AC 2012-5480: USING ROBOTICS TO PROMOTE LEARNING IN ELEMENTARY GRADES

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Using Robotics to Promote Learning in Elementary Grades

Abstract

This paper considers the use of LEGO robotics as a tool to allow students in a fourth grade math classroom to engage in experimenting, sense-making, and developing visual understanding of ideas. To enhance students' conceptual understanding of the abstract concepts of units and unit conversion, an illustrative example of a hands-on robotic activity is considered. The robotics activity allows for simultaneously implementing different theories of learning effectively and accommodating the learning styles of different students. To illustrate the effectiveness of the robotics-based lesson, the paper provides results of pre- and post-activity assessment, including statistical analysis.

1. Introduction

Learning for many adults is a routine part of life, however in the developing minds of elementary grade students, learning is a relatively new concept. Currently no universal theory of learning exists, therefore experts employ varied lenses of learning theory to examine important elements of learning.[1] For example, behavioral scientists consider the *observable*[2] effects of experiences and environment on learning. Moreover, proponents of behaviorism examine how various stimuli produce positive or negative learning outcomes.[3,4] In fact, behaviorists hold that motivation to learn can be a result of a combination of stimuli such as reward or punishment.[2] In contrast, cognitive scientists study *learning with understanding*[2] through the consideration of mental processes by which information is processed and interpreted. The cognitive science approach has been used to address a diverse array of situations, including learning simple to complex tasks, learning by trial and error, learning with tools and instruments, and learning by memorization.[5] Alternatively, humanistic psychologists consider learning to be the driver of individual growth and development. The practitioners of humanistic learning emphasize consideration of development of personality and acquisition of ideas, attitudes, and opinions.[6] Yet other cognitive and developmental scientists highlight the significance of meta-cognition, which is learning how to learn.[1,2] Meta-cognitive learning may include personally-attuned learning techniques (e.g., mnemonic strategies, effective problem-solving), self-motivation, and being aware of one's own unique strengths and weaknesses.[7] Each of the aforementioned views leads to differences in teaching methodologies, learning environments, and assessment approaches.[1] For example, behavioral theory leads to a teacher-centered instruction whereas the humanistic theory suggests personalized, student-centered learning.

Typically, humans learn through an array of methods, including listening, observing, reading, writing, conversing, memorizing, practicing, by consulting with others, or by performing activities. Adults are generally believed to be autonomous learners who are self-directed with minimal supervision.[3] In contrast, young learners depend on their teachers, parents, or adult mentors to guide their learning. Young students can learn through methods such as learning from teachers, memorizing, practicing, building on pre-existing knowledge, and active learning.[1,2] First, students can learn from information and explanations conveyed by their teachers in the classroom. Second, students can learn through memorization since many students believe that[1] "Learning is about getting it into your head. You just have to keep writing it out and eventually it will go in." Third, students can learn by practicing facts or procedures and doing things over as in homework and exams. Fourth, students can learn by correcting their inaccurate preconceptions and by building on their pre-existing knowledge. Lastly, students can learn by engaging in activities, experimenting, and making sense of the outcomes, thus developing their own understanding. Unfortunately, learning in many elementary grade classrooms emphasizes the use of the first three or four methods rather than the last method.[1] Learning through sense-making may challenge educators attuned to teacher-centered paradigms. Yet, one method to allow students to learn through sense-making entails active learning where students are engaged in activities that are not only fun but also impart learning, thus creating a learning environment supportive of meta-cognitive and humanistic learning.

It is critical to engage students while teaching them in order to increase their enthusiasm for learning new concepts. Educational researchers have concluded that active engagement in learning is an important tool to improve students' comprehension. Over the past several decades, education research has demonstrated that learning through actively thinking and applying prior knowledge to new situations is of significant value to students' learning than simply listening to lectures, learning new theories, or memorizing facts and equations.[8] Thus, students must be provided opportunities to apply their learning to varied situations and encouraged to apply their knowledge for their own use in real-world situations.

Learning through active engagement is essential because it enables students to develop a conceptual understanding of the material being learned, instead of the mere ability to recall facts and numbers.[9] Moreover, active learning allows students to learn to ask questions, construct their own understanding, and explain their ideas to others—practices suggested by education researchers. Teaching strategies and environments that develop such learning in students allow them to respond to new situations and serve as a foundation for lifelong learning. Active learning allows one to retain information for a longer period of time and making sense of what has been learned.[10] Moreover, a clinical study[11] has demonstrated that having some control over how one takes in the new information significantly improves one's ability to remember it.

This paper reports on the implementation and outcome of an active learning activity performed in a New York City (NYC) school with fourth grade students to allow them to bridge the gap between (a) what they learned in class through the common methods mentioned above (teacher-directed, memorization, and practicing procedures) and (b) developing their understanding of learned concepts through active engagement. LEGO robotics was employed as a tool to accomplish active engagement among students in sense-making and developing understanding. Use of robotics to teach science, technology, engineering, and math (STEM) concepts is not a new idea; in fact, literature on this subject covers a wide array of topics from elementary to graduate education.[12,13] Yet, much work remains to be done to implement robotics-based lessons and assess their effectiveness in elementary grade classrooms for formal learning. Moreover, the potential of exploring math and science principles using robotics as a sense-making tool remains largely unexplored in many K-12 public schools.[6] Encouraging students to become active seekers of STEM knowledge and principles through robotics encourages them to develop skills in problem-solving, communication, and collaboration and allows them to view the connections between the disciplines of science, math, and technology. Through experience and interaction with state-of-the-art technology, students are allowed to go beyond the walls of the classroom by learning to be young scientists, explorers, and communicators in pursuit of building and demonstrating their knowledge and understanding.

The primary focus of this paper is to provide an overview of how robotics was used to promote learning in an elementary school classroom. LEGO robotics can be used to teach students to learn, explore, and visualize abstract math and science concepts. Specifically, concepts that students find difficult to understand through theory can be simplified by the mere implementation of engaging robotic activities to facilitate experimenting, sense-making, and visual understanding of ideas. In difficult classroom situations, where students are not willing to learn due to lack of interest, robotics can be used as a powerful motivational tool to provide an inviting and exciting learning environment. This paper focuses on a math-based activity that attempts to bridge the gap between what a teacher taught and what students learned.

2. Objectives and Assessment Methods

Unit conversion is a topic that is found on a typical fourth grade New York State (NYS) exam, therefore this topic is taught by teachers like other topics found on the NYS exam (e.g., multiplication, division, fraction, etc.). The notion of converting one unit of length into another may seem straightforward to teachers and adults, however, the unit conversion process was found to be abstract in the minds of fourth grade students. Therefore, a robotic activity was developed to promote the learning of unit conversion following a discussion of real-world applications of units. The activity was designed primarily to strengthen students' skill in converting length measurements from one unit to another with relative ease. This activity was developed and implemented by a mechanical engineering graduate student from the Polytechnic

Institute of NYU (NYU-Poly) in partnership with a teacher in a public elementary school located in Brooklyn, NY. Prior to the administration of the robotic activity by the graduate student, the classroom teacher reviewed, revised, and approved the lesson to ensure its alignment with the fourth grade curriculum (Common Core State Standards for Mathematics[14]).

Classroom observations by the graduate student determined that even though fourth graders found comprehension and conceptualization of the unit conversion topic to be abstract and relatively more difficult than other topics, the typical classroom instruction did not give any special attention to address this issue. Therefore, the main goal of the newly designed lesson was not to teach students a new math topic, instead it was to strengthen students' conceptual understanding of a topic that the classroom teacher had already taught several weeks prior to the implementation of the robotic unit conversion activity. That is, the lesson aimed to utilize an exciting, engaging, and active hands-on LEGO environment to strengthen a previously taught math concept that appears on the NYS exams. The activity also incorporated student-friendly software for programming LEGO robots as well as applications of measurement units in real-world scenarios.

To measure the effectiveness of the use of robotics activities in building students' understanding of unit conversion, pre- and post-lesson assessments were administered to the entire class. The pre- and post-assessments mimicked unit conversion questions that appear on the NYS standardized tests. In addition, the pre- and post-assessments contained questions that were both identical in content and difficulty. However, different numerical values were used on several pre- and post-assessment unit conversion questions. The pre-assessment questions were administered before the implementation of the robotic activity to establish how well the students understood the unit conversion concept based solely on what the teacher taught. Likewise, the post-assessment questions were administered after the implementation of the robotic activity. Analysis and comparison of the pre- and post-assessments allowed effective measurement of whether or not the robotic activity made any actual difference in students' learning and understanding of unit conversion.

In between the two assessment sessions, conducted on the same day, the robotic activity was administered to an entire fourth grade class in which students interacted with the robots and collected data. Allowing students to collect data individually and perform mathematical operations promoted independent learning. Moreover, the session imitated a research-like environment such as when a scientist or engineer performs real-world measurement and data collection. The design and implementation of the assessment was discussed with the classroom teacher prior to the classroom implementation. The primary goal in the design of the assessment was to ensure content validity, i.e., test students on the content that was taught.[15] To achieve content validity, the assessment was administered in a timely, appropriate, and responsive fashion in the classroom itself. The pre- and post-assessment questions were graded for each student and analyzed to determine activity effectiveness.

3. Lesson on Unit Conversion

The lesson "Unit Conversion" was intended to reintroduce the concept of converting from one unit to another to the target audience of a typical fourth grade class. As previously mentioned, the topic had already been taught to the students by a math teacher. However, the teacher and graduate student sensed that fourth graders were not fully comfortable with the method of converting different units of length. A survey revealed that a majority of the students (82%) were confused by this topic. This further reiterates the point that the typical teaching and learning methods used in the classroom were not sufficient for students to grasp an understanding of this abstract topic. An effective way to illustrate this type of mathematical topic, e.g., relating yards to inches, is to give students a visual representation of the different units of length using an activity that engages their interest. Fourth grade students are already familiar with taking measurements in inches and centimeters, however they are not yet familiar with the relationship between inches and centimeters or between any other length units. Another disadvantage observed includes teachers "jumping" into teaching unit conversion without giving students any formal introduction or application related to this topic. One way to introduce this topic may begin by posing questions such as: "Why do we need to learn about units or what are its applications in the real-world?"

Apart from the lack of a formal introduction and students' conceptual difficulty with units, it was also observed that students simply memorized, or felt pressured to memorize, the "conversion factor" between different measurement units. For example, they memorized that to convert from feet to inches one multiplies the measurement in feet by twelve to obtain the measurement in inches hence the conversion factor from feet-to-inches is twelve. Similarly students memorized the conversion factor from inches to yards, etc. After students memorized the various unit conversion factors, the teacher proceeded to workout on the board various example problems, which were selected from a textbook and are part of the curriculum in the NYS learning standards. This method of memorizing, then solving textbook problems that are "theory-based", and doing problems in class by the repeating the procedures over and over constitutes a typical example of how elementary school children learn. As mentioned previously, teachers are focused on applying the first three methods of learning and unfortunately neglect learning by sense-making and developing conceptual understanding of newly introduced material.

Students were over-burdened by having to memorize the conversion factors without having a visual and conceptual meaning of what these factors physically represent. Prior to implementing the robotic activity, students were provided a formal introductory session that addressed what unit conversion is and why it is important to learn about units. The idea behind a formal introduction is to get students engaged and give them a motivation to learn and familiarize themselves with units and unit conversion topics. Examples given to the class were simple: unit conversions are needed by scientist and engineers for blueprints; perhaps it is easier to measure a bridge in yards rather than inches; incorrect application of units can lead to catastrophic failures as in the case of a Mars orbiter which was lost in 1999 due to metric versus English unit confusion. It was also mentioned that applications of units can range from scientists to engineers who take different measurements in laboratory and need to convert from one unit to another for different calculations.

After the aforementioned formal introduction, students were introduced to the LEGO robot of the lesson and given a data sheet where they were instructed to record measurements. To optimize visual aid and reduce the cognitive load of memorizing the conversion factors, three "tracks" using tape were made: the first track measured in yards, the second in feet, and the third in inches (see Figure 1). In addition, the tracks were labeled and numbered, for example, 1 yard corresponded to 3 feet and 36 inches respectively across the other two tracks. After students were introduced to the tracks, the next part of the activity focused on interacting with the robot and collecting data.

Figure 1: Three tracks numbered and labeled right to left in yards, feet, and inches respectively.

Table 1 was used by students to collect data. Students were instructed to fill in the blank spaces independently after allowing their robot to travel various specified distances. The robot was programmed to go to specified distances listed in Table 1. Once the specified distance was reached students read and recorded the values marked on the adjacent tracks of the robot. This allowed the students to visually see, e.g., how much one yard corresponded to in different length units. The proper labeling of distances along the tracks eliminated the need for students to perform unit conversion during data collection, instead students' focus was on visualizing and comprehending the physical length of each unit. To elucidate this process, consider row one of the data sheet (Table 1). The robot was placed on the yard track, positioned at the zero mark. Students would allow the robot to go one yard and record the corresponding values in feet and inches by going across to the adjacent tracks. Instantaneously, students observed that 1 yard in length corresponded to 3 units in feet and 36 units in inches. As a result students were able to conclude both visually and mentally that 1 yard was indeed the largest in size *vis-à-vis* 1 foot and 1 inch. After the students had gained a better mental model of units, the class was asked to redo the activity sheet (Table 1) without any visual aids (the tracks), i.e., they were simply asked to convert the units numerically by hand.

Table 1: Data sheet for unit conversion.

Yards	Feet	Inches
1		
2		
3		
	1	
	4	
	7	
		6
		12
		18

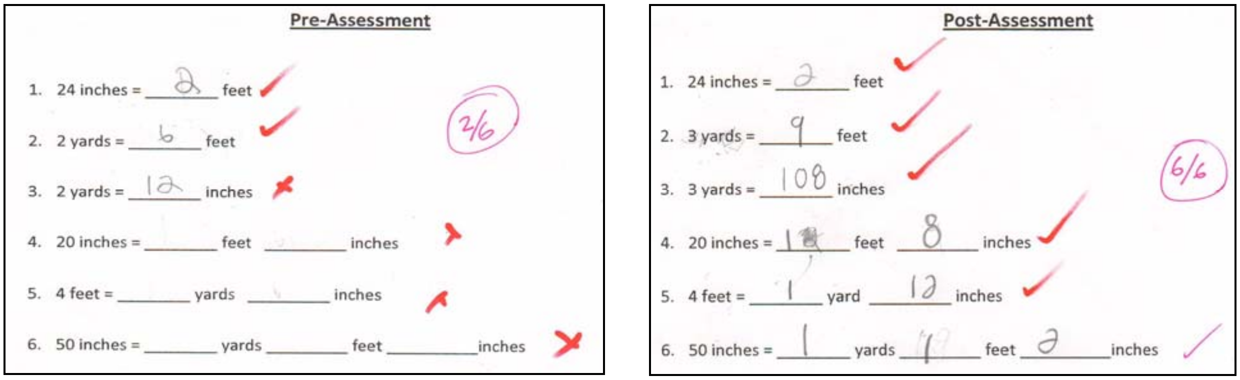
4. Lesson Assessment

To assess the effectiveness of the unit conversion lesson, 15 fourth grade students in a math class were introduced to the experimental setup. Students were divided in groups of three to use 5 LEGO robots that were available for the class. Each student was administered the pre- and post-assessment questions prior to and after the lesson activity, respectively. The assessment questions were all in accordance with the NYS learning standards and mimicked what was found in the textbook used for mathematics. Table 2 below depicts the topics that the activity covered in compliance with the current NYS learning standards. Note that the Common Core State Standards for Mathematics[9] are to be implemented in NYS in fall 2013 and the unit conversion activity is aligned with several Common Core fourth grade math standards (e.g., 4.OA, 4.NBT, and 4.MD). As seen from Table 2, multiplication and division play a significant role in the fourth grade mathematics. The NYS standards also require students to know standard units of length, appropriate conversion factors, and tools used for length measurements. Both measurement topics were covered thoroughly by the visual aids and numerical calculations within the robotic activity.

Table 2: NYS learning standard addressed in unit conversion activity.

Topic	Content
Number sense and operations	4.N16 Understand various meanings of multiplication and division
Number sense and operations	4.N17 Use multiplication and division as inverse operations to solve problems
Measurements	4.M03 Know and understand equivalent standard units of length: 12 inches = 1 foot, 3 feet = 1 yard
Measurements	4.M01 Select tools and units (customary and metric) appropriate for the length being measured

The primary objective of the assessment is to verify whether or not the robotic activity had any influence on students' learning and understanding. A higher score on the post-assessment will indicate an improvement in comprehending the material whereas a decrease in the score will indicate an adverse effect of the lesson. Figure 2 shows the sample pre- and post-assessment material administered to a fourth grade student. To maintain content validity, six questions were chosen with increasing order of difficulty. The questions of both pre- and post-assessments were kept same, only numerical data on several problems was changed in the post-assessment. This ensured a fair comparison of whether students exhibited any improvement on the post-assessment and whether students exhibited any improvement in answering questions of greater degree of difficulty. Figure 2(a) depicts the response of a student on the pre-assessment and the results indicate that the last four answers were incorrect. The post-assessment results in Figure 2(b) show improvement since the student overcame difficulty and answered all questions correctly. The teacher allowed ten minutes for students to complete each of the pre- and post-assessments. In addition to questions requiring numerical calculations, open response questions solicited students' responses to assess how comfortable they felt with unit conversion before and after the robotic activity. Figure 3 illustrates a student's answers to open response questions. Open response questions were given to students in order to fully understand their attitude towards the unit conversion topic. The numerical assessments (Figure 2) provided an objective measurement of the student's performance and how well students understood units on a conceptual basis whereas the open response questions (Figure 3) were used to evaluate the subjective opinion of how students felt toward this activity.


Pre-Assessment

1. 24 inches = 2 feet
2. 2 yards = 6 feet
3. 2 yards = 12 inches
4. 20 inches = ____ feet ____ inches
5. 4 feet = ____ yards ____ inches
6. 50 inches = ____ yards ____ feet ____ inches

2/6

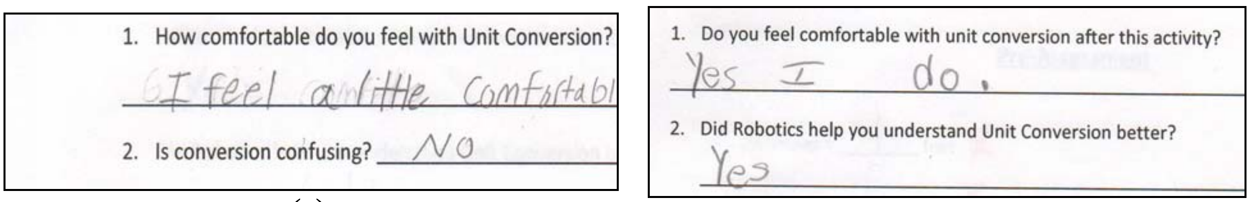
Post-Assessment

1. 24 inches = 2 feet
2. 3 yards = 9 feet
3. 3 yards = 108 inches
4. 20 inches = 1 feet 8 inches
5. 4 feet = 1 yard 12 inches
6. 50 inches = 1 yards 1 feet 2 inches

6/6

(a) (b)

Figure 2: Content questions: (a) pre-assessment and (b) post-assessment.


1. How comfortable do you feel with Unit Conversion? I feel a little Comfortabl
2. Is conversion confusing? NO

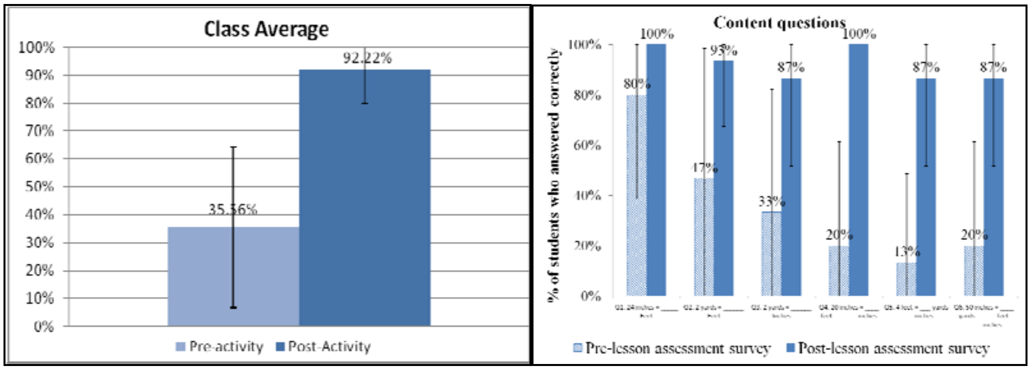
1. Do you feel comfortable with unit conversion after this activity? Yes I do.
2. Did Robotics help you understand Unit Conversion better? Yes

(a) (b)

Figure 3: Open response questions: (a) pre-assessment and (b) post-assessment.

As shown in Figure 4, analysis of the pre- and post-assessment data indicates an increase in students' performance after the robotic activity was conducted. Figure 4(a) shows comparison of class average on the pre- and post-assessment, with the post-assessment showing a large increase. Specifically, the average performance of the class increased from 36% to 92% after the activity. Moreover, students also show a significant improvement on individual questions that they were unable to numerically evaluate in the pre-assessment (Figure 4(b)). Note that the questions gradually increased in difficulty (from Q1—Q6) and as a result in the pre-assessment average class scores were extremely low for Question three to six. However, in the post-assessment, students demonstrated significant gains on these questions. As seen in Figure 4, the spread of the data (measured by standard deviation) decreased significantly following the activity, indicating that many students benefited from the activity.

The pre and post assessment data was partitioned and analyzed based on gender also. The fourth grade class was comprised of seven girls and eight boys. Results of the assessment by gender are shown in Figure 5. Both boys and girls had similar scores on the pre-assessment and boys scored marginally higher than girls on the post-assessment. In fact, Figure 5 reveals significant pre- to post-activity performance gains for both groups, the average score increased for boys by 58% and for girls by 55%. Thus, there is no evidence of girls' learning being adversely affected by the robotic activity. Finally, classroom observations showed that the class as a whole took active part in the activity and all students showed interest and positive attitude towards robotics regardless of gender.



(a) (b)

Figure 4: Performance of class before and after activity, (a): Class average of entire assessment (b): Class average of individual questions.

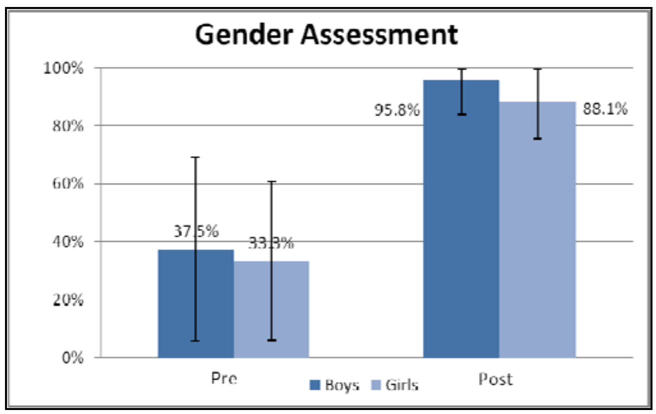
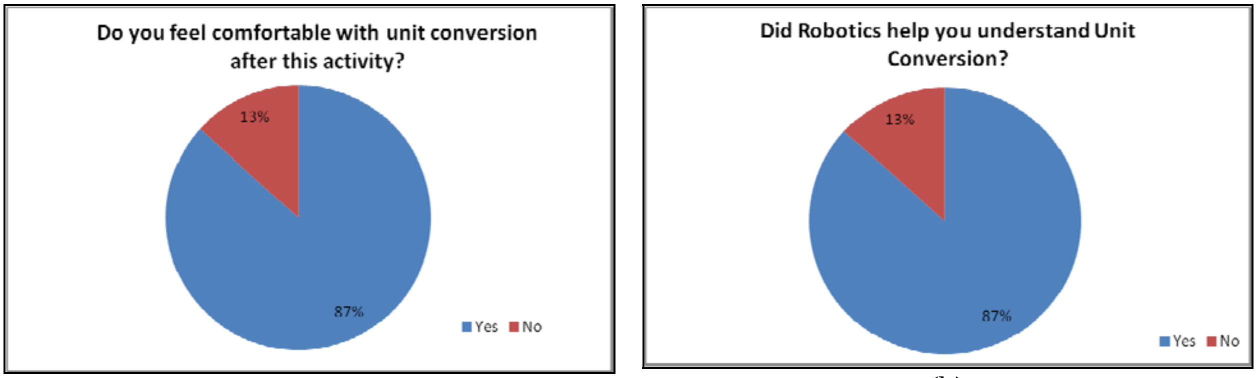


Figure 5: Comparison of the performance of boys and girls.

5. Results of Assessment

Results of the assessment indicate that the activity played an important role in students' success in comprehending the unit conversion material with ease. Not only did students improve on the assessment scores, it was observed that they remained more focused throughout the activity. Since younger students have a short attention span, it can be a challenge to keep them focused when teaching an abstract topic. However, their attention was well maintained when robotics was used to learn and understand the material. Perhaps students find the use of toy robots as a fun-method to learn and prefer this method over the boredom that they face when learning from textbooks. As previously mentioned, 82% of the students originally found the unit conversion topic to be confusing. To determine whether the robotic activity fixed this problem and whether students felt that robotic activity helped them understand units better, an open response post-activity survey was conducted. The results in Figure 6 show that a majority of the students (87%) reported a positive response concerning their comfort level with unit conversion after the robotic activity was administered. Moreover, a similar percentage of students felt that robotics helped them understand unit conversion.



(a) (b)

Figure 6: Students response to post assessment questionnaire to unit conversion activity.

To measure the effectiveness of the robotic activity, a *t*-test[16] for paired samples (pre- versus post-activity) was performed. Results of the *t*-test (see Table 3) reveal improvement that is statistically significant. The *t*-value was calculated to be 7.64, which is higher than the *t*-value at $p = 0.001$, corresponding to a confidence level of 99.9%, which indicates that the activity played a significant role in students' improvement.

Table 3: Results of a dependent *t*-test for paired samples. Values calculated using students average scores on pre and post content questions.

n	Mean Difference	Standard Dev.	*t* calculated	*p* Value
15	0.567	0.287	7.64	0.001

An unpaired two-sample *t*-test with unequal variances was conducted and revealed that gender specific pre- and post-activity performance data show no significant difference at the 10% level. Specifically, the two-sided significance level for gender specific differences in pre- and post-assessment scores was found to be $p = 0.79$ and $p = 0.61$, respectively. This indicates that there is no evidence to support the common misconception of girls being adversely affected by robotics as a learning tool.

6. Conclusion

Learning is perhaps more a form of art rather than a science, we all have different ways of learning and each individual has a different way of storing what they have learned into their brains. This may well be a reason why there is no universally acknowledged definition of learning. However, to help form the minds of elementary students, an effective method of presenting an idea to them may be through an active and engaging activity so that they can easily remember what they have learned by relating to their novel experiences. Such a novel experience can be as simple as a robot used as a learning tool that teachers can utilize for students to understand an abstract topic with visual and conceptual ease.

To promote the concept of learning through sense-making and understanding, a LEGO robot was used as a tool in a fourth grade math classroom. This paper presented an illustrative example of a hands-on activity that resulted in better comprehension of students' conceptual understanding of the abstract concepts of units and unit conversion. The evaluations showed students increased conceptual understanding of the subject content and enthusiasm towards utilizing robotics as a sense-making tool. Furthermore, the activity exposed students to real-world applications of mathematics outside of classroom. Such examples are important for students' development and connecting their minds to real-world applications of STEM at a young age.

In contrast to traditional instructional methods, LEGO robotics offers a number of advantages in an elementary school classroom. First, it is viewed by students as a reward and they are enticed to learn. Second, it provides an opportunity for developing a meta-cognitive approach to learning among students, by being both hands-on and minds-on. Third, it facilitates a humanistic approach to learning by engaging students in small teams to conduct the activity in a way that every team-member learns. In this manner, robotics allows for simultaneously implementing different theories of learning effectively and accommodating the learning styles of different students.

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