AC 2010-2269: INFORMAL ENGINEERING EDUCATION: UNDERSTANDING HOW SEVENTH GRADE STUDENTS BUILD ROBOTS TO MIMIC SPECIFIC DESERT TORTOISE BEHAVIORS

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Informal Engineering Education: Understanding how Seventh Grade Students Build Robots to Mimic Specific Desert Tortoise Behaviors

Introduction

This paper describes the implementation and results from the study of a novel teaching and learning experience in informal K-12 Engineering Education. The experience was embedded in a technology centered discovery-based afterschool program designed and delivered to 116 seventh grade students. Participants were expected to take part in the afterschool program for two-years, beginning in their seventh grade, thereby providing for an in-depth year-round experience. This effort is part of a three-year National Science Foundation (NSF) sponsored project under the Information Technology Experiences for Students and Teachers (ITEST) program. Middle school students took part in a long-term in-depth afterschool program over two-years that included both school year and summer experiences where they engaged in a variety of technology-rich project-based challenges. Site selection met the NSF ITEST program objectives of targeting underrepresented populations in the STEM fields. A purposeful selection strategy was used to select cohorts from four middle schools in the greater Phoenix area in Arizona. The project was launched in 2007 with cohort 1 (n=48) drawn from two schools. In 2008, cohort 2 (n=68) drawn from two other schools was added.

Research efforts reported here focus on studying the impact of a Desert Tortoise thematic unit. This thematic unit was the first experience in the students' two-year long engagement with this project. Students were charged with creating a desert tortoise simulation and a realistic desert tortoise habitat. Desert tortoise simulations were created using Lego Mindstorms NXT, while the habitats were constructed from existing landscapes, household materials, and common art supplies. In this paper we describe strategies used to access seventh grade students' understanding of the natural sciences related ideas of desert tortoise behaviors and the direct relationship of these ideas with their notions of what was necessary to build a robot to mimic those behaviors.

To accomplish the overall challenge, students studied the behaviors and habitats of the desert tortoise. Students had access to live desert tortoises that were brought to their classroom where they could examine the tortoise and its behavior first-hand. Students also had access to a herpetologist and botanist during a field trip to the local zoo where they visited the desert tortoise exhibit and the Sonoran Desert trail to understand the tortoise and its habitat. Students were introduced to Lego Mindstorms NXT kits in small teams of two. They were provided with time to explore the materials on their own. Subsequently, they were introduced to programming via initial exercises that then led to small-project based challenges. These challenges were designed to include the use of sensors and the related programming skills to effectively use the sensors in their robot designs. Students were provided with time to iteratively design, build, program, and test their robots. The criteria for desert tortoise robot design included the use of at least one sensor from their choice of temperature, touch, sound, or ultrasonic sensors. Students were not precluded from using more than one sensor. As a part of the overall project-based challenge, students needed to figure out how their desert tortoise robot would move—with legs or wheels, with the use of motors and gears.

Pre- and post-assessments were administered at the beginning and the end of the unit. The pre-assessment was accomplished using open-ended questions that were designed to access what students already knew about the topics in general prior to the project-based learning experience. The same assessment was used after the project so students could share their knowledge after experiencing the project-based challenge. Assessments were analyzed to determine what impact the program had on average student learning and connections made to the natural and mechanical sciences. Raw scores were converted into percents and paired samples dependent t-tests were conducted on mean differences. Test score analysis revealed a potential to enhance learning when we engage youth in experiences that emphasize both utilitarian and inquiry-based motivations. Investigations into observed patterns in the data focused on issues of moderate group gains vs. large individual gains and why such differences exist in the assessed contexts of mechanical and natural science. Further investigations looked into interpretations of the quantitative results. The data analysis we offer here demonstrates overall learning gains between pre- and post-assessments, but such results are expected due to the novel nature of the experiences. We note that aggregate quantitative scores when considered alone without other related contextual data are not sufficient to identify or concede relational understanding gains. These types of gains can only be investigated when we begin to focus on the veiled connections inherent in student responses across questions in the open-ended assessment. Results of our investigations into student scores on two questions are shared in order to demonstrate the need for contextual interpretation of quantitative scores. The two questions (see Appendix A) from our open-ended pre- and post- assessment are:
Question 4: What should your robot do to act like a desert tortoise?
Question 5: What components will your robot need to act like a desert tortoise?
Question 4 is labeled the natural sciences aspect of the assessment, as this probe requires students to demonstrate what they already know about desert tortoise behaviors; specifically within the context of the posed challenge of creating a simulation of desert tortoise behaviors using robotics. Question 5 is labeled the mechanical sciences aspect of the assessment, as this probe requires students to demonstrate what they already know about the mechanical parts needed to accomplish the simulation or mimicry of desired desert tortoise behaviors using robotics. Analyses will show that high scores on these questions do not imply how student knowledge of the natural sciences (how the desert tortoise robot acts) relates to the mechanical sciences (what components the robot needs to mimic the noted acts in the natural sciences portion of the assessment). And similarly, a low score does not imply a lack of understanding of these issues either.

Project Tools

The use of robotics in K-12 education gives students the opportunity to design and construct physical objects according to real world challenges. With the use of computers and relevant software students can even control the behavior of their objects through programming. Many researchers[1,2,3] have explored robotics to teach ideas in mathematics and engineering (e.g., control systems, computer programming).

Over the last few years, robotics-based educational programs have become a popular activity in the United States and around the world[4]. With the increasing popularity of programs like FIRST

Lego League, students ages 9 to 17 are afforded opportunities to build their own robots using programmable kits like Lego Mindstorms and VEX Robotics. Most programs typically engage students in designing and building robots modeled after print material accompanying the robotics kits[4]. As an introduction, students are usually asked to build a robot by following these instructions. For example, the Lego Mindstorms RCX kits included instructions for building a “battle tank” robot. Building vehicles and navigating mazes are a common activity in many robotics-based programs and competitions[5].

While one can argue there is nothing inherently wrong in introducing robotics in both formal and informal K-12 learning settings by giving students the task of building a robotic vehicle and navigating mazes. We advocate that such efforts are narrow and limit student creativity[6]. It is important to note that robotics includes a large variety of programmable machines that carry out actions based on inputs from sensors. For example, a garage door sensor that detects when an object is in the path of the garage door, a home security system that sounds an alarm when it detects motion, a backyard rain gauge system that triggers the irrigation system based on its detection or absence of rain, and the microwave in the kitchen that can detect when the frozen entrée is cooked, are all instances of robotics that make our lives easy.

Baker & Leary[7] found that girls liked learning science in a social context where they could interact with others and take part in learning experiences that did not isolate them. They also found that girls selected science careers because they had a strong desire to help. The American Association of University Women Educational Foundation-AAUW[8] noted that “Girls and other nontraditional users of computer science – who are not enamored of technology for technology’s sake – may be far more interested in using the technology if they encounter it in the context of a discipline that interests them” (p. v). In a 2004[9] report that surveyed Science, Technology, Engineering, and Mathematics (STEM) programs which focused on gender equity in the sciences, the AAUW found that a majority of engineering programs that focused on: “the development of construction skills, such as building robots or bridges, was prominent, followed by technology tool skills and communication skills. Research skill development was rarely found” (p. 11). These reports strongly advocated the integration of research skills and the STEM subjects with art, music, and literature.

Our project goal was to attract female and other nontraditional populations to explore STEM subjects. Therefore, it was important to create learning experiences that were not embedded in technology for technology’s sake (e.g., building bots for a robot race or a competition). In keeping with our philosophy of promoting discovery and innovation, we wanted to offer diverse pathways into robotics as a means to engage with STEM education[10,11]. This is essential if we are to ensure participation of individuals in the STEM fields who may have a diversity of interests. By utilizing a project-based learning approach[12,13,14,15,16,17], we hope to foster valuable connections by giving students the choice to pursue avenues and experiences that interested them.

For this particular challenge we selected the LEGO Mindstorms NXT kit that had its origins in the research of the MIT Media Lab. For other project activities in the overall effort, we also used another MIT Media Lab created construction kit, the PICO Cricket kit which is appropriate for the integration of art and technology. These construction kits come with a programmable brick, Lego bricks and wheels, a set of sensors (touch, resistance, light, ultrasonic, and sound), and mechanical parts such as motors, gears, cams, and nuts and bolts. They can in turn be integrated with found objects to create installations which interact with the physical world. These kits require programming on the computer to fully realize their potential as autonomous artificially intelligent objects. They provide the basic software and hardware for participants to engage in a process of discovery that leads to innovation in finding solutions to their engineering design based challenges. In this project, these kits are employed as tools for participants to discover, explore, and incorporate in their multi-disciplinary project-based challenges.

Program Activities

Although this paper specifically focuses on how we accessed students' thinking in meeting the posed challenge, we feel that a brief description of the various project activities in which the Desert Tortoise unit is situated will be useful background information. The long-term engineering education program was delivered though informal after-school activities[18,19]. These activities were organized into school year activities and summer activities, thereby effectively providing year-round programming. Activities were offered for 78 contact hours during the academic year and 48 contact hours during the summer; each year of the two-year student experience. Units delivered throughout the academic years include:

1. The Desert Tortoise: Study desert tortoise behaviors and habitats and build a toy robot that behaves like a desert tortoise using LEGO Mindstorms NXT robotics kits.
2. Circuits/Chain Reaction: Study systems concepts (e.g., inputs, outputs, power supply), actions, reactions, and closed systems by building chain-reactions using electrical circuits, Pico Crickets, and found objects.
3. Urban Heat Island: Study the heat island phenomenon and build models to mitigate heat.
4. Exploring Mars: Study the surface of Mars, getting to Mars, exploring Mars, and living on Mars.

Units delivered during the two summers comprised:

1. Youth-Docentship: Study science and engineering phenomenon at the Arizona Science Center. Demonstrate knowledge gained throughout this year-round program by engaging younger peers and their families visiting the center through small-scale hands-on workshops on specific project-based challenges.
2. Industry-Internship: Study alternative energy sources (wind, solar, hydro, and hydrogen fuel-cells) and build renewable energy models at the Salt River Project, a local water and energy service provider.
3. Technology Workshop: Study basic TI-84 plus graphing calculator functions (graphing, creating tables, performing calculations, etc.) and its connection to basic programming, data collection probes (temperature, ultra-violet ray, moisture, acceleration, pH, and light), and the CBR2 a device that has sonic motion detector capabilities.

Students and parents attended four family nights per year. These family nights were designed to give students an opportunity to share their completed projects and learning with family members, school administrators, teachers, and peers.

Teachers

At each of the project sites, two teachers were identified to serve as after-school program facilitators. The principal investigator, the school district liaison to the project, and the school administrator met with interested teachers individually and selected the two project facilitators for each site. Criteria for selection included expressed interest in the project curricula, curiosity and enthusiasm to explore new ideas and content, and availability for the duration of the year-round project. Teachers received a $3,000 stipend and seven professional development days where the district paid for a substitute teacher to work in the teacher's regular classroom.

Project Team

The project team included nine university researchers and faculty with expertise in the areas of engineering (Materials Science and Engineering, Industrial Engineering, Computer Science and Engineering), sustainability, science education, mathematics education, earth and space science, geology, counseling psychology, instructional technology, and education research methods. Project staff included: a) a female science educator with a masters degree in education and 14-years of experience teaching in high school settings and in a community college; b) a male graduate research associate with a bachelor's degree in mechanical engineering and a master's degree in mathematics education who worked part-time as a high school mathematics teacher while also enrolled in a doctoral program in mathematics education; c) a female teacher with ten-years of experience working with women in science and engineering who was also enrolled part-time in a master's degree in bio-engineering. In addition, six undergraduate research interns representing these engineering disciplines worked to help facilitate the project: Electrical and Electronics Engineering (female, Latino), Chemical Engineering (female, African American), Mechanical and Aerospace Engineering (1 female, White; 1 male, African American), Computer Science and Engineering (male, White), and Materials Science and Engineering (male, White). These undergraduate research interns served as peer-mentors working side by side with the participants and shared their educational pathways to their chosen field.

Participants

The engineering-education project spanned three years and included four junior high schools from a large district in the Southwest. In 2007, two seventh grade groups from two junior high schools were selected using a purposeful selection strategy to form cohort 1. In 2008, two additional seventh grade groups from two different junior high schools in the same district were selected to form cohort 2. Each participant was expected to stay with the program for two years, throughout his or her seventh and eighth grade experience. Participant demographics are provided in Tables 1 and 2.

Table 1. Participants by Gender

	Number		
Gender	Cohort 1	Cohort 2	Percent
Female	32	35	58%
Male	16	33	42%
Total	48	68	

Table 2. Participants by Ethnicity

Ethnicity	Number Cohort 1	Cohort 2	Percent
African American	5	0	4%
Asian American	2	0	2%
Caucasian	12	21	28%
Hispanic	25	46	61%
Indian American	4	1	4%
Total	48	68	

The Desert Tortoise Unit

The overall charge to students was to design a robot using LEGO Mindstorms NXT software and hardware to simulate the behaviors of the desert tortoise. To accomplish this charge, students studied the behaviors and habitats of the desert tortoise through activities focused on engagement and exploration of the desert tortoise and the technologies. These activities provided environments where students could: a) interact with desert tortoises—baby and adult tortoises were brought to the after-school program; b) visit a desert tortoise habitat at a local zoo; c) meet and interact with experts, seek answers, and share ideas—a desert tortoise conservationist visited the after-school program and students could interact with a herpetologist and a botanist during the zoo field trip; and d) explore the topic on their own through a university research magazine[20] focused on desert tortoise, the zoo's newsletter feature on the desert tortoise, children's books and poetry[21,22], resources from the state's Game and Fish Department, school and university libraries, and internet resources.

The desert tortoise unit spanned sixteen meetings (90 minutes each) and included seven sub-units. Common threads throughout the sub-units included: whole class brainstorming, student exploration/research, and group share activities. Student exploration and research is the most consistent of the three and refers to allocated time for students to explore further the specified topic however they saw fit. Brainstorming activities were used to engage, while group sharing activities (e.g. whole and small group discussion, white board presentations, demonstrations, vocabulary word walls) held students accountable for their learning. The collection of sub-units included: Environment of the Desert Tortoise, Physical Nature of the Desert Tortoise, Hands-on and Observation, Introduction to the LEGO Mindstorms NXT kits, Design and Construct an NXT Desert Tortoise, Design and Construct a Desert Tortoise Habitat, and Presentations.

Environment of the Desert Tortoise

This sub-unit spanned two meetings and included introductions to explore media (e.g., magazines, Game and Fish resources, and library print and computer resources), whole class brainstorming about the desert tortoise habitat, student exploration, and group share activities.

Physical Nature of the Desert Tortoise

This sub-unit spanned one meeting and included whole class brainstorming about the desert tortoise, student exploration and research, and group share activities.

Hands-on and Observation
This sub-unit spanned two meetings and included a desert tortoise conservationist visiting the school with desert tortoises and a field trip to the local zoo where students could interact with a botanist and a herpetologist, explore desert tortoise habitats and the Sonoran desert where the *Gopherus Agassizii* lives. It is important to note here that the *Gopherus Agassizii* is a protected species in Arizona.

Introduction to the LEGO Mindstorms NXT kits
This sub-unit spanned three meetings and included an introduction to the Mindstorms NXT Kits where students explored the parts included in the kit and a shared understanding of the student's responsibilities in managing their robotics kits were developed. This was followed with student exploration and building of a robot, computer programming with NXT software, and a group share activity. This sub-unit was separated into two phases: student exploration and structured building/programming in teams of two students. In the first phase teams were given time to explore all aspects of the kits on their own. During this time, facilitator interactions were limited to answering direct questions when prompted. In the second phase, we provided a rigorous structure to what the students could build and program. In each case we provided structured blueprints for building a prototype robot and programming challenges that used the various sensors in the prototype robot. These activities were aimed at providing students with the initial success needed when learning a new form of technology. From prior experience working with Lego Mindstorms RCX and NXT kits project leaders had learned that without structured learning experiences, seventh grade students could potentially be frustrated with the building and programming aspects of such an effort.

Design and Construct an NXT Desert Tortoise
This sub-unit spanned three meetings and included an introduction to the engineering design process, student robot construction and programming, and a group share activity. To begin, students were asked to dismantle the prototype robot that they had constructed in the previous unit. During this sub-unit, students used the engineering design process to iteratively design, construct, and program a robot that mimicked the physical appearance and behavior of a desert tortoise.

Design and Construct a Desert Tortoise Habitat
This sub-unit spanned three meetings and included group brainstorming, student research, assigning students to teams that engaged in habitat design and construction in a 10'x10' area in their school backyard.

Desert Tortoise Robot Navigation of Habitat
This sub-unit spanned two meetings and included tying-up loose ends, desert tortoise robot testing and modification, introduction to presentation strategies and techniques; and student presentations (including an audience of family members, principals, and district administration).

Implementation and organization of the activities in each sub-unit followed the 5-E learning cycle (Engage, Explore, Explain, Elaborate, and Evaluate)[23,24,25] instructional design approach. In the *Environment of the Desert Tortoise* sub-unit, we used the 5-E learning cycle as follows. We initiated the sub-unit by engaging students in brainstorming activities to elicit their prior knowledge about the desert tortoise habitat. Facilitators validated student prior-knowledge by summarizing the large group's collective input on the class white board. Brainstorming sessions were followed by student exploration of related topics on their own. Students were paired together and encouraged to explore areas of their choosing through a multiplicity of materials and resources. Provided with prompts to guide their exploration of resources, students successfully documented the new knowledge in their notebooks. In a whole group share activity, each group was given an opportunity to explain what they had learned using white-board presentations. During the group share activity project facilitators elaborated on topics where appropriate, to include informal questioning concerning topics that were deemed important, but not reported in the group share activity. The unit culminated with students making journal entries with descriptive notes and drawings. Each unit followed the same basic outline.

Student Work

Even though student work varied in appearance and performance, there were many similarities in the designs. Figures 1-3 shows three desert tortoise designs, representing the basic similarities and differences throughout all student work. In each case, students used wheels as a means of moving their desert tortoise. We can see from Figures 1-3 that the number and relative position of the wheels varied.

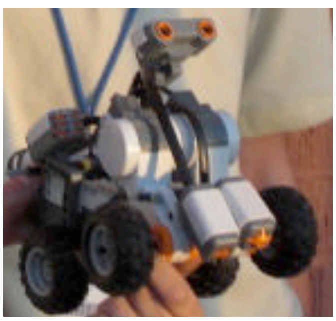
Figure 1: Student Design 1

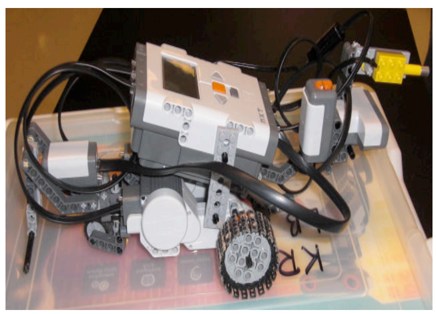
Figure 2: Student Design 2


Figure 3: Student Design 3

Before building the desert tortoise habitat, students produced a sketch of their intended habitat. We can see from Figure 4 that the design includes desert plants, a man made danger area (the highway), and a burrow. The terrain features came to life through existing desert terrain (as a part of the school grounds), construction materials, and art materials. Figure 5 shows the 'highway' as depicted in the sketch. Figure 6 shows a simulated burrow with golf balls representing desert tortoise eggs.

Figure 4: Student Habitat Sketch


Figure 5: Student Habitat


Figure 6: Student Habitat

Data Analysis

Student learning was assessed using formal and informal methods. Formal assessments consisted of pre- and post-assessments. Informal assessments consisted of whiteboard presentations, open-ended questioning, demonstrations, journal write-ups, and teacher observations. These were used to guide daily activities and lessons.

Pre- and post-assessments in the form of open-ended and fill-in-the-blank questions relating to major unit content were administered. These assessments consisted of five questions (Appendix A). Questions 1-3 focused on the natural sciences of the desert tortoise where students identified physical features and behaviors of the desert tortoise and its habitat. Questions 4 and 5 focused on the mechanical sciences of the simulation where students identified behaviors and components necessary to simulate a desert tortoise with robotics. Analysis was conducted on each category of questions to determine what impact the project had on student learning. Equal sample size dependent t-tests and qualitative comparisons were conducted to compare differences in the relationship between pre- and post-assessment responses and scores. All scores were converted into percent correct as a way of standardizing the scores between years. The resulting statistics can be found in Table 3.

Results

Table 3. Desert Tortoise Simulation Unit, Pre-Post Assessment Percent Scores

	Questions	Assessment	Mean	SD	Mean Difference	t	P	Effect Size
Cohort 1 (n=37)	1-3	Pre	39.19	16.39	33.78	12.53	< .01	2.14
		Post	72.97	15.25				
	4 & 5	Pre	14.32	8.01	28.38	21.56	< .01	2.48
		Post	37.03	14.88				
Cohort 2 (n=45)	1-3	Pre	52.73	23.16	21.43	6.21	< .01	1.02
		Post	83.41	18.67				
	4 & 5	Pre	12.05	13.18	31.94	16.21	< .01	2.11
		Post	38.22	17.15				

Paired samples dependent t-tests were conducted on the pre- and post- scores. Although we had 48 students in cohort 1 and 68 students in cohort 2, we excluded student records as follows: a) instances with no pre- and post- assessment data and b) instances with incomplete or no answers for some of the pre- or post- assessment questions. Therefore the sample sizes were constant for each cohort. Since the sample sizes were constant, the effect size for each set of pre- and post-scores was determined by dividing the mean difference by the average standard deviation between pre- and post- scores. Statistical analysis showed statistically significant differences between the means for the pre and post assessments; $t(36) = 11.741$, $p < .01$ *and* $t(36) = 21.48$, $p < .001$, $t(44) = 8.76$, $p < .01$ *and* $t(44) = 12.58$, $p < .001$.

The analysis demonstrates that on average student participants in the Desert Tortoise unit scored significantly higher on the post-assessment in both the natural sciences of the desert tortoise and the mechanical sciences of the simulation categories. These results were expected. Students had not previously engaged in the topics associated with this unit and as a result they experienced high levels of learning. The data demonstrates that the technologically centered discovery-based curriculum delivered in this project had a significant impact on average student learning in both the natural sciences and mechanical sciences. Effect sizes are generally large, above two standard deviations with one exception. With cohort 2, for questions 1-3 the effect size is located at one standard deviation. We found that cohort 2 students had more prior knowledge about desert tortoises than the students in cohort 1.

Standard deviations across the pre- and post-assessments imply a difference in the change in score variance for questions 1-3 and questions 4 & 5. Analysis shows a decrease in the standard deviations for questions 1-3 and an increase for questions 4 & 5. As such, the decrease in the variance across questions 1-3 suggests learning achievement as a group, rather than a select few with outstanding gains compared to stagnant or negative gains for the rest of the group. However, this is not the case for questions 4 & 5. The analysis demonstrates an increase in the standard deviations from pre- to post- scores. Even though mean differences between scores are statistically significant, we cannot conclude that the average achievement occurred as a group.

The next phase of analysis focused on determining if student participants made a connection between the natural sciences (question 4) of the desert tortoise robot and the mechanical sciences (question 5) of the robotics simulation. As presented in the previous analysis phase, on average, student scores increased from pre- to post-assessment. Accordingly, investigating question 5, "What components (parts) will your friend's robot need so that it can act like a desert tortoise?" we note a similar increase in the post-assessment scores (Table 4). Elements of Table 4 list the number of students who scored low and high on question 5 according to the pre- and post-assessments. Question 5 was scored on a scale from 0 to 4 (Appendix B), where 0 indicated no knowledge of the subject. Students who scored 0 and 1 were deemed "Low", while scores of 2, 3, or 4 were deemed "High".

Table 4. Number and Percent of Students who Scored "Low" and "High" on Question 5.

	Question	Assessment	Low Score (0-1) #	(%)	High Score (2, 3, 4) #	(%)
Cohort 1 (n=37)	5	Pre	36	(97)	1	(3)
		Post	8	(22)	29	(78)
Cohort 2 (n=45)	5	Pre	42	(93)	3	(7)
		Post	11	(24)	34	(76)

Guided by previous experience, we decided to investigate the meaning behind the increase in pre and post scores, i.e., were students regurgitating learned vocabulary and facts or were they making informed choices based on the relationship between desert tortoise behavior and the robotic components necessary to simulate said behaviors? To investigate this phenomenon, we compared student responses for:
"Question 4: What should your robot do to act like a desert tortoise?" and "Question 5: What components will your robot need to act like a desert tortoise?" How students responded to these questions allowed us to explore the connections between the natural sciences of the desert

tortoise and the mechanical sciences of the robotics simulation. For instance, if students noted in the natural sciences portion of their assessment that a desert tortoise reacts to temperature, then we would expect to see the student note that a temperature sensor would be necessary for their desert tortoise robot to mimic this behavior. Our rationale for focusing on the student score for question 5 rests in the inherent connection between the natural and mechanical sciences of this question. When prompted to identify what components the robot will need so that it can act like a desert tortoise, especially in responding to the post-assessment, we expected students to consider the behaviors identified in question 4 as they relate to this prompt in question 5. By investigating the score students earned for question 5 and the relationship between responses to questions 4 and 5 we hoped to identify the potential reasons for the varying responses. Our aim was to learn if students were merely recalling components learned throughout the unit without actually demonstrating an understanding of whether these components were needed for specific desert tortoise behaviors they wanted to mimic using the robotics kit components. In this regard, student responses were classified into four categories:

1. HR- Scored high on question 5 with a relationship between question 4 and question 5.
2. HNR- Scored high on question 5 with no relationship between question 4 and question 5.
3. LR- Scored low on question 5 with a relationship between question 4 and question 5.
4. LNR- Scored low on question 5 with no relationship between question 4 and question 5.

Table 5 shows the number of student responses from the post-assessment that we determined had demonstrated a relationship between questions 4 and 5, where the term relationship indicates a clear connection between the natural sciences of the desert tortoise and the mechanical sciences of the robotics simulation. To illustrate what we mean by "relationship" let us examine a few student responses.

S1: Q4 - The robot should walk like the desert tortoise. The desert tortoise has a pattern of how it walks. It walks in the pattern 1, 4, 2, 3. Also, the desert tortoise should make the robot so it can climb over small objects. The desert tortoise should be able to walk when a certain temperature comes up.
Q5 - Temperature sensor - temperature has the robot move when it is at a certain temperature; Touch sensor - when the robot is touched it moves; Ultrasonic sensor; sound sensor - when you talk the robot moves.

S2: Q4 - Sense heat
Q5 - Motors

Student 1's (S1) response to question 5 received a high score for listing a majority of the components needed from the LEGO Mindstorms NXT robotics kits to simulate a desert tortoise, while Student 2's (S2) response to question 5 received a very low score. In both cases, S1 and S2 make references to actions performed by a desert tortoise that cannot be simulated by the components listed in question 5. The lack of a relationship between questions 4 and 5 could indicate that these students are separating the natural sciences of the desert tortoise and the technology of the LEGO Mindstorms NXT robotics kits.

The next set of student responses demonstrates a relationship between the students' responses to question 4 with their responses to question 5. Similar to S1 and S2, S3's response scored high, while S4's response scored very low.

S3: Q4 - He should make it move slowly to be able to sense danger and different temperatures and be able to hear.
Q5 - A temperature sensor, a light sensor, a sound sensor and an ultrasonic sensor. It will need wheels or feet that will let it move too.

S4: Q4 - Be listening for sounds
Q5 - A sound detector

In contrast to S1 and S2, S3 and S4 in response to question 5, demonstrate knowledge of the mechanical/technical components necessary to simulate the actions they had listed in response to question 4.

Table 5. Relationship Between Post-Assessment Questions 4 and 5, by Number of Students.

	Score	Relationship (R) #	(%)	No Relationship (NR) #	(%)
Cohort 1	High Score (H)	17	(46)	12	(32)
(n = 37)	Low Score (L)	3	(8)	5	(14)
Cohort 2	High Score (H)	20	(44)	14	(31)
(n = 45)	Low Score (L)	3	(7)	8	(18)

Referencing Table 5 we can see that in the post-assessment, with cohort 1, 46% (17 out of 37 students) and with cohort 2, 44% (20 out of 45 students) demonstrated an understanding of the relationship between the natural sciences of the desert tortoise and the mechanical sciences of the robotics simulation. In contrast with cohort 1, 33% (12 out of 37 students) and with cohort 2, 31% (14 out of 45 students) demonstrated no such relationship. We note that regardless of the relationship type between questions 4 and 5, with cohort 1, 78% (29 out of 37 students) and with cohort 2, 76% (34 out of 45 students) scored high on question 5. However, it is clear that with cohort 2, only 46% (17 out of 37 students) and with cohort 2, only 44% (20 out of 45 students) of these high scoring students seemed to understand the relationship between these questions. When the data are examined in this manner, the diagnostic limitation of focusing solely on post-assessment increases becomes clear.

The large number of students who demonstrated no relationship between the knowledge gained during the Desert Tortoise and Lego Mindstorms NXT explorations suggests an incomplete picture of the learning gains portrayed by the pre- and post-assessments. Therefore, analytic techniques required careful expansion from quantitative analysis of pre- and post-assessments, to additional measures of student learning that included interviews with project participants, the use of the engineering design process in designing their robot, and the related computer programming necessary for autonomous operation of their desert tortoise robot.

When we interviewed students who had demonstrated no relationship between questions 4 and 5, it was clear that this group included students who had difficulty with programming the use of the sensors for their robot that would achieve the desired behaviors (e.g., robot moves into or out of the burrow when it senses a temperature change; robot moves when it senses a particular sound, such as the raven's call). We found that these students also had difficulty with writing a program that used loops to repeatedly sense for triggers that would result in related desired behaviors (robotic actions). It is important to note that students worked in teams of two to iteratively design, build, program, and test their desert tortoise robots. Teams were encouraged to share their successes with each other, and we observed many teams learning from their peers. Frequently this meant that a team would ask a peer to come to their table to help them with a programming challenge they had encountered or would look over the shoulder of a peer at her successful program.

However, when it came to individual team dynamics and how that played out with meeting the challenge we found that teams which had both student members who said that they preferred "designing and building to programming" and student members who said that they attended the after-school program primarily to "socialize with friends" over "learning how to program a robot" had more difficulty with successful implementation of desired desert tortoise behaviors with their robots. Later, as students were exposed to the PICO Cricket robotics-based construction kit, some of these same students noted that the "Lego Mindstorms NXT programming was hard", but they found the "PICO Cricket program [software user interface] easier and more fun." Whereas, there was also a group of students who preferred the Lego Mindstorms NXT kit as they could build "mobile robots with the NXT" and it was "harder to build robots that could move with the PICO Crickets." It was clear that there were some students in the afterschool program who reached a frustration threshold early in the process of iteratively designing, building, programming, and testing their desert tortoise robot. Some of them said, "I am tired of programming," and "want to give up, because it is too hard!"

As a result, we have considered making specific changes to the manner in which we introduce and structure the programming aspects of this project-based challenge. We have also considered starting with a unit that uses the PICO Cricket kit prior to introduction of the Lego Mindstorms NXT kit. Our aim is to further explore a set of instructional strategies that offer a smooth technological ramp from the concrete to the abstract with enhanced scaffolding to improve student understanding of how sensors work and how successful use of sensors can help achieve the programming of desired robot behaviors.

One of our considerations is to provide learning experiences that allow for early success, a key element in maintaining sustained engagement with the larger project-based challenge. In future implementations, we will make adjustments to our instructional and engagement strategies to assess whether we can create conditions in informal learning that allow for more enhanced and in-depth learning than our initial experiences as noted in this paper. While it is clear that student participants in this program have demonstrated remarkable learning gains, we also want to acknowledge that it is necessary to systematically study informal learning experiences, especially such as the one described in this research effort so we can further enhance their impact and broaden participation to all students.

Scientific Significance of the Study

We have discerned that by engaging youth in learning, which emphasizes both utilitarian and inquiry-based motivations, the outcome leads to enhanced learning in the specified content area. The analysis from this study demonstrates the effectiveness of a technologically centered discovery-based curriculum on student learning. When given the chance to independently explore ideas and contexts, students are capable of achieving significant learning gains in both academic and technology centered contexts; as such they become an empowered part of the learning process.

Care needs be taken when interpreting learning achievements resulting from inquiry-based curriculum. In the case of our study we found a statistically significant difference in the pre- and post-assessment scores. We can and did conclude that positive learning gains were made throughout the unit. However, it is too easy for researchers to assume understanding, through a range of contexts, when learning is statistically present. To make such assumptions would be a mistake. For example, we can responsibly conclude that students did in fact produce learning gains in the contexts of the desert tortoise, the desert tortoise habitat, and the NXT Mindstorms components. However, we cannot responsibly conclude that students understand the connections necessary between the actions of the desert tortoise and the performance of NXT Mindstorms components.

Educational Importance of the Study

Students who find traditional in-school science and math curricula uninteresting and disconnected from their lived-experiences need to be engaged in learning by doing[26]. The critical issue for our nation is to enthuse all youth, particularly, traditionally under-represented students: *females and ethnic minorities*, in STEM subjects. Results from this study will be useful for others who are interested in informal learning strategies and studying the impact of such efforts.

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Appendix A

Desert Tortoise Unit Pre- and Post- Assessment

1. Your friend wants to look for a desert tortoise. To help him/her list the items that can be found in the desert tortoise's natural habitat. (List as many as you can)

2. Your friend doesn't really know what a desert tortoise looks like. Help your friend by listing the physical features of a desert tortoise. (List as many as you can)

3. Since your friend does not know much about the desert tortoise you have decided to give her/him some information before he/she goes out to look for one. To help your friend, complete the sentences below.
   a. A desert tortoise gets water by ___________________________________.
   b. A desert tortoise digs a burrow with _______________________________.
   c. A desert tortoise uses a burrow to _________________________________.
   d. In its natural habitat, a desert tortoise eats __________________________.

4. Your friend wants to build a robot that acts like a desert tortoise. What actions might the robot perform to act like a desert tortoise? (List as many as you can)

5. What components (parts) will your friend's robot need so that it can act like a desert tortoise? (List as many as you can)

Appendix B
Desert Tortoise Unit Assessment Rubric

Question 1: Describe the habitat. (Pictures should follow the same criteria)

0	1	2	3	4
-No Answer -Entire answer is incorrect. -Desert	Any (1-2) of the following: 1) Sand/Dirt 2) Hot/Dry 3) Cactus 4) Burrow 5) Rocks 6) Desert trees 7) Desert bushes/shrubs 8) Little water	Any (3-4) of the following: 1) Sand/Dirt 2) Hot/Dry 3) Cactus 4) Burrow 5) Rocks 6) Desert trees 7) Desert bushes/shrubs 8) Little water	Any (5-6) of the following: 1) Sand/Dirt 2) Hot/Dry 3) Cactus 4) Burrow 5) Rocks 6) Desert trees 7) Desert bushes/shrubs 8) Little water	Any (7-9) of the following: 1) Sand/Dirt 2) Hot/Dry 3) Cactus 4) Burrow 5) Rocks 6) Desert trees 7) Desert bushes/shrubs 8) Little water

Question 2: Describe what a desert tortoise looks like. (This question has two scores) (Pictures should follow the same criteria)

Group A	- Hard/Round shell. - Rectangular bumps on the shell. - Brown/Green in color. - Claws on front legs. - “Beak” mouth (no teeth) - “Thick” back legs. - Short tail. - “Leather” skin. - Head/ 4 Legs/ Long neck / Eyes - Head (feet) go into its shell - Can be big.			
Group B	- Carapace - Plastron - Tympanum - Solar Eye			
Score 1				
0	**1**	**2**	**3**	**4**
-No Answer -Entire answer is incorrect.	(1-2) in A/B	(3-4) in A/B	(5-6) in A/B	(7-14) in A/B
Score 2				
0	**1**	**2**	**3**	**4**
0 in B	1 in B	2 in B	3 in B	4 in B

Question 3: One point for each correct answer.

Question 4: What should the robot do?

0	1	2	3	4
-No Answer -Entire answer is incorrect.	Any (1-2) of the following: 1) Walk/Slowly (alternating legs) 2) Sense temperature 3) Evade predators (hear/see) 4) Dig 5) Climb in and out of a burrow. 6) Find Shade 7) Sleep/Eat/Drink 8) Protect itself.	Any (3-4) of the following: 1) Walk/Slowly (alternating legs) 2) Sense temperature 3) Evade predators (hear/see) 4) Dig 5) Climb in and out of a burrow. 6) Find Shade 7) Sleep/Eat/Drink 8) Protect itself.	Any (5-6) of the following: 1) Walk/Slowly (alternating legs) 2) Sense temperature 3) Evade predators (hear/see) 4) Dig 5) Climb in and out of a burrow. 6) Find Shade 7) Sleep/Eat/Drink 8) Protect itself.	Any (7-8) of the following: 1) Walk/Slowly (alternating legs) 2) Sense temperature 3) Evade predators (hear/see) 4) Dig 5) Climb in and out of a burrow. 6) Find Shade 7) Sleep/Eat/Drink 8) Protect itself.

Question 5: What components does the robot need? (This question has two scores)

Group A	- Motor(s) - Temperature sensor - Distance/motion sensor - Light sensor - Speaker	- Sound Sensor - Touch Sensor - Legs/Wheels - Wires - Power (On/Off) - Screws/Metal/Plastic
Group B	- Sensor(s) - Program	- Inputs/Outputs - NXT Brick/CPU/Microchip

Score 1				
0	**1**	**2**	**3**	**4**
-No Answer -Entire answer is incorrect.	(1-2) in A/B	(3-4) in A/B	(5-6) in A/B	(7-11) in A/B
Score 2				
0	**1**	**2**	**3**	**4**
0 in B	1 in B	2 in B	3 in B	4 in B