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Middle School Teachers' Evolution of TPACK Understanding through Professional Development

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Middle School Teachers' Evolution of TPACK Understanding through Professional Development

1. Introduction

In recent years, educational technologies have become an essential tool used to engage and improve student learning of science, technology, engineering, and math (STEM) content. The increasing use of technology in education to promote effective pedagogy of STEM content has led to the development of the conceptual framework of "technological, pedagogical, and content knowledge", also known as TPACK.[1] This framework emphasizes teachers' use of educational technologies to improve student understanding of content that imposes pedagogical challenges. The TPACK framework is derived from the interactions between three knowledge domains: technology-, pedagogy-, and content-knowledge. In the context of TPACK, technology encompasses technological products and the knowledge, skills, tools, and processes needed to design, build, and operate these products.[2,3] Pedagogy refers to principles and techniques of conducting and assessing effective teaching and learning. Finally, content refers to fundamental concepts, theoretical foundations, and knowledge connections and arrangements useful in classroom environment.[4] An *intentional* application of the TPACK framework can facilitate effective pedagogy through technology integration by making use of the interactions among the three underlying knowledge domains. Thus, for teachers to make effective use of this framework, they require the knowledge of the disciplinary content, as well as an understanding of the educational technology and its practical applications in education.

The use of the LEGO robotics kit as an educational tool has engaged students in STEM content, and recent years have witnessed an increase in its popularity.[5] Robotics has demonstrated the ability to instill excitement and encourage participation in the classroom from a wide range of learners.[6] It is critical to mention the vast scope of content that the robotics kit is capable of addressing, ranging from fundamental programming concepts[7] to advanced engineering content[8] such as modeling and control theory. Middle school mathematics and science curricula include a wide range of content that can benefit from the integration of the robotics platform. The LEGO robotics kit offers instructors opportunities to present disciplinary content through visual representations, while simultaneously creating an interactive and collaborative learning environment. The robotics platform has been shown to motivate and reinforce autonomous learning, problem solving, and teamwork through an active learning environment[9] and has been implemented in conjunction with the TPACK framework to develop lessons that address disciplinary STEM content.[10] Specifically, Ref. 10 identified pedagogical issues associated with three STEM topics and developed robotic-based instructional lessons to address the challenges. After incorporation of the robotics platform in the classroom instruction, researchers observed students demonstrating collaborative participation, positive social and emotional interactions, as well as improved learning outcomes.[10] In this paper, we examine middle school teachers' development of TPACK through a summer professional development (PD) workshop focused on exploring the design and testing of robotics-focused lessons as well as their alignment with science and math learning standards.

The PD workshop centered on collaboration between engineers, education researchers, and four middle school science and math teachers. Prior to the workshop, the engineers and education researchers created a standards-aligned curriculum consisting of five math and five science lessons aimed at mitigating content-specific pedagogical struggles through the integration of robotics. Unlike a technocentric approach, in which lessons are planned around a technological application,[11] the development of each lesson was driven by content-specific needs. Throughout the PD, a TPACK perspective was employed to introduce each lesson to the teachers, allowing them to examine, understand, and critique the teaching and learning benefits derived from the robot-based lesson. The strength of TPACK became apparent during the third week of PD when investigating a geometry-focused robotics lesson. This lesson was intended to explore how 3D objects consist of 2D layers. A robot was used to draw 2D shapes on a cardboard surface following which students cut out the drawings to construct a 3D object, similar to a 3D printer. We explored teachers' negative reactions to the robot's role in this lesson and their justifications. Having determined that the originally designed lesson lacked relevance to the classroom, participating teachers and researchers discussed other math content that middle school students struggle to understand. The teachers then created a mobile robot-based lesson to transform one of their existing lessons, on addition and subtraction with positive and negative integers, to create an exciting and effective classroom activity with a visual representation of the solution process.

As a final assessment of teachers' TPACK, on the final day of PD, they answered a set of questions designed to identify the role of the robot in each of the 10 lessons. The teachers identified the pedagogical constraints and the benefits of incorporating the robot as a teaching tool for each lesson. This paper provides a description of three of these lessons, and an assessment of teacher reflections toward these lessons.

2. Professional Development Structure

The goal of the professional development was to collaboratively and iteratively construct ten lessons that infused the LEGO EV3 robotics kit into existing middle school math and science curricula; allowing participating teachers to make use of these lessons in their classrooms in the following school year. These lessons were divided equally among science and math content, producing five lessons in each knowledge domain. In preparation, graduate level engineering students and science education researchers collaborated to construct the initial set of robotics-based lessons. The PD was then structured as a design-based experience, in which the teachers and researchers worked together to test and modify the existing set of lessons. The engineering expertise was provided by the graduate students, while teachers' knowledge of middle school students' constraints, middle school math and science state standards, and pedagogical challenges faced in classroom teaching allowed the teachers to produce constructive criticism for each lesson. The TPACK framework was discussed as new content was presented; allowing the teachers to consider the challenges faced when teaching each topic in the classroom. Teachers' understanding of the practical implementation of the TPACK framework was demonstrated through the development of the robotics-based curriculum, and through a final reflection conducted at the closure of the PD workshop. This section will discuss the participants involved, the preparation taken, and the daily operations of the PD workshop.

2.1. Participants

The participants included a team of engineers, education researchers, and four middle school teachers. The professional development created a space for learning opportunities for all participants in the design process. Each group offered a unique area of expertise, and a collaborative work environment allowed the contribution of each individual to improve the development of each lesson. Throughout this study, the engineers and education experts are referred to as the researchers, while the four middle school teachers are referred to as the teachers.

The team of engineers was comprised of three graduate-level mechanical engineering students and a professor of mechanical engineering. The engineering students had previously conducted math and science lessons in K-12 classrooms using the LEGO EV3 robotics kit which prepared them for development of preliminary lessons to present to the teachers. Their experiences in classrooms allowed for a practical design of each lesson, considering factors such as: classroom time constraints, student abilities, and student behavior issues. The team of engineers aimed to design robotics-based science and math lessons tailored specifically for classroom applications. The science education researchers included a doctoral student and a professor of science education. These individuals offered expertise in pedagogy and their knowledge of science education theory enhanced preliminary and subsequent lesson development.

The four middle school participants were current teachers at two different inner-city, public schools in Brooklyn, NY; one math and one science teacher from each of the two schools. Each had been exposed to the LEGO robotics kit prior to the PD. During the PD, each of the lessons developed by the researchers was presented and conducted with the teachers. The teachers' responsibility was to provide useful criticism and discussions on the practicality of each lesson for classroom usage. Their expertise teaching in middle schools allowed them to critically analyze the potential success of each lesson, as well as offer useful feedback on potential extensions or modifications to the lessons.

2.2. Preparation

In preparation of the PD, the researchers worked to develop preliminary designs of the robotics-based lessons and an overall structure for PD. The preliminary lessons were developed to meet state standards for middle school science and math, based on the Next Generation Science Standards[12] (NGSS) and Common Core State Standards for Math[13] (CCSSM). The structure of the PD was centered on a design-based research[14] (DBR) approach, in which iterative changes are made to improve outcomes. The teachers' role in the design process allowed them to adapt and redesign lessons to improve their application as necessary. Additionally, a collaborative work environment was used to invoke group discussions and exploit the expertise of each participant, both researchers and teachers.

The preliminary design of each lesson coincided with the robotics learning sequence, in which students learn math and science content while simultaneously being exposed to important robotics concepts. The robotics learning sequence consists of five specific domains: construction, motion, actuation, sensing, and programming. The ten initial lessons were designed to introduce students to all five domains. First, students are to be exposed to the construction phase, since a robot must be constructed for each lesson. However, to reduce classroom time spent on building and to create more opportunities to engage in math and science, a base-robot (Figure 1) was designed ahead of time onto which small attachments may be constructed, as needed, to execute each lesson. The motion and actuation phases are addressed through several applications of a mobile robot, where visible changes in the robots motion are a direct result of physical alterations to the robot. Students are exposed to applications of sensing through data collection using multiple types of sensors such as: gyroscope, ultrasonic, touch, and color sensors. Finally, students are introduced to programming in each lesson, where they must either create their own program or modify an existing program. Each of these phases in the robotics learning sequences allows students to engage in new experiences, which instill excitement throughout the learning process.

The TPACK framework was infused in the development of each preliminary lesson by considering the role of the robot and known pedagogical constraints of specific content. In an attempt to direct teachers' thinking toward the TPACK framework and to improve their understanding of it, each day the researchers engaged the teachers in discussions on difficulties students exhibit when learning that day's material. The inclusion of TPACK oriented discussion in the development of each lesson created a more thoughtful conception of technology integration, and allowed the teachers to acknowledge the role of the educational technology.

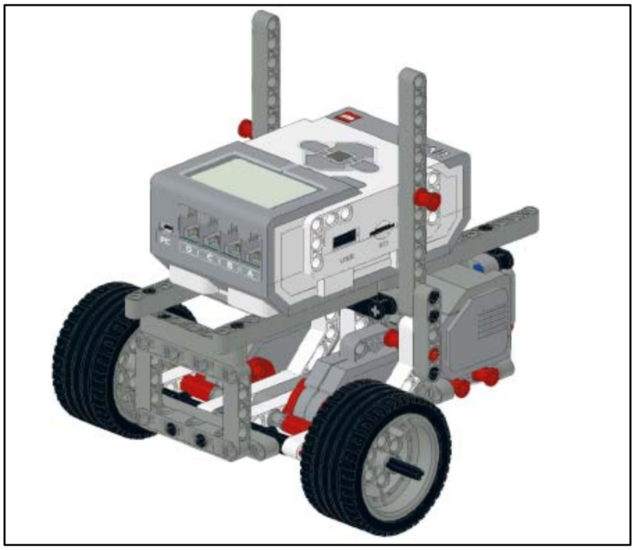


Figure 1: Base robot used in each lesson to learn mathematics and science.

The role of teachers in the design processes was an important consideration prior to the start of the PD. The researchers determined an "apprenticeship" model,[15] wherein teachers learned from experts and performed an active role in the design process, would provide them with the necessary skills to implement the lessons in their classrooms. Although the expertise of each individual enhanced and contributed to the design of each lesson, the apprentice model was only implemented in the robotics domain. This allowed the teachers to envision the role of the instructor from an apprentice perspective.

Implicitly, the PD structure and activities were aimed towards facilitating what Lave and Wenger[16] call a "learning curriculum" for all participants, including researchers. A learning curriculum consists of situated opportunities for the improvisational development of new practice. The researchers made use of situated learning, where the teachers' learning directly reflected the setting in which they will apply it. Therefore, the design process of each lesson required little lecture-based instruction, but instead provided a space for the teachers to directly experiment with the robot through each preliminary lesson. This gave the teachers an opportunity to determine the shortcomings in each lesson through practice, and to suggest modifications based on their teaching experience. Participants worked collaboratively through the duration of the PD, through group discussions and reflections.

2.3. Implementation

The PD was conceptualized as a space for production, where collaborative efforts resulted in the development of ten useful lessons utilizing robotics in classrooms to teach math and science. Through the use of DBR, the structure of the PD was consistently modified to improve learning outcomes; however, this process is not discussed in this paper and after several changes, a working model was established. This structure consisted of focusing on a single lesson each day that was split into a morning and afternoon session; the morning session was a hands-on, design-based learning experience and the afternoon session involved constructing useful documents for classroom implementation. During both sessions, instances of TPACK surfaced through discussions and observations.

During the morning session, the researchers provided the teachers with a short presentation containing the lesson content, the robot's role in the learning process, intended activities, connections to educational standards, and a discussion of content-related instances of TPACK. The researchers inquired on the pedagogical challenges teachers faced when presenting content related to the day's material. Through the hands-on, design-based approach, the teachers would then perform the activities themselves, identifying any practical limitations of the lesson. This allowed the teachers to demonstrate their TPACK through realizations of useful, or even superfluous, applications of technology.

Integration of technology in the K-12 classroom is sometimes criticized as an expensive addition to schools, without bringing improvements in learning.[17] Technology integration in the classroom should advance students' ability to learn, rather than serving as a gratuitous enhancement. Robotics-based lessons have great potential in this respect, because the robot acts as a manipulative that makes many abstract STEM concepts more accessible to learners. However, the robot should be used as a tool in the learning experience rather than seizing students learning experience by performing important tasks for them or serving as a distraction. Following the testing phase, the teachers and researchers discussed the lesson, and determined whether it was suitable for classroom teaching, required modifications, or was an unnecessary use of robotics to demonstrate such content. In one instance, the use of the robot was deemed to be of no added value, which led to the development of a more impactful integration of robotics. These group discussions allowed the teachers to express their conception of TPACK and provided useful feedback to the researchers.

Throughout the afternoon session, the teachers and researchers compiled results of the morning session into valuable lesson plans, classroom worksheets, and assessment tools. The teachers created fully developed lesson plans, including: scalability, extensions, essential questions, and more. Along with the lesson plans, the teachers created classroom worksheets to guide students through the lesson and to log experimental data. Pre- and post-assessment tools were also developed to evaluate student performance when executing these lessons. During this time, the researchers worked on producing useful guides for both teachers and students to navigate the existing programs and different user interfaces on the robots. Once these tools were developed, the teachers took the lead and presented their work to the researchers, demonstrating their understanding of the lesson.

The engineering and education researchers provided support, both technical and collaborative, to help the teachers perform the tasks and provide their own adjustments and feedback for the lessons. Organic discussions and collaborations between all participants emerged, as activities could not be performed exactly as planned, tools worked in different ways, and the specific breakdowns occurred. Often times these discussions were rooted in content standards, student knowledge, or the ease of use for the robotic tools.

Each day ended with formally facilitated discussions, in which all participants reflected on how well the lesson could be implemented in math and science classrooms. During this time, the teachers demonstrated the benefits of combining technological knowledge with their expertise; predictions of future students' reactions, as well as detailed knowledge of classroom environment, educational standards, and pedagogical constraints. For instance, during one session (described below) a completely different lesson was designed collaboratively when all participants came to realize that the integration of technology, as originally conceived by the researchers, was superfluous.

3. Case Study

Earle[17] suggested the following five criteria by which to judge whether a given technology brings value to a classroom or is unnecessary. Does the technology "allow new instructional and learning experiences not possible without them; promote deep processing of ideas; increase student interaction with subject matter; promote faculty and student enthusiasm for teaching and learning; and free up time for quality classroom interaction"? According to Ferdig,[18] there are three criteria for evaluating the effectiveness of technologies in pedagogy: (1) appropriate use of technologies, (2) content learning outcomes, and (3) qualitative and observational data of social and emotional outcomes.

In the design of robotics-based lessons, teachers must be capable of evaluating the appropriate use of the robot and its value to enhance student learning, as demonstrated in a case study of a geometry-focused robotics lesson. The initial lesson was intended to demonstrate how 3D objects consist of 2D layers. We explored teachers' negative reactions to the robot's role in this lesson and the justifications behind their responses. In response to the teachers' reactions, participating teachers and researchers discussed other math content that middle school students struggle to understand. The teachers then created a mobile robot-based lesson to transform one of their existing lessons on addition and subtraction with positive and negative integers into an interactive and effective classroom activity with a visual representation of the solution process. This section will describe the original lesson proposed to the teachers, discuss the teachers' responses, and present the redesigned lesson.

3.1. Original Lesson

The original lesson covered scaling, and the relationship between 2D and 3D shapes. The CCSSM[14] for 7th grade require students to be able to describe the 2D figures that result from slicing 3D figures (7.G.A.3). The two types of 3D figures that are explicitly referenced to in the state standards are right rectangular prisms and right rectangular pyramids. CCSSM also require 7th grade students to be able to solve problems involving scale drawings of geometric figures (7.G.A.1). To address these state standards, a robotics-based lesson was constructed. This lesson uses the mobile robot shown in Figure 1, to demonstrate how 3D right rectangular pyramids are composed of scaled drawings of 2D rectangles.

To begin the lesson, students are introduced to concepts associated with scaled drawings and 3D shapes through an oral presentation. This allows auditory learners to more readily receive the content, and students engage in active learning through hands-on interactions with the robot in subsequent components of the lesson. As an introduction, a classroom discussion is generated on the effects of scaling a shape on its perimeter and area. This allows students to conceptualize the effects of scaling up versus scaling down. Inquiry-based learning is used to generate participation and critical thinking. For example, by presenting students with a rectangle with known dimensions, the instructor can pose questions such as, "if you were to scale the rectangle by ½, does the perimeter increase or decrease", or "how is the area of the rectangle affected". To reinforce their understanding of scaled drawings students can investigate more complicated shapes. A discussion is then generated to evaluate how 3D shapes are composed of 2D layers. Once again, inquiry-based learning is used to encourage participation, and students are presented with examples of 3D shapes and their corresponding 2D layers. For example, spheres are composed of different sized circles stacked on top of one another. To create a visual representation of this phenomenon, a mobile robot is incorporated into a hands-on classroom activity.

The mobile robot is constructed to drive on a cardboard surface in a path that outlines the perimeter of a rectangle. The user interface built into the LCD display on the EV3 brick allows students to scale up or down the size of the rectangle. Students are responsible for inputting the scale factor, and the robot draws the resulting rectangle. The mobile robot shown in Figure 1 is instrumented with a marker that is used to trace the path the robot travels. A marker can easily be affixed to the mobile robot using tape or rubber bands. Students outline several rectangles at different scale factors and, using scissors, cut out each traced path. The cardboard cutout shapes are then arranged by size from largest to smallest. Students then glue the rectangles together with the largest piece at the base of the pyramid. This activity provides students with a visual representation of how 3D figures are composed of layered 2D figures, and creates an opportunity for kinesthetic learners to engage in hands-on learning. The robotics component of the lesson provides new representations of disciplinary content; for example, the affect of rectangle scaling on the distance the robot travels (perimeter).

3.2. Teacher Responses

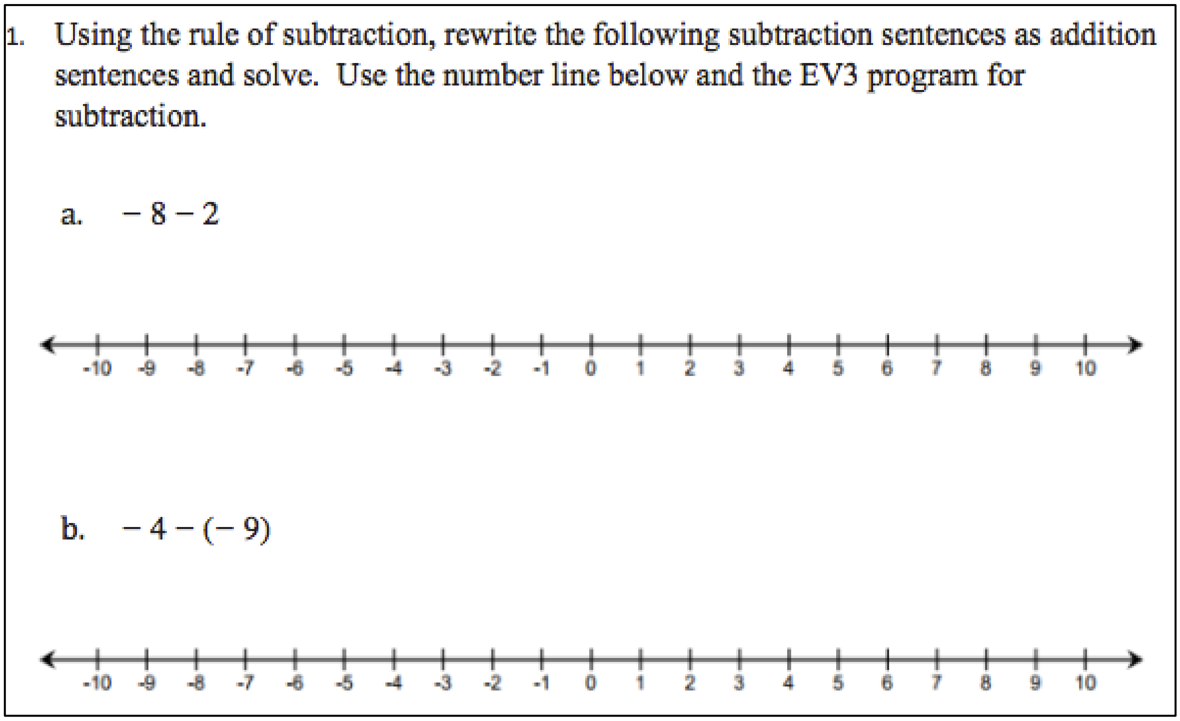
While the lesson presented above coincides with the CCSSM, the middle school teachers had negative responses to the lesson corresponding to Ferdig's first and Earle's second criteria for assessing technology's use in a classroom. The lesson was not evaluated with students; therefore, content learning outcomes and social/emotional responses are not discussed. The main functions of the mobile robot in the geometry-focused lesson are to draw and scale rectangles on the cardboard surface. Although this can be accomplished, the teachers argue that the technology is not being used appropriately. Students must be able to draw the shapes themselves. Therefore, using the robot to produce the rectangles is taking the learning experience away from the students and is considered an unnecessary integration of the technology. Students must also be able to scale the rectangle by calculating the length of each side of the shape. Thus, automating the process through an interactive user interface is also hindering students' learning outcomes. The lesson illustrated above would be a useful classroom activity without robotics.

Following the teachers' recommendations, the researchers inquired from them about math topics that present pedagogical challenges. This introduced an opportunity for the teachers to demonstrate the strength of TPACK, through the full development of a lesson. A list of topics compiled by the teachers included: line of best fit, linear equations, addition and subtraction of positive and negative integers, exponents, and scientific notation. The group decided to construct a new lesson based on integers and made use of the TPACK framework, throughout.

3.3. New Lesson

Based on their collective experience, the teachers collaboratively discussed difficulties students face when adding and subtracting with positive and negative integers. They elaborated on the conceptual challenges students have with integers and described the problem as a "fundamental issue". They have observed that students spend a significant amount of time trying to memorize rules, such as "keep-change-flip", that distract them from the content. This results in students practicing incorrect methods for too long. To address this issue, a hands-on lesson that makes use of a mobile robot was constructed.

To introduce this lesson, basic rules associated with integer arithmetic are reviewed with students. For example, addition and subtraction are discussed with reference to a number line, indicating positive numbers to the right end and negative numbers to the left end, as displayed in Figure 2. The teachers also acknowledged that students demonstrate major difficulties when working with negative numbers due to sign convention issues. To prepare for the introduction of the mobile robot, students are presented with a worksheet that includes problems to solve using a number line (see examples in Figure 2). In the following activity, students use the mobile robot to visually and numerically verify these same problems.


1. Using the rule of subtraction, rewrite the following subtraction sentences as addition sentences and solve. Use the number line below and the EV3 program for subtraction.

a. $-8-2$

b. $-4-(-9)$

Figure 2: Example problems on subtracting positive and negative integers.

For the robotics portion of the integer lesson, students begin with constructing a mobile robot using instructions provided by the teacher. The program is preloaded onto the EV3 brick by the instructor and students use the buttons on the face of the brick to interact with the robot. Teachers construct a number line made of tape on the floor and the robot drives along a path that follows the number line. Each unit on the number line is spaced four inches apart with the origin located at the center, as shown in Figure 3. As illustrated in Figure 4, students place the mobile robot in the center of the number line, and input the desired equation to solve on the EV3 brick. Then, the mobile robot illustratively solves the equation by driving along the number line in accordance with the values the student entered. For example, in problem (a) from Figure 2, the mobile robot would begin by driving backward 8 units from the origin, pause, and then travel backward 2 additional units. Students can then numerically and visually verify the robot's final position, while the process of obtaining the solution is visually illustrated to the students.

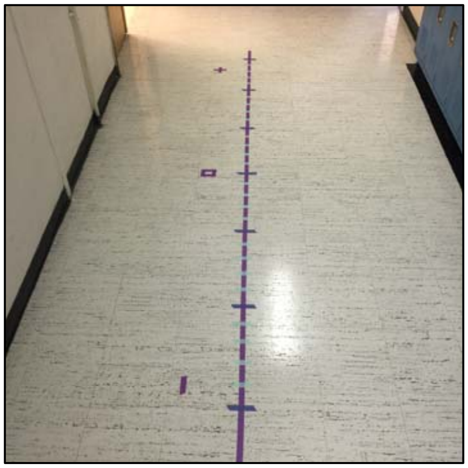


Figure 3: Number line made of tape.

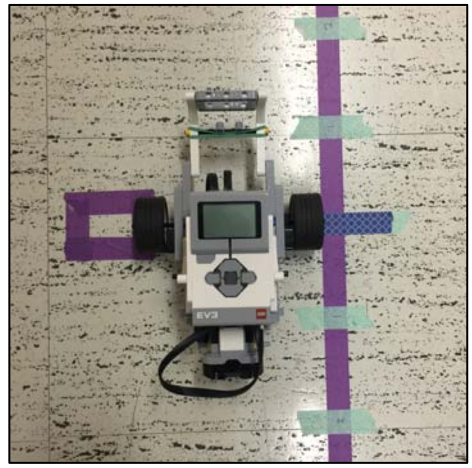


Figure 4: Mobile robot placed at the origin of the number line.

Teacher responses to the integer lesson were positive and demonstrated the TPACK synthesis process. The teachers unanimously agreed the visual nature of the robotic intervention was the most impactful component of the lesson, where students would have the opportunity to visually examine the location of the robot at each step to verify the process and the solution. Additionally, the direction the robot travels along the number line helps students internalize the sign conventions embedded within the problem. This lesson passes Ferdig’s first criterion for judging inclusion of technology in the classroom: appropriate use of technology. The robot is used as a tool within the lesson, not as a toy. As previously, content learning outcomes and social and emotional outcomes cannot be determined at this point. The teachers acknowledged that the robot demonstrates the solution in the same manner in which students are taught the material, meeting Earle’s first criterion: a new instructional and learning experience, possible only with inclusion of the robot. The lesson would also meet Earle’s third criterion: increase student interaction with the subject matter, since students would have to enter the equation into the robot and place the robot at the proper location next to the tape. The teachers’ positive evaluation of this lesson suggests it would pass Earle’s fourth criterion: promote faculty and student enthusiasm. Since this paper’s work’s focus was on PD outside of a classroom, Earle’s second and fifth criteria could not be evaluated.

During the process of this lesson development, the teachers critically evaluated the role of technology in pedagogy. By combining their knowledge of the lesson content, knowledge of pedagogical strategies that would or would not hinder their students, and knowledge of robotics technology, the teachers were able to quickly reject a lesson plan for which robotics would have been unnecessary and even an impediment to learning. The teachers were then able to develop a lesson in which robotics technology served to enhance teaching and learning. For this activity, the robot would allow students to actively engage in the learning process rather than focusing on memorizing rules, which the teachers initially described as problematic. This lesson would extend itself to students with learning disabilities and create a visually stimulating environment for learners.

4. Teacher Final Reflections

Throughout the professional development, the teachers refined the identification and design of useful instances of technology integration, as predicated within the TPACK framework. They demonstrated an increased understanding of the value of the TPACK framework and its practical classroom applications. The adaptation and design of several robotics-based lessons provided the teachers with necessary experience to translate their rich conceptualization of this technology into the classroom. As a final assessment of teachers' TPACK, researchers posed the following set of open-ended questions aiming to investigate teachers' perception of the educational technologies' value: how do you currently teach this topic; what are the constraints when teaching this topic to students currently; and how does using the robot change the lesson? Earle's five criteria for analyzing the value of an educational technology are used to judge the technology integration. The teachers' responses also shed light on their use of TPACK in assessing the technology integration. Teachers' final reflections and an analysis of their responses to the open ended questions are presented in this section for lessons on three topics: proportional relationships, modeling, and statistics.

4.1. Proportional Relationships

The essential goal of this lesson is to provide students with the necessary skills to identify proportional relationships between two quantities or values using real world situations. To accomplish this, a mobile robot instrumented with an ultrasonic sensor and three different gear configurations (Figure 5) is used. In this lesson, students investigate the influence different gear ratios have on the distance the robot travels in a given time period. The ultrasonic sensor attached to the robot is responsible for measuring the distance between the robot and a wall. The starting distance between the robot and the wall is measured when the program begins, and a final measurement is taken after the robot drives for 5 seconds. The difference between the two measurements is then displayed on the screen of the EV3 brick for students to record as experimental data. Students conduct the experiment multiple times per gear ratio, using a 1:1, 3:1, and 1:3 configuration, allowing them to manipulate the gears on the robot and examine the resulting change in its displacement. Student engagement and participation is promoted through this sense of immediate gratification. The use of different gear ratios is applied in many real world applications and this activity creates an opportunity to discuss those practical uses, such as in vehicles. As an extension, students can investigate the relationship between the different gear ratios and the velocity of the mobile robot, since the two share a proportional relationship, as well. These activities allow students to visually inspect and qualitatively assess the relationship between the gear ratio and displacement of the robot, before they calculate the numerical value.

Positive teacher responses toward the lesson on proportional relationships indicate a useful technology integration, through which student learning benefits. Each of the teachers expressed their current approaches to demonstrating this topic, which included: having students replicate examples provided by the instructor, the use of educational videos, introducing sports scenarios to create real world connections, and the use of scaled drawings to measure proportional factors. The constraints of such methods were expressed as: identifying relationships when given real world scenarios, engaging students in the lesson, and motivating student participation. The TPACK framework supports the integration of technology to address the pedagogical constraints this lesson's content introduces. Teacher reflections regarding the influence of the robot on pedagogy demonstrates sound technology integration. The teachers believed that student interactions with the robot may create real-world connections necessary to translate the information that they would otherwise struggle with, meeting Earle's first criterion. The use of student knowledge to create visually observable changes to promote deeper processing of the content would meet Earle's second criterion. Teachers also acknowledged the importance of the hands-on experience created with the mobile robot, which meets Earle's third criterion of increased student interaction. Additionally, the interdisciplinary nature of robotics allows students to gain understanding of a simple machine. Ferdig's first criteria of effective technology integration would be met by this lesson.

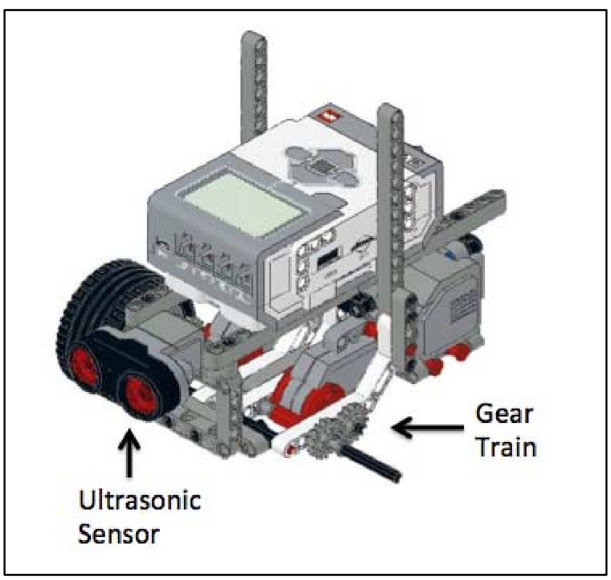


Figure 5: Mobile robot used to teach students ratios and proportional relationships.

4.2. Modeling

To introduce students to concepts such as center of mass and modeling, a mobile robot is used to investigate a real-world scenario. The main objective of this lesson is to provide students with the experience and knowledge necessary to locate the center of mass of a system and formulate predictions of its effects on the system, given a scenario. The mobile robot used in this activity has a vertical track that allows students to reposition the EV3 brick in multiple locations along a vertical axis. As a result of changing the location of the EV3 brick, the center of mass for the robot is changed. The EV3 brick is shown at the highest and lowest configuration along the vertical track in Figure 6. Throughout this activity, students are assigned an investigatory role and attempt to determine the cause of several automobile accidents that resulted from vehicles tipping over when driving around sharp turns. To justify their answer, students make use of the mobile robot as a physical model to recreate this real world situation. A program is preloaded onto the EV3 brick, instructing the robot to make several rapid sharp turns. Students are responsible for positioning the brick at several different locations along the vertical track and recording observational data of the robot's stability. They will observe the stability of the robot being jeopardized when the center of mass of the robot is raised over a certain limit. When students return to the automobile accident scenario, they can present arguments using observational evidence collected during the robotics intervention.

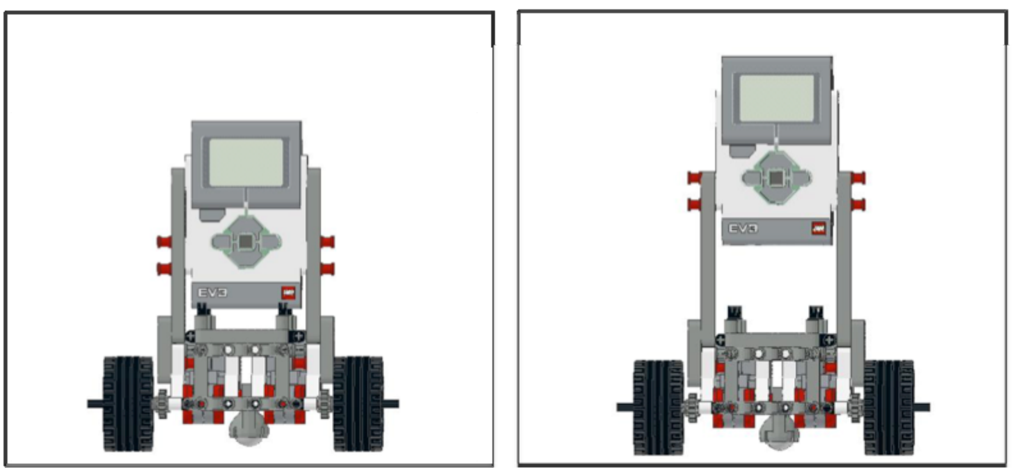


Figure 6: Mobile robot used in the modeling lesson, with EV3 brick mounted at its lowest (left) and highest (right) position.

The robotics-based lesson on modeling and center of mass creates a collaborative learning environment that can motivate classroom participation and the teachers considered the robot to be a useful integration of technology in pedagogy. Currently, teachers attempt to demonstrate these concepts through educational articles and videos, classroom demonstrations and discussions, as well as laboratory activities. Often, these approaches are constrained by students' lack of knowledge in physics, misunderstanding of the importance of the topic, and inability to conceptualize and predict how the center of mass affects real world situations. The teachers believe this lesson would bridge the gap and add to students' knowledge of physics, which would meet Earle's first criterion. They suggested that students' potential role as an investigator and the use of the mobile robot to model automobile accidents would allow for much richer student comprehension, meeting Earle's second criterion. Group dynamics are typically affected by the incorporation of robotics; a collaborative learning environment emerges and student conversation is elicited, meeting Earle's third criterion. Teachers also suggest that interaction with the robot would instill motivation in students, meeting Earle's fourth criterion. Thus, in this lesson the mobile robot acts as a useful pedagogical tool, which improves student learning, and creates an interactive, collaborative learning environment.

4.3. Statistics

As in the previous two lessons, the importance of real world connections is stressed in this robotics-based statistics lesson, focusing on central tendencies. The objective of this lesson is to provide students a research experience in statistical variability given a real world scenario. A mobile robot instrumented with an ultrasonic and touch sensor is incorporated, as shown in Figure 7. As a motivator, students are assigned a task, as aeronautical engineers, to determine which aircraft landing procedure is more reliable: automatic or manual. This real-world scenario encourages classroom participation and demonstrates the importance of statistical measurements. To justify their answers, students collect experimental data from the robot, which acts as a model of the aircraft. The ultrasonic sensor onboard the robot is pointed toward a wall and the displacement of the robot is measured in the same manner as in the proportional relationships lesson. The touch sensor is used for students to control the manual landing procedure for their "model airplane". To simulate manually landing the aircraft, students are instructed to press and hold the touch sensor for 3 seconds. This step is repeated several times to generate sufficient data. Students then measure the distance traveled by the robot in that time frame. As a result of human error, the experimental data collected for the manual landing will exhibit variability in measurements. For the automatic landing, the robot is preprogrammed to drive at the same speed for 3 seconds; measurements gathered from the automatic landing procedure should have significantly less variability. Once students have collected experimental data for both the automatic and manual landing simulations, they are responsible for calculating the mean, median, and mode of the distance the robot traveled. Students then select the more reliable landing procedure, using experimental data to justify their arguments.

The teachers considered this lesson on central tendency, "the best lesson on interdisciplinary instruction", attributed to the integration of robotics. Currently, to instruct students on these concepts the teachers make use of educational articles and videos, as well as predefined data sets that are supported by scenarios. To promote student engagement, the teachers attempt to incorporate scenarios that make the content more relevant. For example, one teacher uses actual test scores from the classroom using raw data available through the school's online grading system. However, the teachers still find students struggling when trying to connect real-world scenarios to central tendencies. Additionally, these data sets are often generated by the instructor in contrast to student-collected experimental data. Hands-on activities are also typically lacking when students learn about statistics such as mean, median, and mode. Teacher responses suggest that this integration of technology meets Earle's first and third criterion; the use of manipulatives to collect experimental data offers a new instruction and learning experience. While the teachers aim to develop more relevant scenarios for students, an opportunity to model airplane landings would both engage students in arguments supported by research and demonstrate a practical application of mathematics in the real world, supporting Earle's second criterion. Motivation is essential for student engagement. Teachers believe that this lesson would reinforce the value of real-world scenarios to validate Earle's fourth criterion.

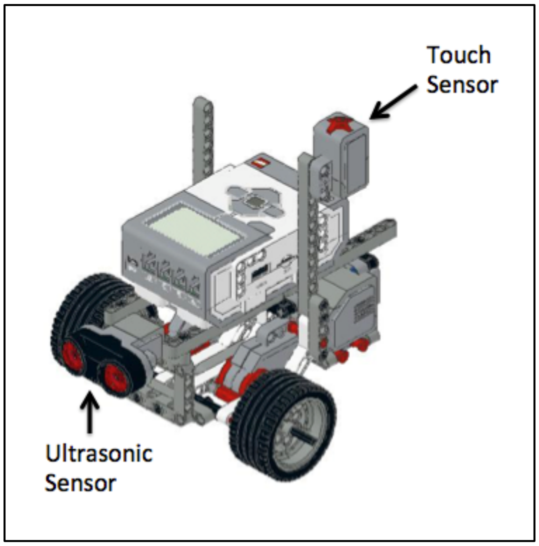


Figure 7: Mobile robot used to demonstrate statistical variability.

5. Conclusion

The use of LEGO robotics has been well documented to create an enhanced learning environment that motivates students and generates participation. A unique skill set is required for teachers to be able to construct these types of learning environments. Through the PD described in this paper, the four middle school teachers participating in the study were able to demonstrate their understanding of TPACK through a case study and final reflections on each lesson at the close of the PD. Throughout the case study, the evolution of the teachers' TPACK surfaced. They were able to recognize an unnecessary integration of robotics in a geometry focused lesson and then developed a new lesson to illustrate the solution process for adding and subtracting integers using a number line. This experience highlighted the teachers' ability to construct lessons in which the robotics platform addresses pedagogical challenges they have personally experienced. Additionally, the reflections the teachers provided at the end of the PD demonstrated a fundamental understanding of the technology integration and its appropriateness. The quality of the responses from the teachers was evaluated using Earle's five criteria for judging a given technology on its value to a classroom and Ferdig's three criteria for evaluating the effectiveness of technologies in pedagogy. As a result of this work, the middle school teachers are now prepared to integrate the robotics platform into their math and science classrooms.

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