AC 2009-1722: ENGINEERING ENERGY SOLUTIONS FOR THE INSPIRES CURRICULUM

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"Engineering Energy Solutions" for the INSPIRES Curriculum

The INSPIRES Curriculum (INcreasing Student Participation, Interest and Recruitment in Engineering and Science), funded by the National Science Foundation, is being developed in response to the need to recruit more students in the STEM-related fields. The curriculum seeks to accomplish this goal by exposing students to a combination of real-world engineering design challenges, hands-on activities, and inquiry-based learning activities that target the ITEA Standards for Technological Literacy as well as national standards in science and mathematics.

The third module completed and added to the curriculum is "Engineering Energy Solutions: A Renewable Energy System Case Study." The curriculum is designed to be very flexible to accommodate student learning in a variety of environments, from high school to undergraduate classrooms. The overarching concept in all of the INSPIRES modules is the introduction of the engineering design and decision-making process while also teaching basic engineering principles. The curriculum begins by presenting the students with some facts about our nation's current energy challenges, with the rising demands and dwindling supplies, to help students understand the problems that our nation faces and give them a real-world context for the module topic. The students then progress through a series of hands-on activities and demonstrations, web-based tutorials, and computer simulations during which they learn the engineering concepts that influence energy systems, including efficiency, power, energy, and work. Students are able to use the concepts they learned about in the hands-on activities and tutorials and apply them to the computer simulation that allows them to adjust parameters (such as solar intensity, water or wind velocity, and size of apparatus) to see how they affect the amount of energy collected. The students are then challenged to build a renewable energy ***system*** that collects, stores, transports, converts, and utilizes renewable energy.

Currently, the "Engineering Energy Solutions" module is being used in several high school classrooms in Maryland and Virginia. In this presentation, the curriculum module will be demonstrated, and the results of student learning and interest and attitude data will be evaluated.

Background

Since the basis of this nation's wealth has been built on innovation and technology, it is vital that the nation produces more engineering graduates, but enrollment in the engineering disciplines continues to decline.[1,2] In fact, it is anticipated that there will be a shortage of trained engineers in the United States in the near future.[1,2,3] If the nation is to remain competitive with others in an increasingly global economy, students need to be recruited into engineering programs at the university level in the hopes that they will pursue engineering careers. The National Academy of Sciences, National Academy of Engineering, and Institute of Medicine issued a report entitled "Rising Above the

Gathering Storm," which declares that the need to develop new K-12 curriculum materials in science and mathematics is of the highest priority.[4]

In the development of the INSPIRES curriculum, several factors were considered for this new and innovative approach to engineering technology. The intention of the INSPIRES Curriculum is that learning materials should be accessible to all high schools and incorporate hands-on activities and design challenges, while still maintaining the ability to be adopted into a variety of environments.

The **INSPIRES** Curriculum is designed to specifically target three Standards for Technological Literacy put forth by the International Technology Education Association (ITEA):

Standard 8:	Students will develop an understanding of the attributes of design
Standard 9:	Students will develop an understanding of engineering design
Standard 11:	Students will develop abilities to apply the design

The ITEA Standards for Technological Literacy specifically address technology education, and the INSPIRES Curriculum also targets national standards in mathematics and science. This has allowed for adoption of the INSPIRES Curriculum in classrooms in the Maryland and Virginia.

One of the additional goals of the INSPIRES Curriculum is to inspire greater numbers of women and minorities to choose engineering, so the curriculum focuses on solving real-world problems with which students can relate.

The most recently launched module of the INSPIRES Curriculum is entitled "Engineering Energy Solutions," which focuses on the world's energy crisis. As the world moves into the 21st century, the United States and other developing nations only increase the world's energy demands while the amount of fossil fuels continues to decline. Therefore, it is essential that renewable energy sources must rise to meet the shortfalls. The task of finding solutions to the world's energy problems will fall to the next generation of potential engineers. In our Engineering Energy Solutions design project, students are asked to design, construct, test, and evaluate a ***system*** for collecting, storing, transporting, converting, and utilizing renewable energy from a water, wind, or solar source.

The curriculum guides students through the engineering design process, which includes hands-on activities and mini design challenges coupled with the web-based tutorials and interactive simulations, to lead them to the final design challenge. The Engineering in Energy Solutions module has been tested with a wide range of students, and preliminary results from their pre- and post-module test data will be presented.

The INSPIRES Curriculum Structure

Each of the five modules in the INSPIRES Curriculum follows the same general outline of sections to integrate the many different styles of content, including the web-based materials and the hands-on activities. Students start with a pre-module Interest & Attitude Questionnaire and the Module Pre-Assessment to gauge both student interest and abilities in the particular topic specific to the module as well as in general engineering prior to completing the module. The students then watch an introductory video with a practicing engineer discussing a "real-world" design problem, its constraints, and the need for finding a solution to the problem. In the professionally produced video segment for the Engineering Energy Solutions module, engineers and technicians discuss how energy systems have made it possible for society to live comfortably, citing the examples of having light at the flip of a switch and being able to travel by car or plane. They briefly discuss how energy systems work and what their jobs entail. The students then complete a Pre-Module Engineering Challenge, which is called "Power It Up!" for the Energy Module. The students are then brought back to the classroom for an introductory lecture on the featured topic coupled with a series of hands-on activities specific to the module to help demonstrate particular concepts. The students then complete an online tutorial that teaches both engineering concepts as well as information that applies to the topic. In a second video segment, the students are issued the design challenge to motivate them and provide an understanding of the real-world challenges associated with the module's engineering challenge. In the Engineering Energy Solutions module, the engineer and technician discuss the criteria that would make an energy system better from a practical standpoint and issue the challenge to design a renewable energy system.

After the design challenge is issued, the students are brought back to the online materials, where they can manipulate a variety of parameters in a system simulation to prepare them for designing their own solutions. In the Engineering Energy Solutions simulation, students have the opportunity to work with a solar, a wind, and a hydro powered system, and manipulate variables that affect the amount of energy that can be collected and then transported to the next phase in their "system." Students then have the opportunity to design, construct, and test their engineering solution to the design challenge, which is a renewable energy system. The students then complete the Module Post-Assessment and watch a closing video entitled "Careers That Can Make a Difference."

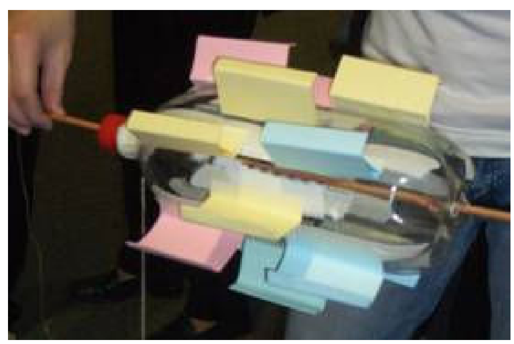
Engineering Energy Solutions: Module Description

In the Engineering Energy Solutions module, the students are exposed to a compelling issue: the world energy crisis. Through in-class lecture material and the web-based tutorial, students see the situation that real-world engineers face when tackling the challenges of our consumption of non-renewable energy sources and the difficulties encountered in the use of renewable energy sources. First, the students are given the basic concepts behind energy, power, and energy systems, and how this applies to renewable energy systems. Throughout the lecture and web-based tutorial, the students begin to see how these renewable energy systems work, from the energy being collected to the end result, whether it be flipping a light switch or running a car. Students are introduced to the idea that challenges in engineering energy solutions are not solely at the collection stage, but are the result of the inefficiencies and difficulties encountered in every step of an energy system from collection to storage, to transport, and to consumption. Most people do not recognize that although it is important to discover and develop alternative sources of energy, it may be even more important to improve upon both current and future technologies for more efficient use of those sources. The Engineering Energy Solutions module addresses both of these issues and teaches students the engineering principles and design skills required for them to understand and tackle them.

Pre-Module Design Challenge

For some of the students that participate in the INSPIRES Curriculum, this is their first encounter with the concept of the design process. The students are put into groups of three to four and are required to build an apparatus to accomplish a task using only the provided commonplace materials. The Pre and Post-Module design challenges are used to assess their abilities to use the design process to work in groups to accomplish a task before and after completing the module. For the Engineering Energy Solutions module, both the Pre and Post-Module design challenges use hydro-power to lift a small weight, which can be used to calculate the amount of energy collected and converted by their devices.

"Power It Up!"



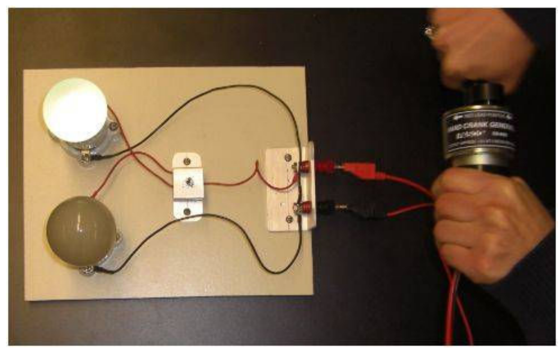
In the Pre-Module design challenge, the students work in groups to design and construct an apparatus using only the provided materials: index cards, masking tape, fishing line, a dowel rod, and a 2-liter soda bottle with holes drilled in each end. Each group is given two quarts of water to power their devices. Each device is attached to a weight on a string, and the kinetic energy from the water powering their device lifts the weight. The product's performance is gauged by the amount of power produced, which is affected by the distance the weight was lifted and the time it took to lift it. The purpose of this activity is to encourage student thinking about the properties of materials and how their shape can affect their device's ability to collect and convert energy.

Although this is a design challenge, product performance is not the sole basis of assessing the success of a design team. In fact, performance in the competition is only one of seven components considered in the assessment of the team. Each team is assessed using a rubric with a point scale (1-4) that reflects the team's demonstration of the seven components. This includes the team's success with following the parts of the design process, including defining the problem, research, brainstorming, and iterative development of a prototype. The group interaction and adherence to safety measures is also assessed, and then finally, the functionality of the product. This student assessment method is based on the guidelines laid out by the ITEA for meeting Student Assessment Standard A-4, which states that "Assessment of student learning will reflect practical contexts consistent with the nature of technology."[5] The rubrics used throughout the INSPIRES Curriculum are based on the ITEA assessment tools.

Hands-On Activities

There are five hands-on activities that are a part of the Engineering Energy Solutions introductory lecture. One of the unique aspects of the INSPIRES Curriculum is its integration of a variety of teaching methods and tools to help students learn concepts while appealing to a diversity of learning styles. One of the goals of the Engineering Energy Solutions module is to help students grasp the concept of energy and the sheer amount of energy that is required to operate everyday devices.

"Crank It Up!"

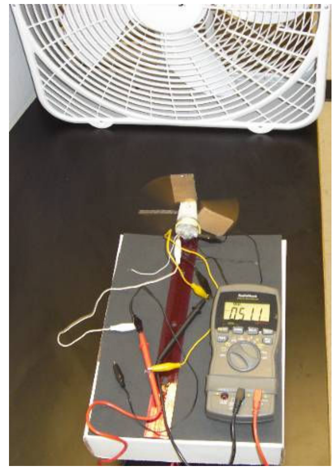


This hands-on activity is specifically designed to help students understand the amount of energy required to operate an everyday device that they take for granted: the light bulb. A hand-cranked generator is used to light two different light bulbs: an incandescent light bulb and a light-emitting diode (LED). Students use their cranking power to discover how much energy it takes to light up each bulb, both of which are only 25-Watt bulbs. In this activity, a generator was used to convert the mechanical energy supplied by turning the crank into the electrical energy used by the light bulb.

"Shaker Flashlight"

In a related hands-on activity, students build a "shaker flashlight" to illuminate a LED from the kinetic energy from passing magnets inside a coil to convert it into electrical energy. The students are asked to compare the two methods of converting their mechanical energy into electricity, and they also compare the two light bulbs. The students are given the opportunity to demonstrate just how much energy it takes to operate those modern conveniences they take for granted.

"Let It Blow!"

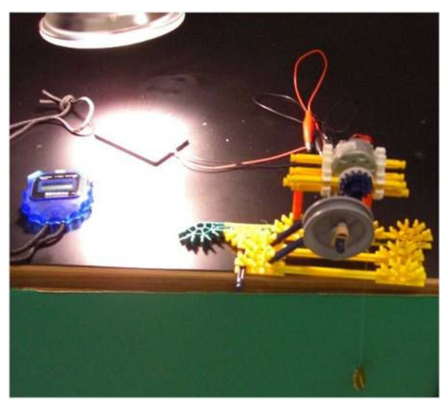


A challenge that engineers face in the energy field is developing an energy system that allows the energy collected to be converted into a form of useful work. The other hands-on activities address this challenge, with the intention of getting students to think beyond energy collection. The "Let it Blow!" activity instructs students to construct a small windmill. Kinetic energy from the wind can be used to turn blades on a wind turbine (a motor connected backwards) and converts the energy into electrical energy which can be measured using a voltmeter or used to light up an LED. The students will begin to learn about how wind velocity is related to the amount of electrical energy which can be harnessed, which will be even further explored in the computer simulation.

"All Geared Up"

To illustrate how engineers must utilize devices to make energy conversion more efficient, gears are used in this activity to demonstrate how gears work and how they can be used to do work. In "All Geared Up," students construct a K'Nex gear system to hold a weight attached to a pulley. Students are able to observe how gears reverse the direction of rotation, can increase or decrease the speed of rotation, and can be used to do work. Depending on the gear ratios, the potential energy transferred from the falling weight to the gears affects the speed of the gears used to pull up a weight on the other side. This demonstrates to students the effect that efficiency has on even a simple system's ability to provide useful work and how to apply this to their renewable energy system design projects.

"Beam Me Up with Solar Power"



In this hands-on activity," the students construct a system with a solar panel attached to a motor. Solar energy can be converted to electrical energy using the solar panel. The electrical energy can be used to power a motor which is used to turn a gear and pulley system, which can lift a small weight. Students can apply the knowledge learned to the computer simulation of the solar energy system as well as their own design projects.

__Final Design Challenge__

The overall design challenge for the Engineering Energy Solutions module is to design and build a system that collects energy from a renewable source (solar, hydro, or wind), converts the energy into a form that can be transported, stores it for a specified period of time, and then uses the energy to illuminate a light bulb. The goal is to optimize the efficiency of the system, which means to maximize the ratio of the useful work output to the energy input. This design project is unique because it requires the students to look at an entire system, as opposed to only a single part. From the engineering design standpoint, it makes the students think not only about how each parameter and principle affects the end goal, but also about how the different principles and parameters relate to and affect one another.

The students have 45 minutes (or up to two hours) in which to collect energy from one of the sources, and that energy must somehow be stored, converted, and transferred to light a 1-cell AAA Maglite® light bulb. The renewable energy sources provided are a 90-W light bulb for solar, a box fan (166, 117, or 87 Watts) for wind, or a water stream that flows at 0.5 liters/second for hydro. The device must cost less than $75, including the collection, storage, transfer, and conversion pieces. Bragging rights for the design challenge are determined with the following equation:

Power Generated x Overall System Efficiency x Device Cost Index

The power generated refers solely to the ability of the system to light the light bulb, not to any power being generated elsewhere in the system. The power generated is determined by the maximum current that the device can produce as measured using a meter.

The *overall system efficiency* is calculated using:

$$\frac{\textit{Useful Work Output}}{\textit{Energy Input}}$$

The energy input is determined from the renewable energy source used (the wattage x time collected), and the useful work output is determined from the energy emitted from the light (wattage x time lit).

The *device cost index* is calculated using:

$$\frac{\textit{Minimum TOTAL design cost of an energy system that meets the design requirements}}{\textit{Team TOTAL design cost}}$$

Although these "bragging rights" calculations excite friendly competition amongst the design teams, product performance is a small consideration in the assessment of the team's entire design project and student grades. In addition to the product, students also have to maintain a design notebook and complete a final design report. The design notebook and report are used to evaluate the team's entire design process, from defining the problem to the final design, and it is required that they include a description of the design, modeling, implementation, and evaluation approaches used by the team to reach their final design. This also includes a mathematical model that predicts the performance of their energy system. While the final design challenge is a competition, the entire design project has many other components, and assessment of the team's success with the engineering design process is based on much more than product performance.

The energy design project has been tested in both the high school and university environments (freshman engineering course at the University of Maryland Baltimore County). Teams have successfully used wind, solar and hydro energy systems, and no one energy source performed the best each time. The design must collect from a renewable energy source, convert the energy into a form that can be transported, store the energy for a specific period of time, and then use the energy to illuminate a light bulb. The majority of students collect from solar, wind, or hydro sources, but the various collection devices are incredibly unique. Most groups that use wind and hydro sources also use a motor-turbine to convert the kinetic energy, and the majority of all groups use rechargeable batteries to store the energy. However, every group has a unique project, and the energy system aspect of the project allows groups additional freedom.

Students prove incredibly innovative when approaching this design challenge, and while some groups can only light the bulb for the minimum required 15 seconds, others are able to light the bulb for hours. Some groups spend the maximum $75 on their design, while others are successful with a minimal cost. As part of the design process, these students learn how to choose the best solution based on all of these considerations.

Post-Module Design Challenge

"Power It Up with Gears!"

The Post-Module design challenge, "Power It Up with Gears!" is similar to the Pre-Module design challenge because the students construct an apparatus to harness energy from two quarts of water, but this time their apparatus must be connected to a geared device which is used to lift the weight. The materials for construction are

K'Nex building parts, small cups, masking tape, and fishing line. Each K'Nex gear, pulley, connector, and rod is given a cost. The goal is not only to lift the weight in the shortest amount of time, but also to minimize the total device cost. This follow-up activity is used to assess the groups' use of the engineering design process and the results can be compared with those from the Pre-Module design challenge. The same assessment methods implemented in the Pre-Module challenge and Design Project challenge are also used in the Post-Module challenge.

Results and Discussion

To date, the Engineering Energy Solutions module has been tested with both high school students and undergraduates. Since fall 2008, the curriculum has been adopted by several Maryland high schools. Testing included students ranging from freshmen to seniors from diverse demographics enrolled in technology education classes. Testing is currently underway in additional schools in the greater Baltimore-Washington, D.C. area. Cumulative data including new data from ongoing high school trials will incorporated into the final manuscript.

Student learning has been measured by comparing the results from the pre-module and post-module assessments, which were administered online prior to and after use of the Engineering Energy Solutions module. The assessments consist of multiple choice, matching, and brief constructed response type questions. The assessments are comprised of both scientific and engineering concepts. Scientific concepts include a range of topics, some of which are likely to be covered in previous high school courses (e.g. the relationships between energy, work, and power) and others that are more specific to energy systems (e.g. renewable and non-renewable energy sources, energy conversion, efficiency).

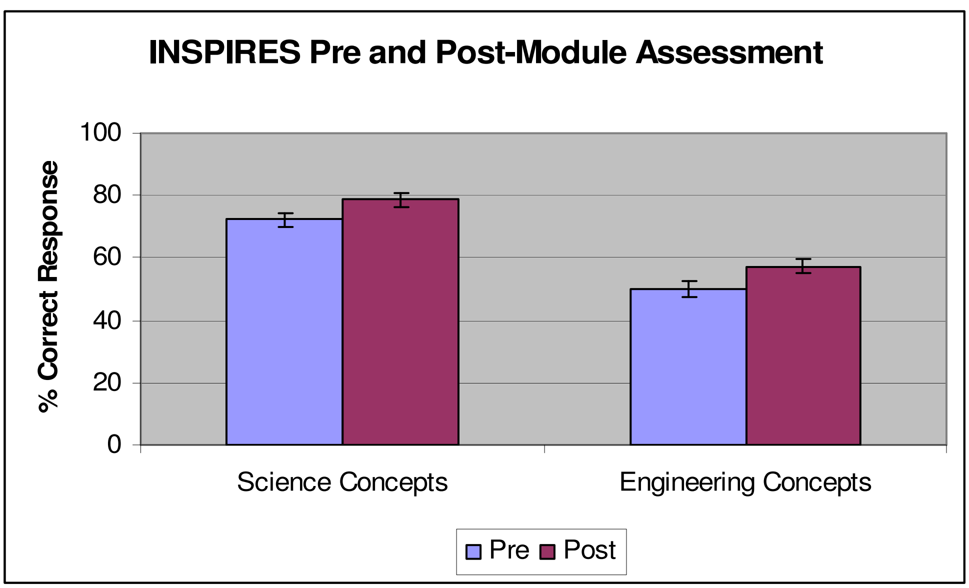


Figure 1: INSPIRES student learning of scientific and engineering concepts presented as mean assessment scores ± standard error of the mean.

Figure 1 shows the INSPIRES high school student scores for the scientific and engineering concept questions both prior to and after use of the curriculum module. Students show improvement in both scientific and engineering concepts, from 72.3(±2.2)% to 78.6(±2.3)% and 49.9(±2.4)% to 57.2(±2.1)%, respectively. The statistical significance of these increases in the mean assessment scores was analyzed with a t-test, and the p-values for the paired student data sets were 0.0002 and 0.0001, respectively. Student learning of engineering concepts is more difficult to assess due to the more open-ended nature of the brief constructed response style questions for the engineering concepts, which could explain the difference between the scientific and engineering mean assessment scores.

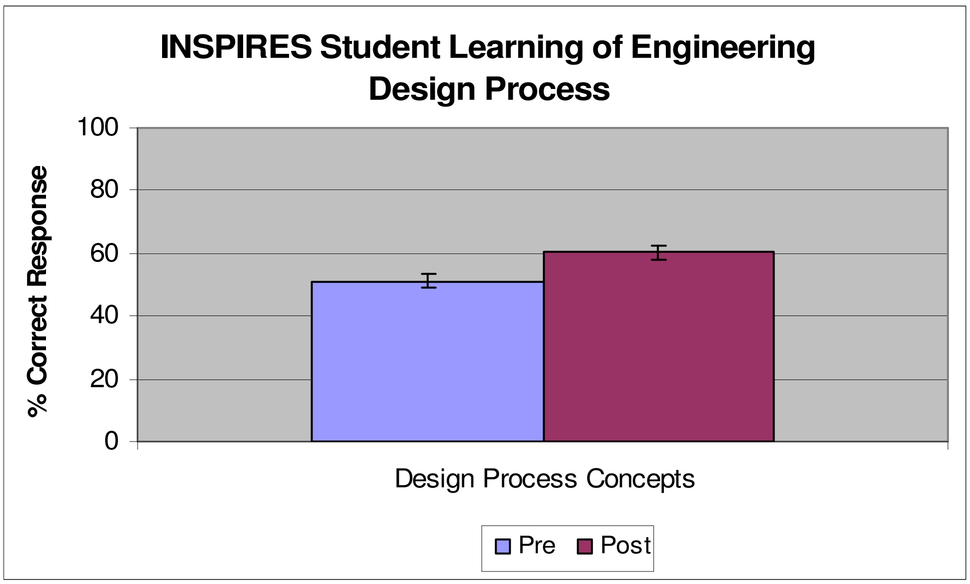


Figure 2: INSPIRES student learning of engineering design process presented as mean assessment scores ± standard error of the mean.

One of the major engineering concepts emphasized throughout the INSPIRES curriculum is the engineering design process. Learning how to solve problems using the engineering design process can be a strong transferable skill for students, and they show marked improvement in their understanding of the process. Student assessment scores show an increase from an average of 51.0(±2.6)% to 60.3(±2.2)% (p=0.00001). The assessment of student learning of the design process includes the "steps" of the engineering design process and the idea that brainstorming is an important part of the design process. The assessment also includes the concept that it is an iterative approach, yielding multiple possible solutions, and that constraints are the limiting factors that both influence the design and the number of possible designs.

Students continued to indicate interest in continuing their education in engineering and technology, and they felt aware of the career opportunities available in those areas. They also showed a preference for learning with hands-on projects and for working in teams. The differences between the pre and post-module results are slight, and further analysis confirms that these results are not statistically significant ($p \geq 0.05$). Possibly, completing the module had less impact on student interest and attitudes towards engineering because students had already demonstrated such a great interest in engineering and technology before completing the module.

Upon completion of the curriculum, questionnaires were used to further assess student perceptions regarding engineering and technology. Students were asked to indicate whether they believed their interest or skills in certain areas had increased, decreased or remained the same as a result of having used the module. The results shown in Table 1 below are presented as the percent of students indicating each response.

Table 1: Student responses to Post-Module Questionnaire

Statement	%Increased	%Same	%Decreased
My interest in pursing a career in engineering or technology has:	48.2%	44.6%	7.1%
My ability to work in teams has:	55.4%	41.1%	3.6%
My confidence in successfully studying engineering or technology has:	51.8%	42.9%	5.4%
My understanding of how math helps solve problems in engineering or technology has:	51.8%	46.4%	1.8%
My knowledge of engineering or technology fields has:	64.3%	32.1%	3.6%
My understanding of design constraints has:	60.7%	35.7%	3.6%
My understanding of mathematical simulation has:	41.1%	58.9%	0.0%
My understanding of the engineering design process has:	62.5%	35.7%	1.8%
My confidence in my engineering or technology skills has:	57.1%	41.1%	1.8%
My understanding of career opportunities in engineering or technology has:	48.2%	50.0%	1.8%

The results of this questionnaire show that students felt their understanding of engineering-related concepts, interest in an engineering career, and confidence in their abilities increased after participating in the Engineering Energy Solutions module.

The assessment methods that have been described for the Engineering Energy Solutions module have been used previously in the two modules already developed for the INSPIRES Curriculum, which has been in use since 2004. The question styles have been used for different topics and in different venues for the curriculum, and the same kinds of questions and assessment structure that have been tested in this diversity of classroom conditions were used to formulate the assessments for the Engineering Energy Solutions module. This includes the pre and post-module assessments for content as well as the interest and attitude questionnaires.

Future Work

The Engineering Energy Solutions module is still being tested in high school classrooms, and the results will be compiled and reported in June. Several high school teachers anticipate adopting the Engineering Energy Solutions module in the coming semester, and they are excited about the topic. The results from the student data collected will also be compiled and presented in its entirety in June.

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