Effectiveness of Professional Development: Integration of Educational Robotics into Science and Math Curricula

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1. Introduction

To ensure the continued U.S. competitiveness and prosperity, it is critical to foster K-12 students' learning in science, technology, engineering, and math (STEM) disciplines so that they become STEM-capable workforce of tomorrow. However, the current decline in the number of students choosing to pursue STEM as a major and career is a significant concern[1,2] for educators, scholars, and policymakers. The prevailing situation suggests a need for reform-oriented teaching practices (RTPs) in K-12 STEM education. The *Next Generation Science Standards*[3] (NGSS) and the NRC *Framework for K-12 Science Education*[4] emphasize the necessity of RTPs that enhance student understanding of the nature of science and practices of engineering. The *Common Core State Standards of Mathematics*[5] (CCSSM) also describe their reform efforts on how teachers need to transform their teaching style from the traditional instructional methods to more reform-oriented methods.

Recent research suggests that effective technology integration has the potential to promote STEM learning through facilitated implementation of RTPs.[6-8] Borko, Stecher, and Kuffner[9] have proposed the ten dimensions of RTPs for teaching science, including the "*Use of scientific resources*" and "*Hands-on*" activity. Literature review additionally reveals that educational robotics as a scientific resource has emerged as a learning tool that has tremendous potential in offering fun hands-on activities in an attractive learning environment.[10-12] Papert[12] indicated that when appropriately used in STEM courses, robotics serves as a tool using which students can engage in inquiry and hands-on learning, which allows them to construct their own understanding of abstract concepts. Another argument that supports adoption of robotics kits in teaching and learning is the notion that many students perceive the robots as toys,[13] allowing robotics to serve as a hook for student engagement in learning. In fact, one widely used robot kit is made by LEGO, a well-known manufacturer of children's building blocks. Students using the LEGO robot kit in a classroom can feel entertained, recalling their joyful experiences of playing with toys at home, which can encourage them to participate in robotic-based learning activities.

Even as educational robotics has been recognized as a useful resource to transform the nature and practice of STEM education, prior empirical studies have shown that teachers are reluctant to use technology in their classrooms.[14] In many cases, teachers do not have the knowledge on how to meaningfully exploit technology for effective teaching and learning of STEM content and they do not have models or understanding of pedagogical approaches to implement technology-integrated courses, in general, and robotics-integrated courses, in particular.[15-18] Moreover, the rapid increase in the availability of innovative and budget friendly technologies makes it difficult for teachers to keep up with the technological developments.[19] A further complication arises due to continuously evolving hardware and software of the educational technologies. Hussain *et al.*[20] and Lindh and Holgersson[21] report that during the classroom robotic activities, students often ask their teachers intricate questions. The aforementioned challenges suggest that it is of paramount importance that school leaders and teachers, respectively, consider preparation of and participation in professional development (PD) programs prior to implementing robotics for reform-based STEM instruction.[22]

Unfortunately, scant research is available on effective PD programs for teachers to create and implement STEM teaching practices using robotics. Thus, we have designed, implemented, and studied a three-week summer PD program (15 sessions, 8hrs. per session) for middle school science and math teachers. Through this PD effort, teachers were expected to deepen their technological-pedagogical-and-content knowledge (TPACK),[23] develop lesson plans by utilizing robotic kits for standards-aligned science and math curricula, and improve their students' STEM interest and achievement through classroom enactments of their new learning. The PD program showcases to teachers illustrative examples of lessons and activities that incorporate robotics into the teaching of science and math. Moreover, the PD program provides teachers guidance on designing and implementing robotics-embedded lessons in classroom settings.

The objective of this paper is to: present empirical evidence on the effectiveness of our robotics-embedded PD program, explore how the PD changes teachers' TPACK self-efficacy and content knowledge for robotics-based lessons, and assess teachers' perceptions of the PD program.

2. Theoretical Framework

This study employs the situated learning theory, constructionism, and cognitive apprenticeship as its theoretical underpinnings to further explore and describe the robotic PD programs for educational purposes. A literature review on robotics-focused PD programs is provided to justify the use of robotic activities in teaching STEM content knowledge. Finally, we review existing studies on TPACK to motivate the development of teachers' ability to integrate robotics in their instructional framework for STEM teaching.

2.1. Situated Learning

Situated learning is achieved through the process of integrating authentic activities and situations with cognition.[24] According to situated learning theory, the content is learned through the process of doing authentic activities, and learning cannot be attained or considered separately from the context and culture in which it occurs.[25] The situated learning perspective has been deemed to offer a theoretical rationale for 'inquiry-based' and 'problem solving' approaches to science teaching and learning, where scaffolding and other forms of social support serve a prominent role in students' learning process.[26] A model of instruction employing situated learning theory has been proposed and proven to yield a practical framework for classroom practice.[25,27] Ref. 25 suggested that the key components of this model include: (1) cognitive apprenticeship and coaching; (2) opportunities for multiple practices; (3) collaboration; (4) reflection; and (5) technology. Cognitive apprenticeship methods allow students to enculturate into authentic practices through social interaction. Cognitive apprenticeship highlights the cognitive tool for accumulation and utilization of knowledge in authentic domain activity.[25] Coaching is a central concept of cognitive apprenticeship. While learners can use their prior knowledge when faced with various kinds of situations and opportunities, they cannot obtain such knowledge without proper coaching from their teachers. In particular, teachers help identify the kinds of information learners should absorb and offer increasingly complex opportunities to allow learners to apply and practice their knowledge set.[25] Collaboration, especially in a classroom setting, is a beneficial component of the framework of Ref. 25 that exposes learners to perspectives from their teacher and peers alike in varied ways to tackle a singular problem, thus building their competency to address similar situations in future. Finally, it is important that the learners have opportunity to reflect on the newly learned material and this may entail the learners exploring practical applications and seeking validation from external sources of their new learning. Integration of robotics-based activities in classroom pedagogy offers opportunities for multiple practices, encourages learners to collaborate, and allows them to reflect as they learn. The power and flexibility of technology can be exploited to support the aforementioned components of situated learning.[25] For example, Ref. 28 indicated that a collaborative learning environment creates a culture that allows students to take on various roles and promotes the sharing of ideas and knowledge through the integration of technology. The role of the teacher is to facilitate students to review and comment on each other's work and build the team's overall synergy as part of the teaching process.

Situated learning theory advocates authentic contextual settings for the learning of technology integrated for classroom pedagogy.[29,30] As an example, science teachers who attended a science geared induction program were more likely to incorporate technology into their teaching practice than those who had not attended the program or any other science-related orientations.[29] According to the authors of Ref. 29, this result was the product of the specificity, in regards to both usage and setting, of the technology instruction for the science-specific induction program. Since the use of robotics in classroom instruction has not been widely explored, there is an urgent need to apply and examine the use of situated learning theory with educational robotics technology in the context of PD programs for K-12 teachers. Such a study will develop teachers' instructional practices and yield a beneficial tool to define and analyze teachers' outlooks in teaching with robotics.

2.2. Constructionism

Inspired by Jean Piaget's *constructivism*, wherein learners create their own knowledge, Papert[12] led the design of a tool called LOGO that would go on to help children with developing their own knowledge. While working in the LOGO environment, the first task that children face is to come up with an object that they want to create using the LOGO commands. Papert[12] asserted that this would allow children to have a sense of control and ownership of the object. This example shows the roots of *constructionism*, wherein learners create their own knowledge as in constructivism but do so specifically through the process of building objects.[12] Constructivism, the process of linking the learners' prior knowledge with newly presented information, produces learning at a higher level of cognitive domain and such learning can be accessible for future reference.[31] According to Ref. 31, constructionism embodies key aspect of knowledge creation structures through human cognitive development and learning in accordance with natural and designed environments. Constructionists subscribe to the ideal form of learning being one that is attained through intimate interactions with tangible objects instead of through abstract thinking.[32,33] This is the underlying rationale for the introduction of technology integration as a learning tool.

The seemingly close and immediate interaction of input and output responses with a concrete object such as a robot enables learners to participate in constructionism learning. This is accomplished in the following four distinct ways. First, the learners place themselves as inputs of the computational manipulative by utilizing their minds in coming up with computations.[12] Second, the process of computation manipulative has a tendency to engender discussion among peers that helps reveal various perspectives and provide insights on resolving specific issues.[34] Third, as students encounter results that do not align with their expectations, they are forced to resolve the misalignment with explanations for specific errors or phenomena and thus enhance their causal reasoning abilities.[35] Fourth, the instantaneous feedback triggers a troubleshooting cycle response that begins with problem identification, proceeds to a contemplation of the present state of the learner and the program at hand, then a tabulation of potential causes of error, and lastly a formulation of plans to fix the issue or loop back in the cycle to gather further information about the problem.[34] This constructionism approach is applicable to the robotics-embedded learning environment where students experience the immediate feedback from the robot and participate in the process of problem solving.

2.3. Cognitive Apprenticeship

Our PD program adopted a cognitive apprenticeship (CA) model, which helps explain the learning process wherein teachers, as learners, experience and perform thinking and knowledge processing tasks with the assistance of domain experts. The concept of apprenticeship draws on social constructivist learning theory in which the zone of proximal development (ZPD) serves as a key tenet.[36] According to Ref. 36, p. 86, ZPD refers to the gap between "actual developmental level as determined by independent problem solving" and the higher level of "potential development as determined through problem solving …," i.e., ZPD is a dynamic region that is just beyond the learner's current ability level. According to Vygotsky's theory,[36] partners or peers with expertise can act as a supportive social tool with whom learners can interact to develop and grow their own cognitive abilities. Such a framework is pertinent to the aim of our PD program, which entails teachers learning engineering practices with guidance from robotics engineers and science educators, lowering the gap between teachers' actual cognitive level and their potential for development through CA. Ref. 37 has proposed six teaching and learning strategies as relevant to CA: (1) modeling: demonstration of the temporal process of thinking; (2) coaching: monitoring of learners' activities and assisting them when necessary; (3) scaffolding: process of guiding learners to develop cognitive and metacognitive awareness; (4) articulation: clarifying learners' own way of thinking, i.e., the results of reflection; (5) reflection: learners' assessment and analyses for their performance; and (6) exploration: exploration of the learned skills and knowledge to promote conceptual understanding.

Researchers have reported that the CA model can strengthen both cognitive and noncognitive skills of learners. For example, Ref. 38 has shown that the web-based CA model increased the performance and attitudes of pre-service teachers, with regards to instructional planning, far more effectively than a traditional training course. Ref. 39 showed a significant change in secondary science teachers' perceptions of inquiry and high self-efficacy through a PD based on a CA model. This study also explored how a PD program specially designed for CA affected the teachers' cognitive and noncognitive outcomes.

2.4. PD Programs for Robotics-Integrated Teaching in STEM Education

Even as the adoption of robotics offers an initial spark to ignite students' interest in a given STEM topic, applying the robotics-integrated teaching for STEM classes is a complex undertaking for teachers. Since the role of teachers is crucial for the successful introduction and implementation of robotics in STEM classrooms, training of teachers through participation in systematic PD programs is of paramount importance.[15] From the development of robotics curricula to the training of teachers and students through STEM outreach programs, higher education institutions have been playing a significant role in promoting robotics programs for K-12 students.

For example, Ref. 40 introduced "Teacher Education on Robotics-Enhanced Constructivist Pedagogical Methods" (TERECop), whose goal was to provide teachers experience in designing computer-based robotic activities and implementing them in classrooms in constructivist ways. Over the three-year project duration (2006-2009), eight institutions from six different European countries participated in the TERECop project. Based on the constructivism perspective, the project supported teachers' professional preparation, enabling them to implement the robotics-enhanced learning in their schools. The project team developed a methodology for designing robotic-embedded learning and teacher education program based on a methodology developed at the beginning of the project. The curriculum and learning materials developed for the teacher education program were pilot tested and revised. The final PD program provided teachers with opportunities to learn about robotic technology and its use to promote a constructivist approach to learning.

In a joint effort,[41] Northeastern University, Tech-Boston—a part of the Boston Public Schools, and Tufts University's Centre for Engineering Education Outreach developed a LEGO robotics PD program for middle school teachers who taught robotics-embedded lessons in after school programs to middle school students. A two-week PD program was conducted on the Northeastern University campus in summer 2005. During the first week, the PD program introduced the participating teachers to ten lessons and helped prepare them to conduct the lessons in afterschool programs in their own schools. During the morning sessions of the second week, the teachers taught the lessons to a group of 4~6 students followed by additional workshops in the afternoon. The participants indicated that the hands-on experience and the large number of activities prepared them in the PD to help teach the robotics-based lessons. Using pre-/post-surveys, the teachers were asked to rate their degree of confidence in their knowledge of engineering fundamentals and their ability to teach engineering fundamentals. The teachers' responses indicated that they had enhanced the degree of confidence in their knowledge significantly. Similarly, the teachers' responses showed an increase in the degree of confidence in their ability to teach, although the increase was not substantial.

The literature related to technology integration for teacher PD[42,43] indicates that teachers who are involved in PD show a higher level of knowledge and far more confidence in incorporating technology into their lessons than those that do not participate.

2.5. Technological Pedagogical Content Knowledge (TPACK)

Building on Shulman's[44,45] pedagogical content knowledge (PCK) framework, Mishra and Koehler[23] introduced *technological pedagogical content knowledg*e (TPACK) as a new framework to the educational research community. According to Ref. 23, p. 1029, TPACK is defined as:

> *… the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones.*

The construct of TPACK shows interconnections of a teacher's technology knowledge (TK) with content knowledge (CK) and pedagogy knowledge (PK). Further combinations of these three core knowledge domains create four additional types of knowledge: pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPACK). Schmidt *et al.*[46] suggested the following definitions for the seven components in the TPACK framework (see Ref. 46, p. 125).

1. *Technology knowledge (TK): Technology knowledge refers to the knowledge about various technologies, ranging from low-tech technologies such as pencil and paper to digital technologies such as the Internet, digital video, interactive whiteboards, and software programs.*
2. *Content knowledge (CK): Content knowledge is the "knowledge about actual subject matter that is to be learned or taught". Teachers must know about the content they are going to teach and how the nature of knowledge is different for various content areas.*
3. *Pedagogical knowledge (PK): Pedagogical knowledge refers to the methods and processes of teaching and includes knowledge in classroom management, assessment, lesson plan development, and student learning.*
4. *Pedagogical content knowledge (PCK): Pedagogical content knowledge refers to the content knowledge that deals with the teaching process. Pedagogical content knowledge is different for various content areas, as it blends both content and pedagogy with the goal being to develop better teaching practices in the content areas.*
5. *Technological content knowledge (TCK): Technological content knowledge refers to the knowledge of how technology can create new representations for specific content. It suggests that teachers understand that, by using a specific technology, they can change the way learners practice and understand concepts in a specific content area.*
6. *Technological pedagogical knowledge (TPK): Technological pedagogical knowledge refers to the knowledge of how various technologies can be used in teaching, and to understanding that using technology may change the way teachers teach.*
7. *Technological pedagogical content knowledge (TPACK): Technological pedagogical content knowledge refers to the knowledge required by teachers for integrating technology into their teaching in any content area. Teachers have an intuitive understanding of the complex interplay between the three basic components of knowledge (CK, PK, TK) by teaching content using appropriate pedagogical methods and technologies.*

TPACK is a useful framework when discussing the integration of technology into teachers' teaching and the further development of this knowledge, and more specifically, for measuring teachers' knowledge level for technology integration. Most of the existing surveys tend to focus on teachers' self-assessment of their levels of technology use. Mishra and Koehler[23] used a survey to track changes in teachers' perception of their TPACK understanding over a course that incorporated educational technology. Moreover, Archambault and Crippen[47] developed 24 survey questions to measure teachers' understanding of various instructional and conceptual issues. This effort adapted a widely used self-efficacy TPACK instrument[46,48] for our PD program, which employs robotics to teach classroom science and math. Moreover, in our study, we reformulated the TPACK survey instrument,[46,48] guided by the self-efficacy research,[49,50] to establish participant's confidence, motivation, outcome expectancy, and apprehensiveness for each of the seven components of the TPACK framework.

3. Research Questions

This study examines the effects of the robotics-integrated PD program on teachers' TPACK self-efficacy, content knowledge for robotics-based lessons, and their reflections. The research questions are as follows.

1. Does a three-week summer PD program that engages middle school teachers in robotics-based science and math lessons contribute to increasing their TPACK self-efficacy and content knowledge for robotics lessons?
2. What are the teachers' perceptions on the effectiveness of the PD workshop for classroom integration of instructional robotics?

4. Methods

4.1. Overview of the PD Context

We implemented a three-week summer PD program (15 sessions, 8hrs. per session) for middle school science and math teachers. In our PD effort, teachers are expected to deepen their TPACK, develop lesson plans by utilizing robotic kits for the standards aligned science and math curricula, and improve their students' STEM interest and achievement through classroom enactments of newly developed and learned lessons. The PD was led by facilitators, consisting of engineering and education faculty, researchers, and graduate students, using a collaborative co-teaching approach to increase teachers' knowledge about robotics and gain experience with robot-integrated science and math lessons. The first week of the PD consisted of an introduction to the LEGO Mindstorms EV3 robotics kit hardware and software and robotics-based hands-on learning activities. On the first day, the teachers had time to familiarize themselves with the robotics kits. They were introduced to the names and functions of various structure and mechanism related parts, sensors, motors, and programming. The next four days of PD were devoted to three illustrative science and math lessons: ratios and proportions, energy, and torque, and presentations about various education research constructs. For each lesson, the alignment with standards related to NGSS and CCSSM was illustrated and the teachers were engaged in performing the lessons, discussing the lessons' appropriateness, and recommending extensions. On the final day of the first week, the teachers participated in a reflective discussion that considered the hands-on lessons, research readings, and feedback to enhance the PD program. During the second week, the teachers were introduced to four robotics-integrated lessons on center of mass, function, number line, and statistics. Moreover, based on teacher feedback from the first week, each day's program included additional instructions, hands-on activities, and challenges on programming to accustom them to robot programming. At the beginning of the third week, the three remaining lessons (i.e., analyzing and interpreting data, rover, and tug of war) were introduced to the teachers. Next, based on their learning thus far, the teachers developed their own science and math lessons embedded with robotics activities. They selected lesson topics that were aligned with learning standards and incorporated robotic activities. The theoretical framework of Section 2 informed the design and execution of the summer PD workshop and its various activities.

4.2. Participants

Teachers were recruited from New York City (NYC) public schools through an online application that was widely disseminated through email and by direct contact with schools and school district administrators. Each school's application, endorsed by the school principal, named a pair of science and math teachers for participation in the summer PD. All participants were required to attend all training, curriculum design, presentation, discussion, and assessment activities during the summer workshop and conduct follow-up activities during the academic year. In lieu of participating in the PD workshop and completing all requirements, each participant received a stipend. The results presented below are based on survey data collected from 20 in-service science and math teachers at eight NYC middle schools. All teachers were asked to respond to a survey instrument that examined their TPACK self-efficacy towards robotics and content knowledge for robotics-based lessons. Moreover, the survey instrument sought the teachers' responses to: reflections about the PD program, their background information including gender, race, educational background (i.e., highest degree), and the length of their teaching experience (years). Data was collected via an anonymous online survey created in Qualtrics. Demographic data for the participants are listed in Table 1. The 20 teachers showed variance in their demographic information including gender, race, subjects taught, and teaching experience.

4.3. Instrument and Data Analysis

Teachers' TPACK self-efficacy was measured using pre-/post-tests, i.e., at the start of the PD and upon the completion of the PD. As indicated above, the TPACK survey instrument of Refs. 46,48 was adapted for our robotics-oriented PD and, inspired by Refs. 49,50, it was reformulated to determine participants' confidence, motivation, outcome expectancy, and apprehensiveness for each component of the TPACK framework. Each item used a 0-100 response format due to higher sensitivity and reliability of the scale.[49] Kan[51] also indicates that the 0-100 response format is psychometrically stronger than a traditional Likert format. Moreover, it is a widely accepted format for evaluating self-efficacy. We believe that TPACK item modifications and eliminations from Refs. 46,48 are relatively minor in nature and do not require an extensive revalidation of the survey. To determine changes in teachers' robotics content knowledge, a 30 item technical quiz was administered as a pre/post instrument. The reflective survey and interviews touched upon and instigated the teachers' ideas and viewpoints on the effects of the PD program on their own instructional practices and students' interests and achievements. The reflective survey was comprised of 55 questions using a 5-point Likert scale. Sample items from the TPACK self-efficacy survey, reflection survey, and robotics content knowledge technical quiz are shown in Table 2. The complete instruments used are not being shared at this time to facilitate their reuse in future offerings of the PD program. To analyze pre- and post-data of the TPACK self-efficacy, a one-tailed pairwise *t*-test was used to present the differences between dependent variables that have a normal distribution, while the non-parametric Wilcoxon Singed-Rank Sum test was performed when the difference between dependent variables did not resemble a normal distribution.

Table 1: Demographic information

	N	Percent
Gender		
Female	15	75%
Male	5	25%
Ethnicity		
African American	4	20%
White	10	50%
Asian	2	10%
Hispanic	3	15%
Other	1	5%
Education		
B.A./B.S	12	60%
M.A./M.S	7	35%
Ph.D.	1	5%
Subject Taught		
Math	9	45%
Science	9	45%
Technology/Engineering	2	10%
	Range	Mean
Teaching Experience		
Teaching years	1~30	10.5
Years teaching STEM courses	0~30	9.6

5. Results

The purpose of this study was to examine any changes in the TPACK self-efficacy of science and math teachers who participated in a PD program to integrate robotics in science and math teaching.

The descriptive statistics of TPACK self-efficacy including means, standard deviations, and the difference between the post- and pre-test means are presented in Table 3. Figure 1 graphically represents the pre- and post-survey means for the seven components of the TPACK construct.

Table 2: Sample items from three instruments

Sample items from TPACK self-efficacy survey
1.Rate your <u>degree of confidence (i.e. belief in your current ability)</u> to perform the following tasks
TK1: Solve technical problems
TK2: Learn new technologies such as LEGO robotics
TK3: Use new technologies such as LEGO robotics
2.Rate how motivated you would be to perform the following tasks
TPK1: Select technology to enhance teaching and learning
TPK2: Adapt technology to enhance teaching and learning
Sample items from reflection survey
1. To what extent, if any, do you agree that you engaged in each of the following types of activities during this workshop?
a. I performed hands-on learning activities with the EV3 LEGO robot
b. I constructed the robot chassis and mechanisms using instructions provided by workshop facilitators
c. I programmed LEGO EV3 brick by following provided sample programs and instructions
2. To what extent, if any, do you agree that you experienced each of the following types of learning as a result of your participation in the workshop?
a. I gained greater understanding of the applications of science, technology, engineering, or math in everyday life
b. I acquired greater understanding of fundamental concepts in science or math
Sample item from robotics content knowledge assessment
5. A robot has wheels with a diameter of 4 cm, if the wheel rotates 8 times, how far does the robot travel? (Round to the nearest integer)
A. 50 cm   B. 75 cm   C. 100 cm   D. 125 cm

In order to identify if there are statistically significant differences between the means of the pretest and posttest responses for the seven components of the TPACK construct, analysis of the self-efficacy survey responses was performed. In doing this analysis, for each teacher, his/her response was coded using the average response for questions within each of the seven categories of the TPACK. In computing the averages within a single TPACK category, each teacher's response was also averaged for confidence, motivation, outcome expectancy, and apprehensiveness (with reverse coding used for the items related to apprehensiveness). Because four TPACK components, *viz.*, TK, PCK, TCK, and TPACK showed normal distribution, one-tailed pairwise *t*-test was used. For the remaining three TPACK components *viz.*, CK, PK, and TPK, which exhibited non-normal distributions, a Wilcoxon Signed Rank Sum test was performed. As evidenced from the following results, pre/post self-efficacy responses show statistically significant differences: a) TK: $t(19)=2.782$, $p = 0.012$; b) CK: $Z = 3.920$, $p < 0.001$; c) PK: $Z = 3.920$, $p < 0.001$; d) PCK: $t(19)=4.077$, $p = 0.001$; e) TCK: $t(19)=3.442$, $p = 0.003$; f) TPK: $Z = 3.323$, $p < 0.001$; and g) TPACK: $t(19)=2.782$, $p = 0.012$. The effect size, as determined by Cohen's d,[52] ranged from 0.683 for the PCK to 0.525 for the TPK, indicating a medium effect size. Teachers' content knowledge increased after receiving the PD training from a score of 14.05 (SD = 2.72) at pretest to 18.45 (SD = 3.47) at post-test ($t(19)=4.274$, $p < 0.001$). The effect size was 0.700, which is considered as medium.

Table 3: Descriptive statistics for items on the TPACK self-efficacy pre and post survey

TPACK components	Pre		Post		Post-Pre	
	Mean	SD	Mean	SD	Mean	SD
TK	74.84	26.69	80.30	25.62	5.46	1.07
CK	83.21	21.62	89.83	18.92	6.62	2.70
PK	82.77	20.46	89.91	16.21	7.14	4.25
PCK	84.05	13.57	89.83	16.30	5.33	2.73
TCK	77.88	23.40	85.38	22.11	7.50	1.29
TPK	77.43	23.38	86.39	21.83	8.96	1.55
TPACK	69.44	28.27	86.76	14.64	17.32	13.63

The analysis of reflection responses regarding the PD workshop revealed that the teachers had positive perceptions towards all the items; engagement, learning outcomes, satisfaction, facilitators' expertise, successfulness, and attitude. The mean value of all reflective responses was 3.87±0.42 out of 5. Almost all the teachers answered that they were highly engaged in the activities implemented during the PD workshop (4.46/5) and achieved positive learning outcomes towards robotics (3.88/5). Although some teachers indicated that the facilitators' expertise needed further improvement (3.31/5), overall, the teachers were satisfied with their PD experience based on the results of the three instruments.

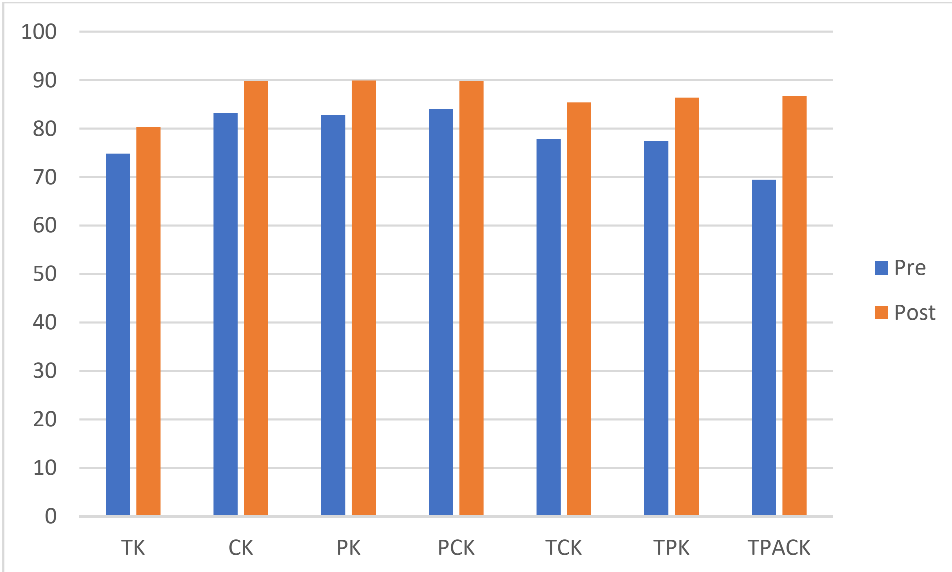

Figure 1: Comparison of the means of pre-/post-survey results for TPACK constructs (N=20)

In the follow-up interviews, the teachers noted that they felt that the PD activities were useful and will yield positive impact in motivating their students. A teacher reflected on the usefulness of the PD for learning math as follows.

> *I believe that my students will develop a more personal connection with mathematics. Unfortunately, most middle school students have become jaded when it comes to performing in the math class. I believe that these robots are going to motivate my students to become more engaged and interested in learning math topics.*

Another teacher indicated that the PD workshop will help her students familiarize themselves with robotics, which can attract them to STEM careers.

> *My students do not have a lot of access to technology in general. Robotics will enable them have exposure to this type of technology and hopefully will spark an interest in pursuing STEM related careers.*

Based on the aforementioned findings, the robotics-integrated PD program produced crucial data on the importance of improving teachers' self-efficacy, content knowledge, and the instructional and motivational benefits that both the teachers and students can receive. Thus, results from this study reveals that an effective PD is a viable tool for integration of robotics to support reform-based science and math teaching, which meets the need of educational reform proposed by several national documents.[3,5,53]

6. Discussion and Conclusions

The four million teachers in the United States do not have the same knowledge and ease (or excellence) of using technology.[53,54] The problem is the lack of effective PD programs for training the teachers to integrate technology into their teaching practices. Researchers have determined that successful technology integration does not occur without meaningful PD.[55-57] The purpose of this study was to evaluate the effectiveness of a PD program designed to integrate robotics into middle school science and math curricula. The effectiveness of the PD was measured with three tools. The first tool was the TPACK self-efficacy survey, which contained the seven sub TPACK constructs and which was adapted to include the dimensions of confidence, motivation, outcome expectancy, and apprehensiveness. The second assessment tool was the content knowledge technical quiz about robotics topics. The third tool consisted of reflection questions and a corresponding interview about the PD program. The first research question was designed to determine whether the PD program was effective in improving participants' TPACK self-efficacy and acquiring the necessary knowledge for improved technology integration. We found that the teachers' TPACK self-efficacy and content knowledge for robotics showed statistically significant increase in the post-test *versus* the pre-test, which is consistent with results from previous studies.[46]

Many educators agree that moving teachers to a new way of teaching is not easy. Based on our experiences and findings, we believe that this PD workshop contributed in important ways to engage the teachers to learn and practice the content of the program. Specifically, intentional program design, standards-aligned curricula, and hands-on activities engaged the teachers in learning. As the teachers developed and demonstrated competency, they were challenged to draw upon their knowledge of content and pedagogy to develop robotics-based science and math lessons. Moreover, during the academic year, the project team provided sustained direction, guidance, and opportunities for the teachers to conduct, assess, and reflect on teaching and learning with robotics. Even as the outcomes of this PD workshop have been successful, there are two limitations to its generalizability. First, this study had a small sample of teachers and, second, the survey instrument entailed self-reporting by teachers of their non-cognitive skill. Several prior studies have indicated that self-report methods are limited in their reliability and validity.[58,59]

PD programs should provide new knowledge and skills to change teachers' pedagogical practice. This change allows teachers to reframe their beliefs, increase confidence and comfort related to technology use, and recognize obstacles to technology integration. Prior studies have shown that the incorporation of robotics as an educational tool in science and math curricula of middle schools can contribute to enhancing student's learning if the teachers are able to transfer their PD experience about technology integration into their own instruction. The potential of robotics to contribute to students' cognitive development process can be additionally explained based on the situated learning and constructionism frameworks. Moreover, Barker and Ansorge[60] argue that robotics produces a high degree of student interest and engagement, and promotes interest in science and math careers. Further, Ruiz-del-Solar and Avilés[61] claim that robotics renders highly motivating activities, allowing students to approach technology entertainingly, while uncovering the underlying science and math principles. Through hands-on experimentation and with teachers' support and influence, such technologies can help students to construct their own understanding of abstract science and math concepts using concrete real-world applications.[62] Students who are proficient in science and math know and interpret scientific explanations of the natural world and participate productively in mathematical discourse. Such reform-based approaches to teaching science and math require substantial changes in teachers' instructional practices, which can be achieved by participation in effective PD activities and their integration in classroom settings.[63] This exploratory study is on-going and the project team is seeking to investigate effects of educational robotics on teachers and students. Specifically, we will examine how the incorporation of educational robotics in science and math curricula causes shifts in teachers' instructional practices, leaning more towards RTPs. Scientific and engineering practices (e.g., using math and computational thinking) advocated by the NGSS constitute one pertinent example of RTPs. To enhance students' interests and learning outcomes, after participating in the summer PD, the teachers are implementing science and math lessons using robotics based on their knowledge, beliefs, and practices gained in the PD. In collaboration with these teachers, the project team will use qualitative (e.g., interview, artifact analysis) and quantitative methods (e.g., pre-/post-tests, attitude survey) to examine changes in students' motivation, engagement, and achievement.

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