computational thinking and programming is often connected with constructionism (Papert 1980), this research is focused more on the application of the robotics to support learning, and therefore more closely aligns with constructivism.

The TPACK framework, paired with Social Constructivist Theory, is an ideal lens through which to analyse this research due to the integration of the social aspect of learning about robotics in relation to content and pedagogy. Methods courses naturally integrate CK with pedagogical practices, and as we progress further into this 21st century; they must also incorporate technology to reflect the dynamics of the technology-driven society of which we are a part. The research being reported in this paper integrates Lego robotics, a specialised form of technology, into a methods course designed to teach pedagogical skills in the content area of mathematics.

Literature review

This literature review will report on research regarding teachers' development of TPACK, the need for further TPACK research and research involving robotics.

As the 21st century progresses so, too, does the ever-increasing need for our teachers to be meaningful integrators of technology in their curricula; learning should be enhanced, or strengthened, through the use of technology. The NCTM (2014) believes technology should 'support effective instruction' (p. 80); however, '[w]ithout well-designed professional development, teachers may feel uncomfortable about using tools and technology in their classrooms' (p. 84). As Niess (2005) posits '[l]earning subject matter with technology is different from learning to teach that subject matter with technology' (p. 509). In order for PSTs to develop TPACK, they must develop in-depth knowledge of their content area in parallel with their development of pedagogical and technological knowledge (Niess 2005).

A founding principle in the TPACK framework is that knowledge in all three domains – technology, pedagogy and content – must mesh cohesively in order for any instructional practice to incorporate technology in a meaningful manner (Mishra and Koehler 2006). In other words, having strong CK and exemplary pedagogical skills does not imply one is able to incorporate technology in a manner that benefits student learning. Christensen (2002) found teachers' attitudes towards incorporating technology into their curricula was influenced by the training they received. Di Blas (2016) found that strong PK supported teachers' success with TK and that learning how to manage activities incorporating technology was much more important than the teachers' deep knowledge of the technology. When teachers consider the full effect of their technology choice in regard to their content and pedagogy when designing curricula and assessments, the result will reflect positive student learning in response to those lessons in which the technology was incorporated (So and Kim 2009).

Researchers So and Kim (2009) investigated teachers' TPACK as they integrated problem-based learning (PBL) and information and communications technology (ICT) and found that many times teachers will only incorporate technology that is familiar to them. However, having knowledge of technology for personal use is much different than the knowledge required when it is used as an instructional tool. PSTs require a more hands-on approach to incorporating technology into their future classrooms, and so just being exposed to the technologies is not adequate (So and Kim 2009). When teachers are not comfortable using and troubleshooting various technologies, the integration of such technologies could actually hinder instruction through loss of time and/or content (Yarbro *et al*. 2016). This is an important aspect of my robotics research – allowing PSTs to learn about the robots by completing various tasks with a partner allowed them the opportunity to troubleshoot problems that could arise in their future classrooms; this type of experience is priceless if it enhances the success of their future students.

Investigating TPACK in more depth

Although there has been much research regarding TPACK over the past two decades, there is still a need to improve the focus of research studies that investigate teachers' development of TPACK (e.g. Rosenberg and Koehler 2015; Willermark 2018). Willermark (2018) proposed that the TPACK framework is difficult to evaluate due to its many entangled components, and that evaluating teachers' self-reports of TPACK acquisition (knowledge) is much different than evaluating TPACK in practice during planning and implementation (competence). Rosenberg and Koehler (2015) built on the work of Porras-Hernández and Salinas-Amescua (2013) to posit contextual factors are an important factor in one's development of TPACK. More specifically, the location and layout of the learning environment as well as the state and national curriculum standards can influence TPACK development (Porras-Hernández and Salinas-Amescua 2013).

Huang (2018) posits teachers need to develop the ability to integrate technology as a means to support teaching and learning rather than to merely present material and found that without fully developing TPACK, teachers are unable to utilise technology to promote students' mathematical understanding. This idea is mirrored in the work of Schmid, Brianza and Petko (2021), who conducted research to investigate PSTs' use of digital technologies used in lesson planning and found that of the 173 lesson plans reviewed, only 26.5% incorporated digital technology for student use, while over 50% of the lessons included techonology for teacher use. Niether of these studies evaluated the development of lessons in the context of teaching the lessons; that is, these findings were based on lesson plan development, only, and did not have a teaching, or lesson implementation, component. My research sought to fill this gap by creating an opportunity for PSTs to learn about robotics and then providing a context for them to plan, design and teach a lesson incoporating robotics technology as a learning tool to support understanding of a specific mathematical concept.

Learning about robotics

Chambers and Carbonaro (2003) created a 1-week, intensive pilot course as part of a teacher education program that allowed 12 pre-service and veteran teachers (seven graduate and five undergraduate) to experience the learning of robotics in much the same manner as their future students would. Chambers and Carbonaro (2003) reported the teachers enjoyed the hands-on, activity-based experience and met the desired goals of the pilot course – understanding how to design and program instructional robotics.

This study conducted by Chambers and Carbonaro (2003), although similar to my research being reported in this manuscript, is also much different in that it was primarily 'self-led' (participants taught themselves using a Robolab instructional book) and was conducted during the course of 1-week. Although this short duration of learning may be beneficial *in the moment*, it is my opinion that incorporating all of the learning into 1-week could be considered 'cramming', and similar to cramming for a test which may produce evidence of learning immediately, but the bulk of the learning will be forgotten within a short period of time (Willingham 2009). Willingham (2009) advocates for spacing out the learning and practice of new concepts; developing new knowledge over time can allow for enhanced memory and application of the knowledge. Additionally, practicing new skills (e.g. learning how to program robots to perform various tasks) should be incorporated into more advanced skills (Willingham 2009), such as applying PSTs' understanding of robotics building and programming to create lesson plans to teach mathematical concepts via the robotics.

Sullivan and Heffernan (2016) found that robotics construction kits (RCKs), such as Lego Mindstorms EV3 robots, provide immediate feedback to learners that promote learning through reflection and discussion. Furthermore, the authors found that P–12 students progressed through problem-solving cycles while learning with the RCKs, which is supported with the findings from research on proportional reasoning (Casler-Failing 2018a, 2018b), in which middle-grades students progressed through the five stages of technology integration – engagement, exploration, investigation, creation and evaluation (Carbonaro, Rex, and Chambers 2004) while solving tasks. I propose allowing PSTs to experience this type of learning in their methods course will support the development of similar instructional practices in their future classrooms.

Whether the student partaking in the learning is a PST or a middle-grades student, 'the value of the technology depends on whether students actually engage with specific technologies or tools in ways that promote mathematical reasoning and sense making' (NCTM 2014, p. 80). PSTs must possess sufficient TK, in parallel with their CK and PK, in order to appropriately meet the needs of their diverse learners. '[T]echnological knowledge should be transformed and integrated into subject content and teaching methods' to 'develop context-based learning activities' (Huang 2018, pp. 2051–2052). This research sought to investigate the transition from learner to teacher with a specific form of instructional technology – Lego Mindstorms EV3 robots – and provide PSTs with specific skills to design and teach using the technology as a means to promote student learning in their future classrooms. This study will add to the current body of literature by providing insight into how learning focused on a specific technology, taught over a longer duration of time in a content methods course and developed in the context of curricular standards and specific learning environments can support PSTs' development of TPACK.

Methods

The nature of this study was to investigate how Lego robotics instruction incorporated into a middle-grades mathematics methods course could inform PSTs' TPACK; in the United States, middle-grades refers to grades 4–8, or ages 9–13 years. This action research study (Anderson and Herr 2005) was conducted using a qualitative framework incorporating multiple cases (Yin 2018). The qualitative framework allowed for a deeper level of analysis than quantitative methods, and the incorporation of multiple cases allowed for an independent analysis of the development of each PST rather than the development of an entire class. Additionally, after analysing each PST as a separate case, a cross-case analysis was conducted to determine similarities and differences between each case (Patton 2002; Yin 2018).

Setting and participants

This research was conducted at a large university in the southeastern part of the United States, in a mathematics methods course of which I was the researcher and the professor. This mathematics methods course is a requirement of the Middle Grades Certification Program at our university for students choosing mathematics as their primary or secondary concentration; in our state, middle grades' teachers are required to be certified in two content areas. Students in this course are either in the 2nd semester of their junior year or 1st semester of their senior year. This course focuses on high-leverage pedagogical practices as related to a grades 4–8 mathematics classroom, including, but not limited to, teaching techniques, planning and instruction, making use of resources, state content standards and assessment strategies.

This research was conducted in my mathematics methods course over several semesters. The participants of this research were five PSTs in an undergraduate middle-grade teacher education program enrolled in my mathematics methods course during the fall 2018 or spring 2019 (see Table 1). Each participant provided a unique perspective, bringing a wide range of experiences to the course, and more specifically, to learning to teach with robotics. A brief introduction to each PST, each representing a single case in this study, is provided later.

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Table 1. Mathematics methods students versus study participants.

Semester	Total students in class	# Students providing consent to participate in this research	# Students completing pre-survey	# Students completing post-survey	# Students included in this study
Fall 2018	9 (one male/ eight females)	8	5	3	3 (three females)
Spring 2019	6 (one male/ five females)	5	5	2	2 (one male/ one female)

River

River, a female in her junior year, had some prior experiences with building robots in high school as well as some experience with coding utilizing AutoCAD software. At the beginning of the semester, River felt she would 'not understand how [to] use [robots] in a classroom setting' (journal entry).

Hunter

Hunter, a female in her senior year, was initially nervous to learn about, and work with, the robots and felt they would be 'over [her] head' because it 'sounded too hard' (journal entry).

Jesse

Jesse, a female, non-traditional student in her senior year, was 'very skeptical' (journal entry) when presented the opportunity to learn about robotics as she 'always considered robotics [to be] more of a tech/science geek hobby' (journal entry).

Cameron

Cameron, a female in her junior year, appeared to be out of her comfort zone (observational field notes) as she did not have previous experience building or programming robots. After building the robot, Cameron was 'excited to start programming, but nervous' (journal entry) she would struggle with it.

Quinn

At the beginning of the semester, Quinn, a male in his senior year, reported being 'excited to see what we can do…[but] scared I'll mess it up' (journal entry) but found success through 'working with my partner and communicating' (journal entry).

Curriculum

The PSTs participated in several robotics activities utilizing the LEGO EV3 Mindstorms robot (see Figure 1) throughout the first 6 weeks of the semester, spacing the learning out over a longer duration of time aligned with the work of Willingham

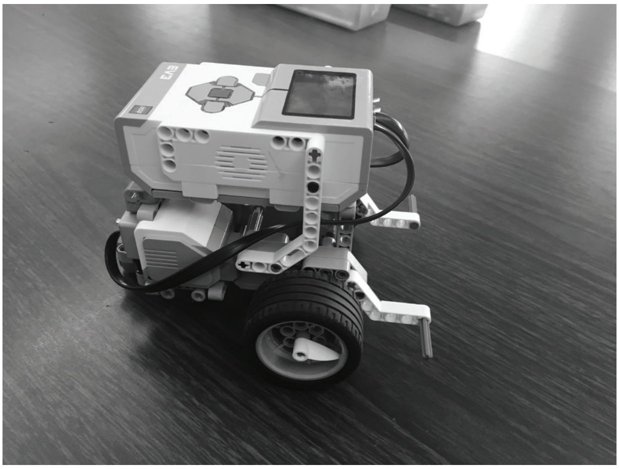

Figure 1. Example Lego EV3 Mindstorms robot build – the driving base.

(2009). Each 3.5-h class would begin with approximately 2–2.5 h of instruction aligned with a traditional methods course (e.g. instruction on designing objectives, creating meaningful learning tasks, etc.). The remaining 1–1.5 h would be dedicated to learning about robotics.

Students were provided instruction on how to build and program the robots to complete various tasks utilizing multiple levels of programming from simple operations (program the robot to travel in the shape of a square) to more complex (program the robot to use a colour sensor to follow a line and stop when a specific colour was detected). As each class progressed, less programming support was provided through instruction; students were tasked with utilizing their prior programming resources, and each other, to successfully complete the new challenges provided (Vygotsky 1978). The culminating activity required the students to work in pairs to create a lesson to teach a specific mathematics standard (from grades 4 to 8) incorporating Lego robots. Students collaborated on this task during weeks 7 and 8 and taught their lessons to their peers during week 9 in the same manner they would conduct the lesson with middle-grades students. I scaffolded students via questioning when providing programming support as they developed their lesson. An exemplar of a robotics lesson I had created and previously implemented in an 8th-grade mathematics class was provided to the PSTs as a visual description of my expectations for their lesson plan. All activities required students to work collaboratively in dyads to support one another's development and understanding of the robotics in a social environment (Vygotsky 1978). As the students worked through each task, they were able to ask questions of each other as well as members of other groups in the class.

Data sources

This action research was completed as a multiple case study, with each student representing a case, and multiple forms of data were collected to understand and evaluate the outcomes (Yin 2018). Due to the fact that I was the researcher and instructor of the course, an action research design was most applicable as it allowed me to revise my curriculum (Anderson and Herr 2005) and allowed me to analyse the data from an

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insider's perspective (Hubbard and Miller Power 2003). Additionally, when research is conducted by the instructor, it is possible for the data process to change during the implementation (Cochran-Smith and Lytle 1993); action research allows for those 'in-the-moment' additions or revisions, which was an important component of the data collection process for this research. For example, when I observed PSTs struggling to achieve success with a task, I was able to add a reflection question to prompt PSTs to reflect on their struggle.

The data collected included online surveys, weekly journal entries, my observational field notes, lesson plans incorporating the robotics and video recordings of the PSTs teaching their robotics lesson to their peers. The surveys consisted of six Likert scale statements regarding PSTs' experience with, and knowledge of, Lego robotics and four open response questions regarding PSTs' perceptions of the benefits and obstacles associated with teaching and learning via Lego robotics; the post-surveys included three additional open response questions focused on the PSTs' positive and negative experiences of working with the robotics during the semester and concepts they would like to teach with Lego robotics. All statements and questions were developed based on research (e.g. Di Blas 2016; Mishra and Koehler 2006) and previous personal experiences teaching students and in-service teachers about robotics. The Likert scales were not quantitatively analysed due to the small sample size and were incorporated solely to determine PSTs' perceptions of their learning and experiences with the robotics (see Figures 2–6). The survey results were compared to my classroom observations and PSTs' journal entries to deepen the data analysis; findings were not dependent solely on the surveys because research has shown that when participants self-report they are more likely to measure one's self-efficacy rather than knowledge (Willermark 2018). The surveys were administered using the Qualtrics survey platform via email links provided to the students during week 1 and upon completion of the methods course.

The PSTs were provided prompts at the end of each class in order to complete their weekly journal entries as a means to connect their newly developed TK to their PK and CK (e.g. *What did you find applicable to mathematics learning in today's robotics activities?*). The prompts were developed based on the specific robotics instruction PSTs participated in each week. My observational field notes focused on the engagement of the PSTs – the amount of collaboration among partners (Vygotsky 1978), perceived mindsets (e.g. 'this is hard' or 'yay, it worked') and the amount of scaffolding required to support students in their successful completion of the assigned tasks. The PSTs were required to submit lesson plans, with all materials required to teach the lesson (e.g. student task sheets, answer keys, etc.), to reflect their ability to merge their TK, CK and PK into a cohesive lesson plan focused on teaching, or supporting, a specific grades 4–8 mathematics standard.

The open-responses from the surveys, and data collected throughout the methods courses (student-created lessons, weekly journal entries and observational field notes) for each case, were independently codified (Grbich 2013); this was the first of three processes. After the codes were identified, I reviewed them across all data sources, case by case, and they were synthesised to develop categories (Saldaña 2016). Finally, the categories were further refined to determine overarching themes (i.e. engagement, overcoming frustration, pedagogical components; Creswell 2007) to assess the depth of PSTs' understanding of the robotics technology – both from a learner's and teacher's viewpoint.

The multiple data sources are an important component in the analysis of the findings to support triangulation as a means to improve reliability (Glaser & Strauss

1965). Since each data source was initially coded independently of the others (student-created lessons, weekly journal entries and observational field notes), common codes that emerged in each of the data sources (e.g. talking within groups, sharing ideas between groups, success with task) supported the reliability of the analysis. Once the analysis of each case was completed, a cross-case analysis was performed to evaluate similarities and differences among the themes in the cases to promote validity (Patton 2002; Yin 2018). Researcher bias was minimised through the use of critical friends (Costa and Kallick 1993); findings were discussed, and questions posed to ensure an accurate interpretation of the data.

Findings

Although this research represents a small sample, findings show the incorporation of robotics into the mathematics methods course increased PSTs' TPACK in regard to the use of robotics as an instructional tool and allowed each PST to experience learning opportunities that can be provided by robotics.

River

When analysing River's survey responses, it is clear there was not a large change in her understanding of programming robots due to some prior experience (see Figure 2). River developed an improved understanding of how Lego robots can support mathematical understanding and reported at the end of the semester 'robotics could be a great tool' (journal entry). However, the largest transition was reflected

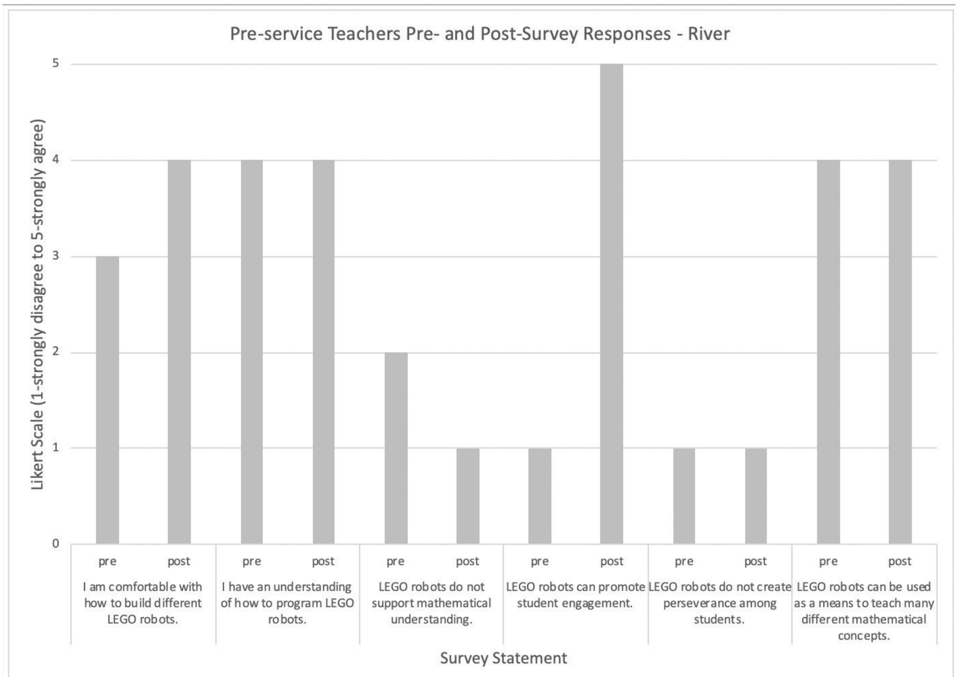

Figure 2. Rivers' responses to the pre- and post-survey, based on a scale of 1 (strongly disagree) to 5 (strongly agree).

in her understanding that robotics can promote student engagement which was also reflected in her statement that robots can be a 'comfortable connection for students' (post-survey). Although there were times that I observed River become frustrated (observational notes), I was able to support her learning process by asking purposeful questions to scaffold her understanding of the process of programming. Additionally, her partner was supportive and encouraging (observational field notes), which helped the team to successfully complete the instructional programming tasks posed by me; River reported in her journal entries that the challenges of programming were easier to overcome when working with a peer (Vygotsky 1978).

The mathematics lesson created by River and her partner showed the willingness of each team member to stretch their robotics learning, and understanding, to a new level as they created a lesson to support student understanding of absolute value. The programming required for their lesson incorporated randomization of the distance travelled by the robot, which was not a programming skill covered through the instructional tasks. When River presented the lesson to her peers, she appeared confident and was supportive (video recording). River's initiative to learn new programming (TK) in order to create a lesson that would support her instruction on absolute value (PK and CK) reflected an alignment of her technological, pedagogical and content knowledge – the development of her TPACK – as related to robotics.

Hunter

Hunter's data reflect a positive development in her skills and understanding of Lego robotics from pre- to post-survey (see Figure 3). Hunter's understanding of programming

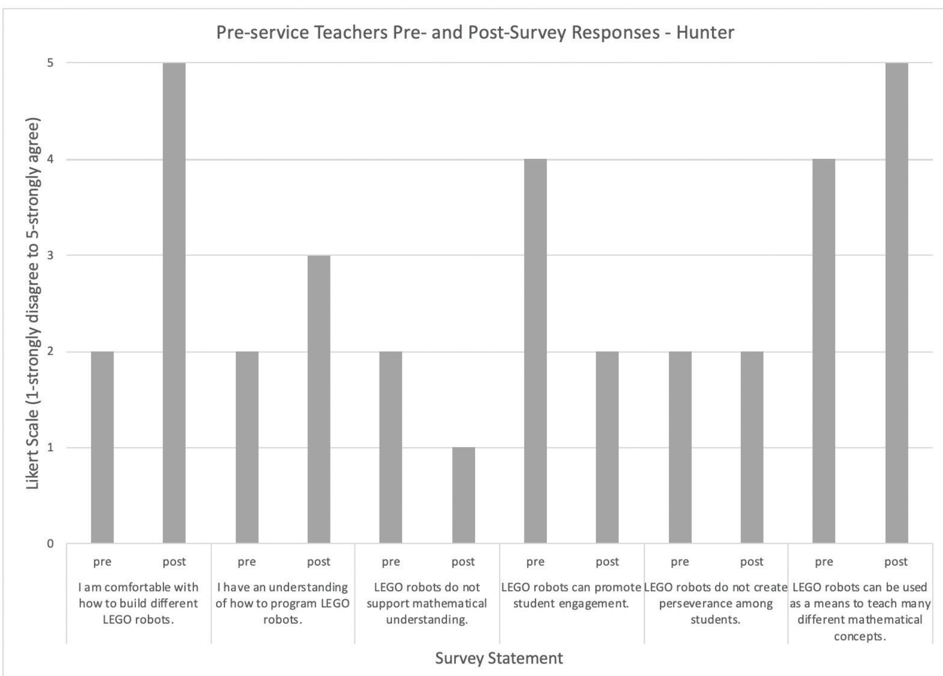

Figure 3. Hunter's responses to the pre- and post-survey, based on a scale of 1 (strongly disagree) to 5 (strongly agree).

and how the robots can support mathematical understanding showed slight improvements from pre- to post-test. It should be noted that for the statement 'Lego robots can promote student engagement', Hunter decreased from agree to disagree – it is unclear if there may have been an error in either, or both, of the survey responses as her journal entries do not reflect this same thinking. For example, in one of her journal entries at the end of the course, Hunter wrote, 'I think that it is a fun way to get students involved' (journal entry); this statement contradicts the results in the survey. Hunter's journal entries revealed that she found the collaborative environment to be beneficial to the learning, and that she and her partner could become experts of one aspect (e.g. building the robot) and supportive in another (e.g. programming) which would lead both to success, which reflects the tenets of Social Constructivism (Vygotsky 1978).

Hunter created a mathematics lesson with her partner that asked students to record the time and distance travelled by the robot. This information was then used to determine the robot's rate of travel as a means to apply their understanding of unit rates. Hunter and her partner incorporated variables into their programming in order for students (in this case, their peers) to develop different data sets as a means to compare and contrast the findings through discussion, which is evidence of her CK. Hunter and her partner reflected confidence in their knowledge of the robots (TK) when they instructed their peers through this lesson and walked around to each peer group (PK and CK; students worked in groups of two as they would in a classroom setting) to support the learning and answer any questions (video recording; observational field notes). Through this lesson, Hunter was able to provide evidence of her TPACK development, in relation to robotics.

Jesse

There were three areas in which Jesse showed a slight improvement in her robotics-focused TPACK development through this experience: ability to build robots (TK), developing the understanding that robots can be a tool used to support mathematics learning (PK) and learning that robots can be utilised to teach many different mathematical concepts (TK and PK; see Figure 4). Jesse's understanding of building and programming is reflected in her journal entries. Jesse reported 'the easiest part of the robots, to me, was the construction process' (journal entry). Her desire to learn and become a teacher with many skill sets allowed her to be open-minded to the experience. She reported the programming was 'intimidating in the beginning' (journal entry) but was able to quickly grasp the basics and become an integral member of her partnership. Later, Jesse wrote 'it did not take long before most of my initial fears regarding the robots and their programming were partially eliminated' (journal entry); however, she also reported that she still did not feel confident enough to write programs independently.

Jesse partnered with River throughout the robotics instructional tasks and to design their lesson plan. Through my observations, I witnessed Jesse taking a leadership role with the programming and having productive conversations with River (Vygotsky 1978) regarding the objectives of the absolute value lesson plan. During the presentation of the lesson to her peers, Jesse was comfortable explaining how to use the robot (TK) to achieve the following objectives (CK and PK): understanding that absolute value represents a distance from zero, evaluating the absolute value of a given number and calculating the sum of two absolute values (video recording;

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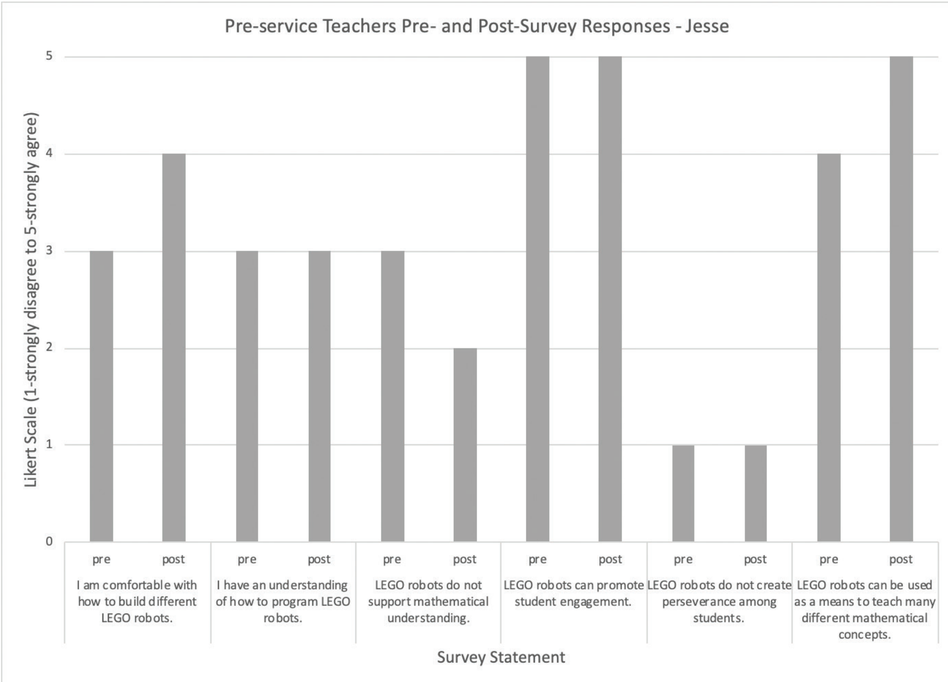

Figure 4. Jesse's responses to the pre- and post-survey, based on a scale of 1 (strongly disagree) to 5 (strongly agree).

observational field notes). Jesse's implementation of the lesson reflected her development of robotics specific TPACK.

Cameron

Cameron showed a significant transition from pre- to post-survey in her ability to build and program the robots (TK); both areas improved from strongly disagree to strongly agree (see Figure 5). There were not any changes in the remaining categories from pre- to post-survey; however, her journal entries provided evidence of her understanding of, and ability to use, robots as a tool to promote mathematics learning (TK and PK). For example, Cameron wrote 'student[s] would be engaged through the lesson because it would be something that grabs their attention and it would be hands-on for them' (journal entry). Cameron also stated, '[i]t has also prepared me to help my students at … middle [school] to … use them' (journal entry). During the instructional tasks, I observed Cameron taking on a leadership role with the robotics, namely the programming (observational field notes); she reported enjoying her programming success when she was able to 'watch the robot move' (journal entry). Cameron and her teammate made a personal connection with the robot by giving it a name (Chambers and Carbonaro 2003); the robot's name, *Split*, often appeared in her journal entries.

Cameron and her partner created a lesson for a 6th-grade class with a focus on statistics; Cameron continued to take on the leadership role as she supported her partner through the challenge of creating a program that included randomization of the robot's

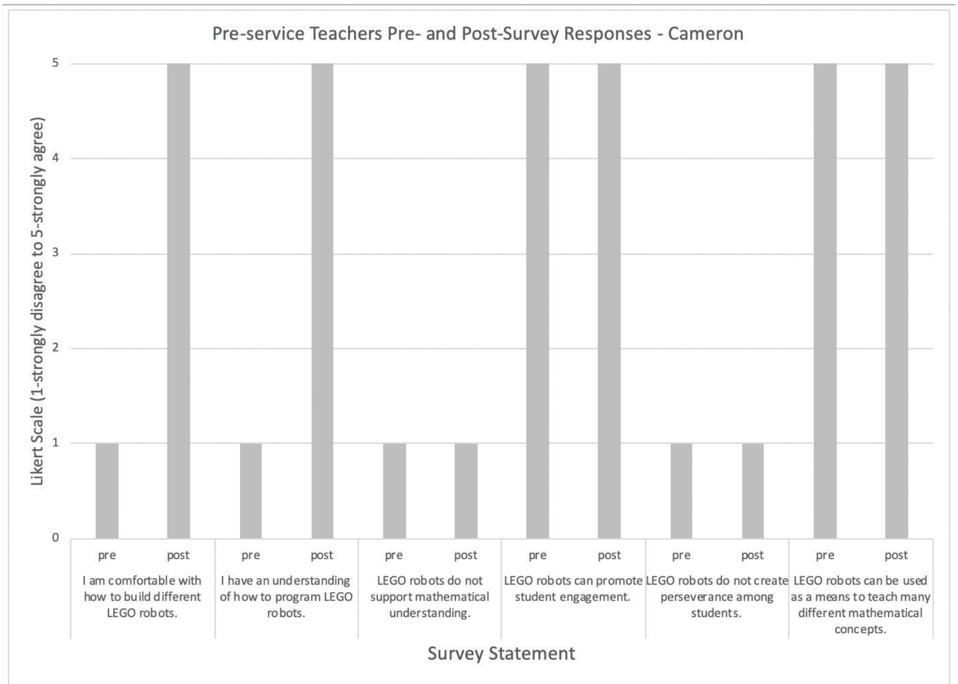

Figure 5. Cameron's responses to the pre- and post-survey, based on a scale of 1 (strongly disagree) to 5 (strongly agree).

movement in order to create a data set. Cameron appeared to be very knowledgeable about the robotics (TK) as a means to collect data as she instructed her peers through the lesson (video recording; observational field notes). The development and implementation of the lesson provided evidence of her ability to effectively integrate robotics technology into her instructional practices to promote the understanding of mathematical content, which reflected the development of her robotics-focused TPACK.

Quinn

Quinn's development in his understanding of programming the robots shifted from disagree to strongly agree through this experience (TK; see Figure 6). Quinn found the collaborative nature of the learning to be beneficial to his overall success (Vygotsky 1978). Additionally, Quinn developed a positive mind shift in understanding the ability of robots to support student engagement, mathematical understanding, development of perseverance among students and aid in the teaching of many mathematical concepts (PK). This evidence was further validated when Quinn stated, 'the robots allowed for deeper understanding of math and really made me think of creative ways to teach!' (journal entry), which reflects an alignment of his TK, CK and PK.

Quinn created a lesson that he could incorporate into his learning segment (all methods students are required to design and teach a 5–6 learning segment as part of the teacher preparation program) that focused on circles. Quinn designed a lesson for 7th-grade students that required a robot to hold a marker to create a series of lines that extended from a single point (the centre of a circle). The objective of the lesson was for students to understand that all radii of a circle are congruent (CK). As

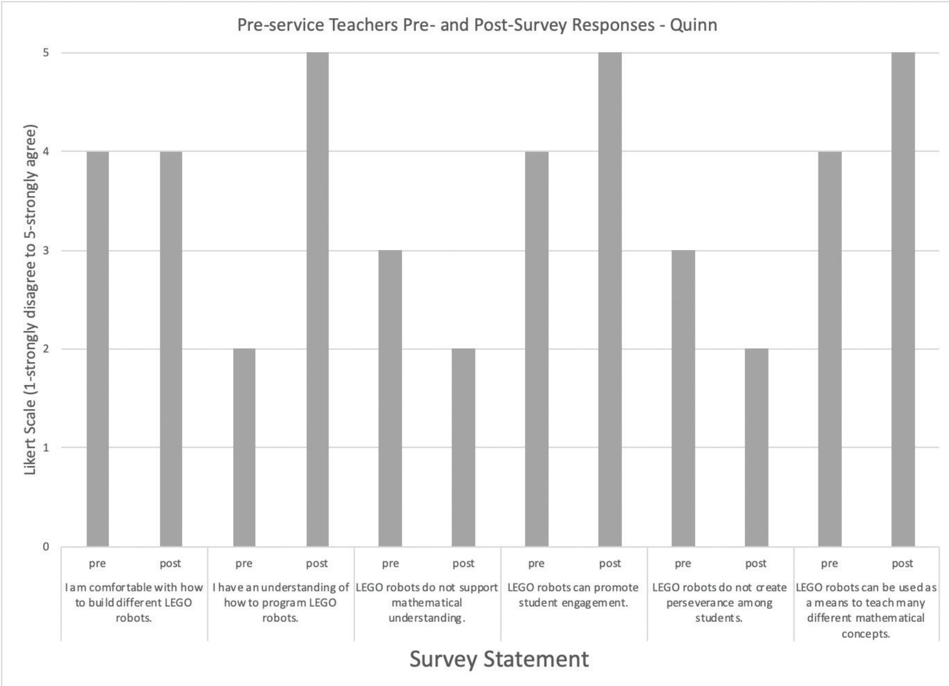

Figure 6. Quinn's responses to the pre- and post-survey, based on a scale of 1 (strongly disagree) to 5 (strongly agree).

Quinn and his partner presented the lesson to their peers, I observed that Quinn was knowledgeable and confident in his ability to provide support to his classmates (TK and PK; video recording). Quinn was the only student to use robotics in his teaching placement, which provides additional evidence for his development of TPACK skills as they relate to robotics.

Cross-case analysis

When conducting the cross-case analysis, three themes emerged: PSTs' improved understanding of building and programming the robots, PSTs' TPACK development in regard to the robotics and the benefit of working with a partner. The most prominent outcome of this research is the increased understanding of robotics (both as a learner and teacher) experienced by the PSTs (pre- and post-survey). Three of the five PSTs reported improved understanding of programming the robots. Additionally, all PSTs developed an appreciation for how robotics can be used as an instructional tool to promote understanding in mathematics classrooms. Willingham (2009) suggests learning is optimised when it is conducted over a longer period of time; the duration of this research study allowed the students to become more knowledgeable about the robotics over the course of several weeks (improved their TK in regard to the robotics), which improved their ability to learn about, and teach with, the robotics.

A second theme present among the data was the development of PSTs' TPACK to meaningfully incorporate robotics technology to promote students' mathematical understanding. Over the course of the semester, the PSTs developed an appreciation for the variety of content that could be taught through the use of the robots as well as the mathematical practices supported by the robotics technology. This is a finding that was dependent on students learning about the robotics while simultaneously developing their pedagogical skills in the content area (Mishra and Koehler 2006). The immediate feedback presented by the robots (Sullivan and Heffernan 2016) in regard to programming (e.g. Did it perform as planned or not?) allowed students to immediately assess their success and make revisions as necessary to complete the given tasks. As stated by River '[t]he robots can be used as a tool and not just be about building and programming the robots' (journal entry); this statement reflects the alignment of River's technological and pedagogical knowledge. An alignment of technological, pedagogical and content knowledge can be found in Hunter's reflection on the experience when he stated, 'I think that they [robots] allow for students to work with the standards for mathematical practice….They also allow for students to question the way things work, which would directly benefit their mathematical thinking and reasoning' (journal entry).

Students felt robotics supported the development of student understanding by creating engagement (Chambers and Carbonaro 2003) 'throughout the lesson because it would be something that grabs their attention and it would be hands-on for them' (Quinn, journal entry). Cameron's experience developed her belief that 'robots allow for deeper understanding of math' (journal entry), and Hunter stated the robotics create a comfortable connection to the concepts for the students by allowing them to '*see* the math' (journal entry); teaching with robotics allows teachers to support students' ability to troubleshoot issues and creates physical evidence of students' efforts.

The third theme present among all learners, as evidenced both in their journal responses and my observational field notes, is reflective of Vygotsky's (1978) Social Constructivist Theory. Students reflected on the benefit of working with a partner to determine strategies not only to complete the weekly tasks but also to develop the lesson plan. Too often I have experienced teachers not wanting to integrate new technologies or lessons for fear of failure, but these PSTs gained an understanding that it is okay to not know everything and to model the learning of new ideas, concepts and technology alongside their peers and students, which reflects the research of Di Blas (2016). My observational field notes provide many instances of students sharing strategies or asking questions of one another, both within and among groups. Further evidence of the amount of understanding gained by the PSTs during this experience is presented by Hunter's response on the post-survey that robotics allows the teachers to learn alongside the students, another facet of the benefits of social learning (Vygotsky 1978).

Discussion

In response to the research question, although a small number of participants were included in this research, the findings suggest the integration of Lego robotics technology instruction into a semester-long mathematics methods course can positively influence PSTs' TPACK in regard to teaching with robotics. These findings reinforce previous research in that TPACK may be best developed over time (Willingham 2009) and with continued practice in the content area while simultaneously developing and/or improving pedagogical and technological skills (Mishra and Koehler 2006; Niess 2005). Willingham (2009) suggests practice should be ongoing, with days, weeks and months between the practicing opportunities; meeting for class once per week allowed time for the students to reflect on their learning between classes.

This research builds on the suggestions of Porras-Hernández and Salinas-Amescua (2013) and Rosenberg and Koehler (2015) by providing a context in which to learn about, and with, robotics. The PSTs who participated in this research were learning about robotics for a purpose – they were learning how to operate the robotics so they could later design lesson plans utilizing the robotics to teach a mathematics concept. Although the PSTs were not able to take the robotics into the middle-school environment to teach their lesson, they were provided an opportunity to teach the lesson to their peers. Additionally, being supported by their partners throughout the learning process created a social learning environment (Vygotsky 1978), where students supported one another and were able to take on leadership roles, such *builder* or *programmer* that furthered their understanding of how they could mesh their technological, pedagogical and content knowledge.

The findings support the incorporation of technology instruction in methods courses as a means to meaningfully integrate the three knowledge domains of content, pedagogy and technology over a longer duration of time as opposed to 'once and done' instructional sessions on technology. Additionally, PSTs' experiences with Lego robotics technology supported PSTs' understanding of how they could support the learning experienced by their future students (So and Kim 2009; Yarbro *et al*. 2016). PSTs were able to experience how a student may feel when learning with robotics and reported on the positive aspects of working collaboratively (Vygotsky 1978) to alleviate frustration and persevere to achieve success. An example is represented by Hunter, 'I thought I would never be able to successfully make them [robots] work…I learned that it does not need to be something that you do alone…together we were able to help each other learn' (journal entry). The experiences, and confidence, gained by the PSTs supported the development and implementation of lessons incorporating Lego robots covering concepts such as unit rates, congruence of a circle's radii, absolute value and statistics, and reflected their abilities to meaningfully integrate technology (NCTM 2014) in parallel with their pedagogical and content knowledge.

Implications and limitations

We are living, and teaching, in an age where much focus is given to mathematics and literacy skills. Induction level teachers need to be knowledgeable about various forms of instructional technology (Mishra and Koehler 2006; NCTM 2014; Niess 2005) that can promote student engagement while supporting student understanding of concepts. Lego robotics is a tool, but not the only one, to integrate all of the above-mentioned skills. PSTs must be provided the in-depth, structured training on the use of specific technologies as instructional tools during their methods courses. Furthermore, PSTs must be provided context in the development of their TPACK (Porras-Hernández and Salinas-Amescua 2013; Rosenberg and Koehler 2015), which can be supported by providing the opportunity to create, and implement, lessons with peers and/or colleagues before presenting them to students to increase the likelihood of incorporation into their future classrooms (Christensen 2002). This research illuminates the need to investigate instructional technologies in depth, rather than breadth; PSTs should not only be introduced to different forms of instructional technologies but also be provided the opportunity to practice with them and create lessons incorporating the technology (So and Kim 2009; Yarbro *et al*. 2016), a practice that has recently been echoed by several of my PSTs. If methods professors carefully select a limited number of technological tools that could be incorporated into their content areas, PSTs could have the opportunity to experience learning content with the technology in the context of planning and teaching content with the technology. I posit this type of technology integration into methods courses would benefit the development of PSTs' TPACK and, ultimately, their future students.

As with all research, this research has limitations. First, although I have made every effort to analyse this data through a neutral frame, my prior experiences with Lego robotics could produce a level of researcher bias that was not intended. Second, this research only investigates one specific type of technology; further research should be conducted to integrate different forms of technology into semester-long methods courses (e.g. investigating Desmos graphing software in the same manner in a mathematics methods course) as a means to further develop PSTs' TPACK. Third, and most importantly, this research has only been conducted in one College of Education, in one program of study, in a rural southeastern community of the United States, with a limited number of participants. The findings of this study warrant further investigation through additional studies inclusive of larger participant enrollments in order to support or argue the findings presented in this manuscript. I intend to continue this research in my middle-grades mathematics methods courses, expand the research to include my secondary mathematics courses and hope to collaborate with methods instructors to investigate instructional technologies more applicable to their content areas.

Although these limitations prevent the generalizability of the findings herein, the benefits to the participants of this study and their future students far outweigh these limitations. The ultimate goal of this research was to develop PSTs' TPACK in regard to Lego robotics technology as an avenue to create a classroom environment, which promotes engagement and understanding when incorporated into mathematics curricula. The PSTs have benefitted from this by learning how to operate and program the robotics and by having the opportunity to create lessons applying the robotics technology to teach mathematical concepts. As this research continues to grow in participant numbers and progresses into the next stage (following the PSTs into their in-service positions with continued support through professional development opportunities), it is proposed that participants, due to their knowledge and understanding of the technology, will be more likely to integrate it into their instructional practices when they become in-service teachers (Christensen 2002). One PST who participated in this study, Quinn, went back to practicum after this experience and found robotics kits in the classroom closet – Quinn had developed TPACK in regard to his robotics knowledge from this experience in methods class at a deep enough level to support the incorporation of robotics into his instruction.

Conclusion

This research has shown that when instruction on Lego robotics technology is integrated into semester long mathematics methods courses, PSTs are able to improve their TPACK in regard to the robotics; I propose this would apply to any technology that is studied in depth and in parallel to the development of content and pedagogical skills. The form of learning discussed in this paper – hands-on, small group instruction (Vygotsky 1978) incorporating technology presented over a longer duration of time (Willingham 2009) – better supports the development of PSTs' TPACK, and I posit the PSTs will be more likely to integrate the technology into their future classrooms. However, in order for this to occur, they will need to be provided access to continued technological support. This is an aspect I am adding to this research as it continues to the next stage – I intend to begin conducting regular professional development sessions throughout the school year and during the summer in order to provide these future teachers with the continued support they need as a means to reduce the obstacles they feel will hinder their ability to implement the technological practices into their classrooms. Additionally, I plan to work with school districts and funding agencies to support the availability of various technologies in the mathematics classrooms. To meet the demands of the teacher shortages while simultaneously supporting the needs of our partner school districts, this research provides evidence of the need to incorporate content-specific technology into all methods courses.

References

Anderson, G. L. & Herr, K. (2005) *The Action Research Dissertation: A Guide for Students and Faculty*, Sage, Thousand Oaks, CA.

Carbonaro, M., Rex, M. & Chambers, J. (2004) 'Using LEGO Robotics in a project-based learning environment', *The Interactive Multimedia Electronic Journal of Computer-Enhanced Learning*, vol. 6, no. 1.

Casler-Failing, S. (2018a). 'Robotics and math: using action research to study growth problems', *Canadian Journal of Action Research*, vol. 19, no. 2, pp. 4–25. doi: 10.33524/cjar.v19i2.383

Casler-Failing, S. (2018b). 'The effects of integrating LEGO robotics into a mathematics curriculum to promote the development of proportional reasoning', *Proceedings of the Interdisciplinary STEM Teaching and Learning Conference*, vol. 2, no. 5, pp. 24–35. doi: 10.20429/stem.2018.020105

Chambers, J. M. & Carbonaro, M. (2003) 'Designing, developing, and implementing a course on Lego robotics for technology teacher education', *Journal of Technology and Teacher Education*, vol. 11, no. 2, pp. 209–241.

Christensen, R. (2002) 'Effects of technology integration education on the attitudes of teachers and students', *Journal of Research on Technology in Education*, vol. 34, no. 4, pp. 411–434. doi: 10.1080/15391523.2002.10782359

Cochran-Smith, M. & Lytle, S. L. (1993) *Inside/Outside:Teacher Research and Knowledge*, Teacher's College Press, New York.

Costa, A. L. & Kallick, B. (1993) 'Through the lens of a critical friend', *Educational Leadership*, vol. 51, no. 2, pp. 49–51.

Creswell, J. W. (2007) *Qualitative Inquiry and Research Design: Choosing among Five Traditions*, 2nd edn, Sage, Thousand Oaks, CA.

Di Blas, N. (2016.) 'Distributed TPACK: what kind of techers does it work for?', *Journal of e-Learning and Knowledge Society*, vol. 12, no. 3, pp. 65–74.

Glaser, B. G. & Strauss, A. L. (1965) 'Discovery of substantive theory: a basic strategy underlying qualitative research', *American Behavioral Scientist*, vol. 8, no. 6, pp. 5–12. doi: 10.1177/000276426500800602

Grbich, C. (2013) *Qualitative Data Analysis: An Introduction*, 2nd edn, Sage, London.

Howland, J. & Wedman, J. (2004) 'A process model for faculty development: individualizing technology learning', *Journal of Technology and Teacher Education*, vol. 12, no. 2, pp. 239–262.

Huang, Z. (2018) 'Theoretical analysis of TPACK knowledge structure of mathematics teachers based on T-TPACK mode', *Educational Sciences: Theory and Practice*, vol. 18, no. 5, pp. 2044–2053.

Hubbard, R. S. & Miller Power, B. (2003) *The Art of Classroom Inquiry: A Handbook for Teacher-Researchers*, Heinemann, Portsmouth.

Koehler, M. J. & Mishra, P. (2009) 'What is technological pedagogical content knowledge?', *Contemporary Issues in Technology and Teacher Education*, vol. 9, no. 1, pp. 60–70.

Martinez Ortiz, A. (2015) 'Examining students' proportional reasoning strategy levels as evidence of the impact of an integrated LEGO robotics and mathematics learning experience', *Journal of Technology Education*,vol. 26, no. 2, pp. 46–69. https://doi.org/10.21061/jte.v26i2.a.3

Mishra, P. & Koehler, M. J. (2006) 'Technological pedagogical content knowledge: a framework for teacher knowledge', *Teachers College Record*, vol. 108, no. 6, pp. 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

NCTM. (2014) *Principles to Actions: Ensuring Mathematical Success for All*, National Council of Teachers of Mathematics, Reston, VA.

Niess, M. (2005) 'Preparing teachers to teach science and mathematics with technology: developing a technology pedagogical content knowledge', *Teaching and Teacher Education*, vol. 21, no. 5, pp. 509–523. doi: 10.1016/j.tate.2005.03.006

Papert, S. (1980) *Mindstorms: Children, Computers, and Powerful Ideas*, 2nd edn, Basic Books, New York.

Patton, M. Q. (2002) *Qualitative Research and Evaluation Methods*, Sage, Thousand Oaks, CA.

Porras-Hernández, L. H. & Salinas-Amescua, B. (2013) 'Strengthening TPACK: a broader notion of context and the use of teacher's narratives to reveal knowledge construction', *Journal of Educational Computing Research*, vol. 48, no. 2, pp. 223–244. https://doi.org/10.2190/EC.48.2.f

Rosenberg, J. M. & Koehler, M. J. (2015) 'Context and technological pedagogical content knowledge (TPACK): a systematic review', *Journal of Research on Technology in Education*, vol. 47, no. 3, pp. 186–210. doi: 10.1080/15391523.2015.1052663

Saldaña, J. (2016) *The Coding Manual for Qualitative Researchers*, 3rd edn, Sage, London.

Schmid, M., Brianza, E. & Petko, D. (2021) 'Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans', *Computers in Human Behavior*, vol. 115, pp. 1–12. https://doi.org/10.1016/j.chb.2020.106586

Shulman, L. S. (1986) 'Those who understand: knowledge growth in teaching', *Educational Researcher*, vol. 15, no. 2, pp. 4–14. doi: 10.3102/0013189X015002004

So, H.-J. & Kim, B. (2009) 'Learning about problem based learning: student teachers integrating technology, pedagogy, and content knowledge', *Australasian Journal of Educational Technology*, vol. 25, no. 1, pp. 101–116. doi: 10.14742/ajet.1183

Sullivan, F. R. & Heffernan, J. (2016) 'Robotic construction kits as computational manipulatives for learning in the STEM disciplines', *Journal of Research on Technology in Education*, vol. 48, no. 2, pp. 1–24. doi: 10.1080/15391523.2016.1146563

Vygotsky, L. S. (1978) *Mind in Society*, Harvard University Press, Cambridge.

Willermark, S. (2018) 'Technological pedagogical and content knowledge: a review of empirical studies published from 2011 to 2016', *Journal of Educational Computing Research*, vol. 56, no. 3, pp. 315–343. doi: 10.1177/0735633117713114

Willingham, D. T. (2009) *Why Don't Students Like School?*, Jossey-Bass, San Francisco, CA.

Yarbro, J., *et al.*, (2016) 'Digital instructional strategies and their role in classroom learning', *Journal of Research on Technology in Education*, vol. 48, no. 4, pp. 274–289. doi: 10.1080/15391523.2016.1212632

Yin, R. K. (2018) *Case Study Research: Design and Methods*, 6th edn, Sage, Thousand Oaks, CA.