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Technology Enabled Projects for High School Physics

Abstract

Louisiana Tech University has recently developed a high school physics curriculum called NASA-Threads which integrates engineering, mathematics, and physics concepts through hands-on projects. NASA-Threads combines NASA applications, fundamentals, technology, and communication with projects that are facilitated by an inexpensive robotic platform. Fundamentals are taught in this active classroom environment as projects unfold. The hands-on projects build excitement and foster the development of student confidence and creativity; they also develop student ability to solve realistic multiple-step problems.

Each student participating in the NASA-Threads curriculum is provided with their own robot (Boe-Bot) which provides a tool for measurement and control of physical systems. We have adopted the Boe-Bot robotics platform from Parallax which comes equipped with a microprocessor, a variety of electrical components, sensors and two servos motors to provide robot locomotion. Students write computer programs using PBASIC to interface their robot with each project.

The NASA-Threads curriculum begins with a focus on electricity and magnetism. Students use multimeters to measure voltage and current in simple circuits constructed on the breadboard of their own Boe-Bot. For example, students first build simple resistor networks powered by the DC voltage supply from the Boe-Bot to discover Ohm's Law and to verify Kirchoff's Current Law. Next, they write PBASIC programs causing LEDs to blink with specified timings; they then extend these skills by developing a countdown timer that utilizes a seven-segment LED number display. As students' intuition for electricity develops, they are introduced to the couplings between electric current and magnetic fields through projects involving motors and speakers. Other projects discussed in this paper include trusses (vectors and forces), servo efficiency (energy conversion), accelerometers (programming, vectors and gravity), homemade guitars (waves and sound), solar ovens (energy and heat), and digital cameras (gravity and projectile motion).

The central focus of the NASA-Threads curriculum is to tie fundamental STEM topics to interesting applications. This paper documents a selection of our major projects and also provides data related to teacher self-efficacy for a summer 2011 workshop that prepared 26 high school teachers to deliver the curriculum at 14 high schools.

Introduction

Numerous publications in recent years have expressed concern regarding preparedness of our students to pursue engineering and science degrees (for example, *Rising Above the Gathering Storm*[1], *The Engineer of 2020*[2], and *Educating the Engineer of 2020*[3]). Clearly, there is a well-defined need for increased enrollment in and graduation from university science, technology, engineering, and mathematics programs. Moreover, there is a critical need for partnerships between universities and K12 schools to increase the mathematics and science abilities of high school graduates – preparing them for any career path, particularly in STEM disciplines.

Two high school based curricula currently being used to address these concerns are Project Lead the Way and the Infinity Project. Project Lead the Way (www.pltw.org) has modules for introducing engineering topics to students in both middle and high school. However, high school teachers in our partner schools have indicated to us that they would prefer a more in-depth curriculum that ties together application and content. The Infinity Project (www.infinity-project.org) focuses on digital electronics, allowing for a rigorous approach, but is limited to a very narrow range of topics. Teachers have indicated to us that they like the rigorous nature of the Infinity Project, but would prefer a broader spectrum of topics which seamlessly integrate science, engineering, and mathematics across the curriculum.

"…it is very difficult to add STEM electives. … an approach which integrates STEM content within the core curriculum is significantly more viable than other, electives-based approaches. "

- Marvin Nelson, Teacher, Benton High School

Project Description

NASA-Threads[4] provides school systems with a rigorous program that showcases a systems-level understanding of real-world applications of mathematics, science, and engineering. Our previous experience has shown that long-term impact on K12 students comes through close collaborative relationships between teachers and university faculty[5-10]. NASA-Threads provides a hands-on, context-based approach to math and science professional development in preparing teachers to become the educators of the future.

The NASA-Threads curriculum consists of self-contained projects that integrate engineering, mathematics, and physics. These hands-on projects develop student ability to solve more realistic multiple-step problems and bring excitement into the classroom. NASA-Threads integrates NASA Applications, Fundamentals, Technology, and Communication through hands-on projects that are enabled by an inexpensive robotic platform called the Boe-Bot[11]. The Boe-Bot provides the enabling technology for projects.

The curriculum is broken into four main sections: Electricity & Magnetism, Work & Mechanics, Fluids-Waves-Light-Heat, and student projects. At the beginning of a typical high school physics course, the focus is on fundamental topics such as motion and Newton's Laws. NASA-Threads introduces Electricity & Magnetism at the beginning of the curriculum to provide a connection to the Boe-Bot (micro-controller) platform. By using a hands-on platform throughout the curriculum, students are able to work with "real" problems. This project-based approach allows the students to gain an intuition about how to solve problems, and helps them understand the fundamental mathematical equations that emerge in the modeling of physical systems. Additionally, by starting with Electricity & Magnetism students are exposed to measurement and data acquisition of real systems. This provides a background for introducing the idea of energy and power, which is expanded in the Work & Mechanics section. Instead of being exposed to mathematical equations without a context, students experience the application and see the need for the fundamentals.

Why Implement a Project-Based Curriculum using Robotics?

Individuals committed to educational reform have long since realized that passive lecture-based instruction should be replaced by active, integrative project-based learning[12]. Throwing a healthy dose of robotics into the mix provides a "magical" element that brings the instruction to life. Robots are machines that sense, think, act, and (more recently) communicate[13]. Robotics is a highly effective tool for implementing hands-on projects that showcase NASA applications. The website for the Mobile Robots Program at Penn State Abington[14] nicely summarizes why robots are an effective educational tool:

- Design of robots is highly interdisciplinary and involves mechanical engineering, electrical engineering, computer science, artificial intelligence, project management, teamwork, communication skills, and creative problem solving;
- The hands on, visual nature of robot design is highly motivating for students;
- Robot design can be easily adapted to meet many educational goals for students of all levels; and
- Availability of low-cost robotics equipment, software, and support allows robotics to be accessible to a wide audience.

Why Use the Boe-Bot Platform? The Boe-Bot robotics platform (below) is used because it is affordable, well documented, and readily interfaces with a variety of sensors, as summarized below:

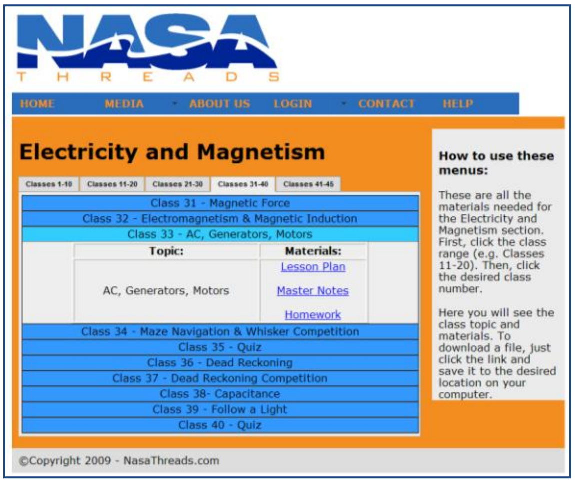
- Various sensors and basic components, such as resistors, capacitors, chips, and LED's can be quickly installed on the integrated breadboard to produce a wide variety of "smart" devices;
- The Boe-Bot comes with a 188 page Robotics manual;
- The Board of Education has 16 I/O pins (as opposed to 4 inputs and 3 motor outputs on the LEGO NXT controller);
- The hardware and programming environment introduces students to RAM, EEPROM, pulse trains to communicate with sensors, etc. This low-level approach, coupled with fundamental physics topics, provides students with a solid introduction to electrical circuits and digital electronics.

Boe-Bots are available from Parallax at volume discount pricing of $110 per kit. Boe-Bot kits contain most of the components required for the projects, including the LEDs, resistors, capacitors, photoresistors, whiskers, IR LEDs and receivers, a piezospeaker, two continuous rotation servo motors, computer cables, and a special version of the BASIC programming language to interface with the microcontroller. Existing computer facilities in K-12 school systems are utilized for supporting the programming activities. Additional reusable components required for schools implementing NASA-Threads projects include an accelerometer ($29), a temperature probe ($16), and a multimeter ($20); these components are easily interfaced with the Boe-Bot. The cost of additional supplies to support the curriculum is small. The initial cost for all the supplies is

Boe-Bot with IR object detection

similar in cost to a typical textbook, and recurring costs are minimal. By using low-cost materials and supplies, the curriculum is easily implemented in any school system. The curriculum provides teachers with a context for the teaching of science and mathematics within their schools.

Curriculum Samples



An online curriculum (www.nasathreads.com) complete with physics fundamentals, detailed project descriptions, and course assignments are provided freely via the Internet. The online content eliminates the requirement of a textbook, reducing overall curriculum cost to the materials and supplies for the projects. In addition, teachers and students have access to high quality media that helps both students and teachers visualize difficult or abstract concepts.

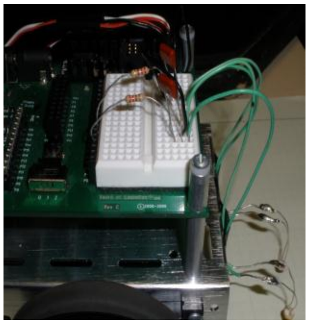
From the online curriculum, each day's lesson plan, master notes, and supplemental materials are easily accessed by the teachers.

Professional Development

Establishing and building relationships with individual teachers and administrators in school systems throughout our region is the most critical component to all of our K12 educational outreach programs. During the summer of 2010, 26 teachers from 14 regional schools joined university faculty for a two-week professional development workshop held at Louisiana Tech

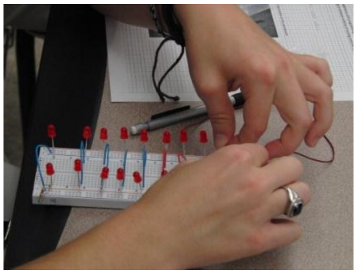
University. The goal was for the teachers to gain experience in implementing the curriculum during the next academic year, as well as improve their self-efficacy in teaching the fundamental material. The following sections present a sampling of some of the projects that are used in the curriculum for showing fundamental physics concepts. Teachers are led by university faculty through projects in the same way that the teachers lead their own students through the material. By having the teachers go through the same process as the students, they are able to not only learn the material, but they experience a similar pedagogical approach as they will be teaching.

Electricity



The emphasis on technology is apparent within the first lesson where teachers and students are introduced to the Boe-Bot. Students initially learn about Boe-Bot motion and because they can make the Boe-Bot move within one class period, they are more engaged and thus more interested. Student inquiry into how the motion is accomplished leads to discussion and further investigation of electricity.

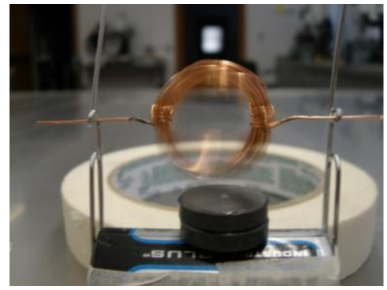
While learning about the grouping of matter, electricity, and magnetism the user becomes gradually more and more comfortable with the robotic platform which in turn allows them to experience success with a technology very quickly. Atomic structure and the role of electrons in atomic bonding provide an opportunity to discuss electron mobility and mechanisms for the passage of electrons through materials. Electron flow leads to definitions of electrical current, resistance and voltage. As Ohm's law is introduced, multimeters are used to measure voltage and current in simple circuits constructed on the breadboard of the Boe-Bot. Students then build circuits containing LEDs, and they write BASIC computer programs causing the LEDs to blink with specified timings. Students then extend their skills to develop a countdown timer that utilizes a seven-segment LED number display. Fundamentals continue to be taught in this active classroom environment as projects unfold.



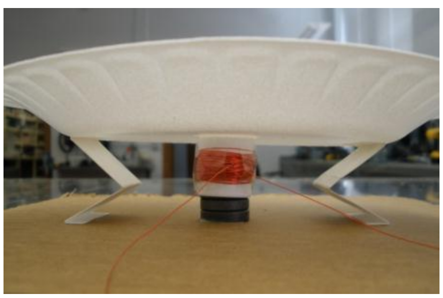
Additionally, students use low cost multimeters to understand the difference between real and ideal components. One way this is shown is through statistics, where students collect data on a random sample of resistors having the "same" ideal value. They quickly learn that the real values are close to the mean of the sample. Building on this, students measure resistance through various circuits and are able to see how resistors can be combined. This leads to understanding of reduction of series and parallel circuits. Through measurement, students can easily see that in series, the resistances are simply summed together. High school students are surprised to discover that this is not the case with parallel circuits. Through measurement, students are guided to consider the three parameters: resistance, voltage, and current. They quickly observe that the current is summed. Using Ohm's law and basic algebra, students can solve for resistance and discover the parallel resistance equation. Thus, the Boe-Bot and multimeter allow the traditional theoretical instruction to meet the practical through these experiments.

Magnetism

As students’ intuition for electricity develops, they are introduced to the coupling between electric current and magnetism and build a simple permanent magnet motor. Students use simple household items, battery, magnet wire, paperclips, tape, and magnets to build a Beakman motor. Building the motor helps to illustrate the effects of a magnetic field.



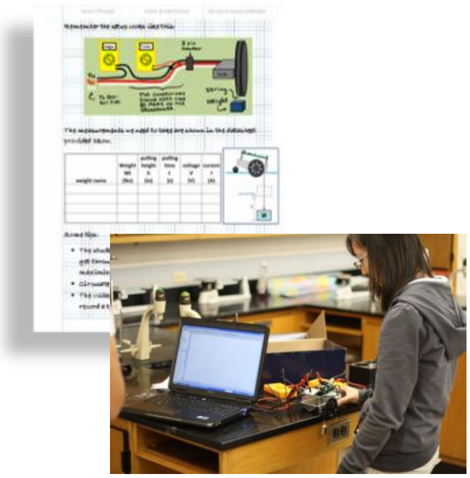
After completing the Beakman motor the students take their knowledge of magnets and magnetic fields and create a speaker. The speaker project utilizes magnets, magnetic wire, and Styrofoam plates to produce sound. In this lesson, the students are introduced to the idea of magnetic force. The students initially build the speaker and connect the wires to a constant voltage source. This causes the speaker to physically move and demonstrates how a magnet can be used to create a force.



Testing of the speakers occur in two fashions: the Boe-Bot is programmed to emit a frequency and secondly a headphone jack connected to a computer or mp3 player. By using the frequency output from the Boe-Bot, students are introduced to the idea of frequency. They can audibly hear the different frequencies. This provides a framework from which the teacher can introduce additional physics concepts such as period, wavelength, amplitude, and frequency. One of the more exciting aspects of the project is to use the headphone jack on a computer or mp3 player to listen to music on the speaker. Students are amazed and excited to hear sound from their speaker and are surprised that using a little wire, a plate, and magnets they could create something that actually plays sound. Many of the teachers have further expanded this project to have their students build speaker boxes to make them sound even better. The students can easily see how magnetism and magnetic force can be used produce sound.

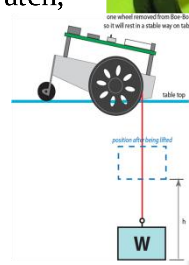
The introduction of DC electric motors in the discussion on magnetism allows for discussing the physics behind the operation of the servo motors that are supplied with the Boe-Bot kit. Students use real servos to begin to see how gear systems work. Student ability to control the servos leads to the implementation of Lunar rovers which are programmed to navigate using dead reckoning programming strategies. Students must use their knowledge of the servo motors to program their Boe-Bots to autonomously maneuver through a maze much like a lunar rover. The project provides an opportunity for in-class competitions. These hands-on projects build excitement and foster the development of student confidence and creativity.

Work and Energy



Work and power is introduced towards the beginning of the Work & Mechanics section of NASA-Threads. The students utilize an Excel spreadsheet to calculate work and power associated with an in class experiment where student pull a weight across the floor. By using a simple fish scale and stopwatch, students learn about work.

The students then learn about the conservation of energy, potential energy, and converting electrical energy to mechanical energy which is a natural progression to calculating efficiency. Students use the Boe-Bot to quantify the electrical energy input and the mechanical work output of a servo as it operates under 4 different loads.

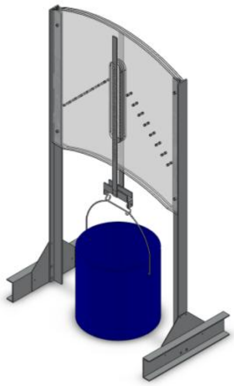


The servo efficiency project requires the students to lay the Boe-Bot on its side, fasten a string to a modified wheel connected to the servos, and tie various weights on the string. The servos essentially act as a pulley lifting the weight over a period of time. Using a multimeter, stopwatch, tape measure, and scale the students collect the necessary data needed in order to find the efficiency of the servos. Students use Excel to calculate the electrical and mechanical energy to lift the various weights being tested. From the calculated data, students create a scatter plot illustrating the servo efficiency versus the weight lifted. This lesson builds on previous concepts presented in Work & Mechanics such as work, power, and energy conservation. Additionally, concepts learned in Electricity & Magnetism, such as electrical power, are used to link fundamental topics. This is not only a great way to demonstrate mechanical energy, but it reiterates the concepts covered in the electricity and magnetism. By using the previous material in a meaningful way, the students are able to further understand the fundamental concept.

Vectors and Forces

Following the Work & Mechanics lessons on forces, students are introduced to the concept of vectors. As an application of these fundamentals, the truss project[15] tasks students with analyzing and building a 2-dimensional truss using mat board and manila folders. Supply materials are individually tested to aid in the design of student built trusses. Students then implement the method of joints in order to analyze and predict the forces associated with each member. A testing apparatus is used to validate the ultimate force that the truss can withstand.

Students learn about forces, resultants, equilibrium of concurrent force systems, and the method of joints for truss analysis as they prepare for the design project. Students compute the forces in each member of their chosen design based on a 1 lb external load applied at a center joint. Students perform tensile testing of the dogbone-shaped manila folder strips to determine their average strength in lbs. Students use this result along with the predicted member loads to estimate truss strength.



Trusses are placed in a testing device, and a loading yoke is pinned to a central truss joint. Loading is applied by gently placing 1 lb bags of rocks in the loading bucket. The testing device can be built for $150 (no labor); plans are available at www.nasathreads.com. Two parallel Plexiglas plates prevent out-of-plane deformation and buckling failure of compressive members. Students understand that they are designing a simplified, 2D truss. Photos of 3D truss structures illustrate the need for cross bracing to eliminate twisting; students are taught that buckling is a primary failure mode that cannot be neglected in practice; buckling failure is eliminated here so that theory better matches test results.

Digital Media (projectile motion, gravity)

One module of the curriculum involves an empirical analysis of falling body data to estimate the local gravitational acceleration. Many digital cameras have the capability to capture video. With video capability, one can now analyze and collect data from an event that happens very quickly. Several software packages are designed to process video files to extract data regarding recorded events Video capture is very beneficial for analyzing time-dependent events in the classroom, however the technology packages (high speed hardware and/or commercial software) can be cost prohibitive for many schools. Alternatively, consumer-grade low-cost digital cameras have video modes that can effectively acquire position versus time data. These standard digital cameras typically record video at rates of 30 frames per second (fps), although other framerates are also frequently available. Hands-on projects that demonstrate many K-12 fundamental concepts can be sufficiently modeled using data extracted from video shot at 30fps. It is critical to note that 30fps digital cameras are not capable of capturing events that are too rapid to be observed by the human eye.

The project is designed so that high school students collect video footage of the object against the backdrop of a length scale. Students advance the video one frame at a time to associate position and time. This data is studied to determine velocity as a function of position, eventually leading to the gravitational acceleration (g). The same sort of analysis is used later in the course module for projectile motion, resulting in the progressive development of student competence in collecting and analyzing this data. High speed video is collected in a number of other cases and added to the curriculum materials to illustrate time dependent phenomena, such as material deformation, waves, pendulum motion and stick-slip friction.

Programming, Vectors, Gravity

After developing a good grasp of vectors and forces, the students transition into understanding universal gravitation, celestial orbits, and circular motion. To help illustrate these concepts the students are introduced to an accelerometer. Initially the students connect the accelerometer to the Boe-Bot and program it to measure tilt then output the associated g-force in the different axes directions. This provides a great real-world example of trigonometry. Students have an intuition about gravity, and are able to understand how the measurement of the accelerometer can be used to determine the tilt and the direction of gravity relative to the Boe-Bot.

After students develop a feel for the accelerometer, the students are tasked with writing programs that enable their Boe-Bot to autonomously navigate though a "valley" created by a rug laid over various objects, much like a lunar rover might encounter. Students use their knowledge of the g-force, tilt angle, and accelerometers to aid in the programming of the Boe-Bot. The Boe-Bot with the accelerometer is able to interpret the tilt angle and g-force to know when to reverse and adjust its path in order to safely navigate though the "valley." This particular project is presented as a challenge where the students are divided into teams and compete against each other in time and efficiency of task completion.

Waves, Frequency, Sound

As the course moves away from the work and mechanics section, the material transitions into waves, frequency, and sound. Music is a natural illustrator of these concepts, thus the students are tasked with building a guitar. The guitar illustrates each of the concepts of sound, waves, as well as frequency in various ways. Students are given a piece of wood (guitar neck), guitar strings, various hardware components and cardboard box, which is typically the box that the Boe-Bot came in.

The initial fundamental concept that is discussed is the idea of frequency. Students use Excel to calculate what length string is needed to provide the notes for a three string guitar. The students must use their knowledge of frequency to calculate the position of the frets on the guitar neck. The students then measure and score the neck so that metal rods (typically nails) can be laid across these fret marks. The rods are held in place using rubber bands. The next step is to attach the box to the neck with wood screws, and then run the strings through the eyebolts and tighten everything up.

After building the guitar the students connect a piezospeaker from the Boe-Bot kit to the guitar, which acts like an electric pickup. This connects back to the speaker that was made. The students are shown that just like electricity was used to move the speaker, they can use the movement in the speaker to create the electrical signal. The students then hook the headphone jack to a computer. This allows them to “tune” their guitar using freely available software or to visually the signal using an oscilloscope.

Using the guitar, the students are taught about waves, frequency, and sound while maintaining a high level of interest in the project along with an element of fun. Students need not be musically inclined to excel in the project. If they grasp the fundamental concepts behind frequency and waves they can make the necessary calculations to build the guitar which provides an excellent example of the theory accurately predicting the actual output.

Heat

Students are introduced to concepts of heat and thermodynamics through a solar oven project. Students are given saran wrap, mat-board, tape, temperature sensors for the Boe-Bot, and miscellaneous electrical components to build the solar oven.

Solar oven projects are a great way of demonstrating fundamental concepts of heat energy, conduction, convection, and radiation. By having student immersed in technology throughout the entire curriculum, it is easy to use sensors and the Boe-Bot as a data acquisition system for furthering the understanding of the solar oven project.

Using a low cost temperature sensor with the Boe-Bot, the students measure the change in temperature inside and outside the solar oven. The Boe-Bot can be used with the sensors to measure the temperature and display the result in an output window. Additionally, the Boe-Bot can be used to record the data over time. The data can then be used to import into Excel, which allows for performing various calculations related to the fundamental heat topics.

Demographics

During the 2009-2010 academic year, the curriculum was piloted at three regional schools. Following this pilot phase, a two-week professional development workshop was held to train the teachers at 14 participating high schools in the region. The teachers were provided with the online curriculum and were lead through a selection of the projects in the curriculum. One of the teachers commented: “I enjoy the way we are being lead to encounter the same problems the students will encounter when we teach them.”

There were 26 teachers that were a part of the training (16 male, 10 female). During the 2010-2011 academic year, these 14 schools have offered physics courses that are using this curriculum. Numbers reported from the schools show that 201 students have been directly impacted through the NASA-Threads course (71% male, 29% female, 24% under-represented). Additionally, the teachers reported that they are using the projects presented in this paper in other courses that they teach. Self-reported numbers from the teachers show that an additional 1358 students are being directly impacted through the projects in this paper being used in other courses such as geometry, robotics, and pre-calculus.

Survey Results

NASA Threads Summer Institute participants completed a web-based survey in which they provided anonymous feedback connected to statements regarding various elements of the training sessions. The survey consisted of five elements (Low, Basic, Proficient, Mastery, Advanced). Each element was evaluated using multiple statements to which the respondents gave feedback using a five point Lickert Scale with 1 corresponding to "Low" and 5 corresponding to "Advanced". The following is a selection of the data that was collected during the teacher professional development workshop.

Survey 1 included an introduction to the NASA-Threads project, an introduction to basic programming commands, and an introduction to the assembly and use of a BOE-BOT. The lessons, located in the Teacher section of the NASA Threads web site included varied activities, such as "Hello World," "Simple Variables," and "Simple Boe-Bot Motion."

Teacher Self-Assessment	Before Workshop	After Workshop	Change
A. Knowledge of a Board of Education Robot (Boe-Bot)	1.57	3.29	1.71
B. Understand the purpose of a microcontroller	2.00	3.14	1.14
C. Connecting a Boe-Bot to a computer	2.00	3.86	1.86
D. Use of the Basic Stamp Editor program	1.48	3.14	1.67
E. Knowledge of characteristics of basic commands	1.90	3.10	1.19
F. How to assemble a Boe-Bot	1.62	3.90	2.29
G. How to store variables using a microcontroller	1.81	3.29	1.48
H. Knowledge of Program Flow Charts	1.86	2.71	0.86
I. Familiarity of servo components	1.38	2.71	1.33
J. How to control the motion of a Boe-Bot	1.76	3.14	1.38
K. Correct set up of a LED/Resistor circuit	1.57	3.24	1.67
L. Knowledge of resistor color codes	1.86	3.24	1.38
M. Knowledge of diodes	1.76	2.76	1.00
N. The concept of "ramping"	1.29	1.62	0.33

Survey 2 included an introduction to electricity, comprising topics such as, resistance, voltage, and current, use of a multimeter, and series and parallel circuits. In addition, basic programming commands were revisited.

Teacher Self-Assessment	Before Workshop	After Workshop	Change
A. Properties of insulators, conductors and semi-conductors, discussing the properties of each	2.43	3.29	0.86

B. Knowledge of the atomic model	3.19	3.57	0.38
C. Problem solving using molar calculations	2.71	3.00	0.29
D. Creating and using a histogram for statistical analysis	2.48	3.57	1.10
E. Knowledge of statistical techniques such as mean and standard deviation	3.24	3.81	0.57
F. Use of Excel to organize data	2.90	3.62	0.71
G. Using formulas in Excel to perform calculations	2.90	3.48	0.57
H. Using a multimeter resistance, current, and voltage	2.33	3.57	1.24
I. Collapsing resistors (series and Parallel) into a single equivalent resistor.	2.67	3.52	0.86
J. Knowledge and use of Kirchhoff's Voltage Law	2.62	3.33	0.71
K. Knowledge and creation of series circuits	2.62	3.43	0.81
L. Knowledge and creation of parallel circuits	2.57	3.38	0.81
M. Knowledge and use of Ohm's Law	2.86	3.57	0.71
N. Knowledge and use of a 7-segment display	1.43	3.10	1.67
O. Knowledge and use of IF/THEN statements and subroutines	1.57	2.81	1.24

Survey 3 covered activities such as the "Whisker Circuit," "Beakman Motor," and "Magnetics and the Development of a Speaker.

Teacher Self-Assessment	Before Workshop	After Workshop	Change
A. Knowledge of how a Boe-Bot receives data	2.00	3.20	1.20
B. Knowledge of a whisker circuit	1.55	3.10	1.55
C. Use of basic programming to have a whisker circuit perform a specific task	1.65	2.85	1.20
D. Application of Ohm's Law and the equation for finding power	2.60	3.00	0.40
E. Knowledge of magnets and magnetic fields	2.60	3.20	0.60
F. Application of the right hand rule to determine the direction of a magnetic field	2.75	3.35	0.60
G. Application of the equation of magnetic field in order to find magnetic field, force, current and length	2.50	2.95	0.45
H. Using Pulse Width Modulation to control a motor	1.60	2.35	0.75
I. Knowledge of electromagnetic induction	2.05	2.55	0.50
J. Using Styrofoam to build a plate speaker	1.40	3.35	1.95
K. Knowledge and application of the relationship between electrical input and audio output	1.70	2.75	1.05
L. Knowledge and use of capacitance	2.00	2.85	0.85
M. Knowledge and use of the RCTime command	1.60	2.85	1.25
N. Incorporation of a photoresistor into circuit construction	1.45	2.70	1.25

Survey 4 consisted of activities that utilized the knowledge and skills developed during the previous days to complete tasks such as “Follow the Line” in which the participants were required to build circuits with one or two photoresistors and make a Boe-Bot follow a line.

Teacher Self-Assessment	Before Workshop	After Workshop	Change
A. Knowledge and skill to make a Boe-Bot perform specific tasks	1.95	3.05	1.11
B. Knowledge and skill to design and construct a circuit that incorporates two (2) resistors	2.68	3.42	0.74
C. Knowledge and skill to teach circuit design and construction	2.47	3.26	0.79
D. Knowledge and skill to teach properties of insulators, conductors, and semi-conductors	2.26	2.84	0.58
E. Knowledge and skill to teach properties of insulators, conductors, and semi-conductors	2.21	2.74	0.53
E. Knowledge and skill to teach the programming and basic operations of a Boe-Bot	2.26	3.16	0.89
F. Knowledge and skill to teach properties of electricity such as capacitance, resistance, voltage, and current	2.63	3.32	0.68
G. Knowledge and skill to teach about magnets and magnetic fields	2.42	3.16	0.74
H. Knowledge and skill to teach the use of a multimeter	2.42	3.32	0.89
I. Knowledge and skill to use basic statistical analysis as a teaching and learning tool	2.37	3.16	0.79

Survey 5 covered the use of Excel, Newton’s Laws (e.g., particle motions and force components), an introduction to accelerometers, and the Boe-Bot Rover “exploration”.

Teacher Self-Assessment	Before Workshop	After Workshop	Change
A. Use of a digital camera to collect video of the motion of an object	2.96	3.63	0.67
B. Use of video editing software for the teaching/learning of physics	2.08	3.25	1.17
C. Use of position and time data to estimate velocity	2.58	3.58	1.00
D. Use of spreadsheet software for the computation and plotting of data	2.75	3.58	0.83
E. Use of best fit position/time and velocity/time data to reduce the influence of error and to determine relationships between variables	2.42	3.42	1.00
F. Knowledge of the definition, attributes and units associated with acceleration	3.04	3.54	0.50
G. Knowledge and identification of measurement error	2.79	3.38	0.58
H. Use of an equation associated with a best fit curve to compute “corrected” height data	2.38	3.21	0.83
I. Development of height and time relationships for objects under the influence of gravity with zero initial position and velocity	2.67	3.33	0.67
J. Computation of height, velocity, gravitational acceleration or time where a minimal set of the other parameters are given.	2.92	3.42	0.50
K. Knowledge of the attributes and relationships between distance,	3.00	3.46	0.46

force, weight, and/or work			
L. Use of US Customary & SI units when solving problems involving energy and power (ft-lb, N-m, J, watts)	3.21	3.58	0.38
M. Calculation of work and power associated with active energy data	2.96	3.46	0.50
N. Knowledge and use of an accelerometer	1.75	2.88	1.13
O. Use of an accelerometer on/with a robot	1.33	2.92	1.58
P. Use of the pulse output of an accelerometer to complete various tasks	1.46	2.83	1.38
Q. Computation of tilt angle based on g-force	1.50	2.83	1.33
R. Creation of a program that causes a Boe-Bot to autonomously navigate through a defined course	1.67	2.67	1.00
S. Refine and optimize a program according to the requirements of changing parameters.	1.88	2.79	0.92

Survey 6 related to engineering design, the use of design software, and the fabrication and testing of materials for the truss project.

Teacher Self-Assessment	Before Workshop	After Workshop	Change
A. Definition of a truss as a component of structure	1.96	3.17	1.22
B. Knowledge of truss members as "two force members" acting in either tension or compression	1.74	3.00	1.26
C. Application of ΣFx=0 and ΣFy=0 to determine the unknown forces in the members of a simple truss	1.87	3.09	1.22
D. Application of the method of joints to determine the unknown forces in a truss	1.61	2.96	1.35
E. Comprehension of the concept of axial stress as force divided by cross-sectional area (stress= Force/Area or σ=F/A)	1.61	2.78	1.17
F. Computation of the stress in axially loaded members with circular and rectangular cross sections	1.57	2.70	1.13
G. Fabrication and testing of paper tensile test specimens	1.43	2.87	1.43
H. Computation of the failure load of a truss as limited by the strength of truss members	1.52	2.61	1.09
I. Designing, fabricating, and testing a 2D truss	1.43	3.00	1.57

Survey 7 covered Projectiles (digital media), Servo Efficiency, Guitar, and Solar Ovens.

Teacher Self-Assessment	Before Workshop	After Workshop	Change
A. Knowledge of relationship between elastic energy and atomic bonds	2.08	2.88	0.79
B. Knowledge of characteristics of a linear spring	2.25	2.96	0.71
C. Development of a formula for elastic energy in a linear spring	2.13	3.08	0.96
D. Knowledge of the area under the Force-Deformation curve as a	2.04	2.83	0.79

representation of the elastic energy stored in an elastic body.			
E. Solve problems using the elastic energy formula developed	2.13	3.13	1.00
F. Definition and attributes of kinetic energy	2.46	3.25	0.79
G. Development of a formula for kinetic energy in a translating body	2.13	3.00	0.88
H. Computations using units associated with kinetic energy	2.54	3.33	0.79
I. Solve a problem using a kinetic energy formula	2.58	3.29	0.71
J. Application of video analysis principles to measure initial velocity of a projectile	1.83	3.08	1.25
K. Application of energy balance principles to estimate a theoretical initial velocity	1.88	2.92	1.04
L. Knowledge of the relationship between theoretical and measured initial velocities.	2.17	2.96	0.79
M. Knowledge of the relationship between projectile range and theoretical projectile range.	2.08	2.96	0.88
N. Evaluation of the efficiency of an electric gear motor lifting various weights	1.63	3.08	1.46
O. Computation of the efficiency of a servo lifting a weight	1.83	3.17	1.33
P. Creation of a spreadsheet requiring data input, computations and plots	2.29	3.33	1.04
Q. Computation of servo efficiency under various operating conditions	1.71	3.08	1.38
R. Solving of work, power and efficiency problems	2.33	3.25	0.92
S. Fabrication of a solar oven from foam board	1.63	3.38	1.75
T. Use of a Boe-Bot to measure temperature	1.46	3.08	1.63
U. Use of uss digital temperature sensors to measure temperature potential	1.46	2.96	1.50
V. Use of a solar oven to explain infrared reflection	1.46	2.71	1.25
W. knowledge of the relationship between thickness of insulation (foam) and the temperature inside a structure (solar oven)	1.83	2.79	0.96
X. Determination of heat capacity using the components of density, volume, mass, & temperature.	1.67	2.63	0.96
Y. Fabrication of a guitar to illustrate concepts of frequency	1.50	2.83	1.33
Z. Knowledge of the relationship of tension, density & length to the frequency in a vibrating string	1.67	2.79	1.13
AA. Knowledge of the attributes of sound	1.83	2.75	0.92

Overall

In general, the participants responded positively to the all elements of the workshop with highest marks given to the effective use of a hands-on, project-based framework to deliver content and assess learning. In addition, the participants remarked repeatedly about the positive learning environment and enthusiasm for content demonstrated during the sessions. The following table shows teacher self-efficacy after the 2-week professional development workshop, where 1 corresponds to "Strongly Disagree" and 5 corresponds to Strongly Agree.

	Avg Rating
A. The presenters/facilitators actively involved me in the learning process.	4.70
B. As a result of this professional development session I feel more confident in my ability to instruct my STEM discipline.	4.55
C. As a result of this professional development session I feel more confident in my ability to use project-based instruction.	4.58
D. As a result of this session I am more motivated to teach my STEM discipline.	4.66
E. As a result of this session I am more motivated to teach using project-based instruction.	4.66

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