AC 2011-2061: ENGINEERING IN HEALTHCARE: A HEART LUNG SYSTEM

Mr. Zachary Vonder Haar, University of Maryland, Baltimore County

Zachary Vonder Haar graduated Cum Laude in 2010 with a Bachelor's degree in Chemical Engineering from the University of Maryland, Baltimore County. While an undergraduate at UMBC, he participated four years at the varsity level on the swimming and diving team while leading his team to a seventh consecutive America East Championship in his senior season. He will finish his Master's degree in May 2011, also in Chemical Engineering from UMBC. He has been working on the INSPIRES project since May of last year.

Taryn Melkus Bayles, University of Maryland, Baltimore County

Taryn Bayles, Ph.D., is a Professor of the Practice of Chemical Engineering in the Chemical and Biochemical Engineering Department at UMBC, where she incorporates her industrial experience by bringing practical examples and interactive learning to help students understand fundamental engineering principles. Her current research focuses on engineering education, outreach and curriculum development.

Dr. Julia M. Ross, University of Maryland, Baltimore County

Engineering in Healthcare: A Heart Lung System

Abstract

INSPIRES is an interactive curriculum designed for high school students with the goal of INcreasing Student Participation, Interest, and Recruitment in Engineering & Science. It was created to target the ITEA Standards for Technological Literacy and to increase involvement in STEM related fields. This curriculum allows for students to learn basic engineering design principles through a variety of ways including hands-on activities, online animations and simulations and culminates in an open ended design challenge that encourages creativity, resourcefulness and teamwork to solve a real world engineering problem.

A new curriculum module was created this year entitled: "Engineering in Healthcare: A Heart Lung System Case Study". Like all of the INSPIRES curricula, it focuses on teaching students basic engineering principles while introducing them to the engineering design and decision making process. The students are introduced to the curriculum by watching a professionally produced video about Tynisha, a 13 year old girl who was born with a heart defect which required lifesaving open heart surgery to repair. Also, they are introduced to the medical team and the device that kept her alive during open heart surgery, the heart-lung machine. The students then go through a series of hands on activities, online content, animations and simulations where they learn about the factors that affect the heart lung machine. The students then build and test a heart lung system, which circulates and cools the blood of the "patient", and then evaluate the effectiveness of their prototype.

Over the first five years of the INSPIRES project, the teacher Professional Development (PD) training was limited to two days. But in the past two years, with the support of a NSF-DRK-12 grant and cooperation with the education department, the PD training was extended to three weeks. This has allowed the teachers to spend more time to learn, practice and reflect. The PD is split into three distinct sessions. The morning session focused on the heart lung engineering content taught by engineering faculty and inquiry-based pedagogical facilitators (one of which is a faculty member in the education department). The early afternoon sessions had the teachers apply what they learned in the morning by teaching the heart lung curriculum to classrooms of students enrolled in the Upward Bound Program. In the late afternoon session, the teachers and INSPIRES faculty collectively reviewed videotapes of that day's session and provided constructive criticism to improve content understanding, teaching pedagogy and curriculum delivery.

Of the twelve teachers who participated in the three week PD training, nine have/are implementing the "Engineering in Health Care: A Heart Lung Case Study" curriculum with their high school students during the 2010-11 academic year. To date, student learning data has been collected and analyzed and are presented here (for seven of the nine teacher classrooms) to determine the effectiveness of the curriculum. Statistically significant results in both engineering and science content have been demonstrated; as well as statistically significant improvements in interest and attitude and which curriculum features were most beneficial.

Background

The INSPIRES project, funded by the National Science Foundation, was created to directly combat declining enrollment in STEM related fields in the United States[1,2]. The INSPIRES curriculum uses real world engineering design challenges, interactive lessons, an inquiry based methodology and a variety of pedagogical techniques to increase student participation and desire to learn. By incorporating basic engineering fundamentals and the design process in high school curriculum, the INSPIRES modules target ITEEA Standards for Technological Literacy, which outline the need for students to be able to understand engineering design and apply the engineering design process.

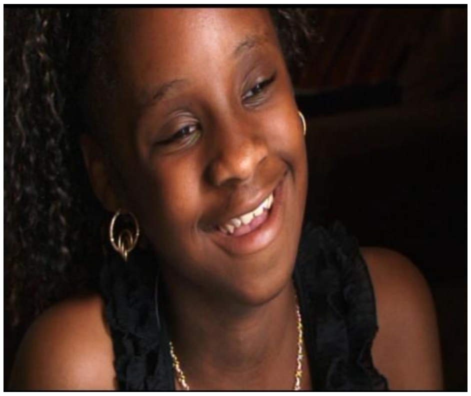
The most recently developed module is "Engineering in Healthcare: A Heart Lung Case Study", is the second INSPIRES module focusing on healthcare. Heart disease, in recent years, has become the number one cause of death in the United States[3]. With increasing rates of heart disease, more people are undergoing open heart surgery to reduce the risk of complications. Developing new solutions to this critical healthcare epidemic will fall to students currently in the education system. For this project, students are required to build, test and evaluate a system that mimics a heart lung machine with the goal of increasing understanding and interest in STEM related fields.

Engineering in Health Care: A Heart Lung System Case Study

With the newly added "Engineering in Healthcare: A Heart Lung System Case Study" module the INSPIRES project consists of five different modules incorporating issues related to engineering such as healthcare, flight and energy. All of the INSPIRES curricula follow the same general structure. The students start the curriculum by taking a pre assessment which gauges their initial knowledge, interest and attitude towards STEM related fields. The students then watch a professionally produced video, which depicts a real world engineering problem which each module focuses on for the curriculum. Next, the students are given a mini design challenge which introduces them to the iterative design process and teaches them about some of the factors that they will need to consider in their final design. Over the next class sessions, the students go through the online content with interactive animations and computer simulations while performing hands on activities that parallel the online module, reinforcing the technical concepts for the students so they have a better understanding of the material. Once finished with the online content, computer simulation and hands on activities, the students design, build, evaluate and report on their final design project. Finally, the students take a post test assessment, which incorporates the same questions as the pre assessment to determine their knowledge, interest and attitudes towards the STEM related fields have changed over the length of the curriculum.

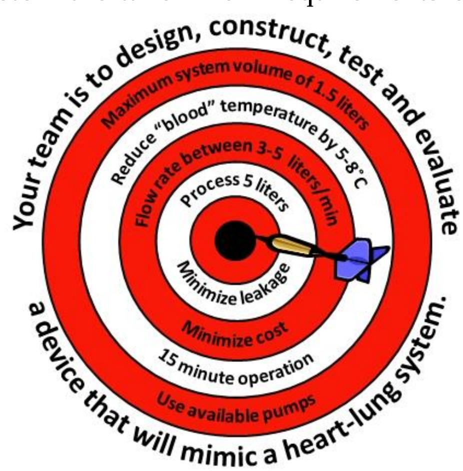
Fixing Tynisha's Heart

For the new module, the students are introduced to Tynisha, a 13 year old girl who was born with a defective heart valve which required lifesaving open heart surgery to repair. The video follows Tynisha through her open heart surgery and the toll it takes on her family. Next, the students are taken on a tour of a live open heart surgery and get to see the heart lung machine and the army of health care professionals that keep the patient alive during the procedure. The perfusionist, who runs heart lung machine during open heart surgery, then describes all the different components of the heart lung machine and the role that each one plays during open heart surgery. The students can use this information to help them with the requirements of their design challenge. This video provides the students a real life example and puts a face to their project with the goal of inspiring students to further their education in the STEM related fields.



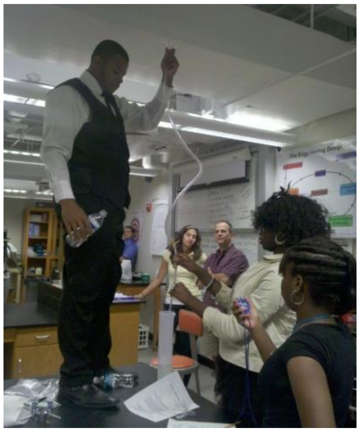
Design Challenge

The culminating design challenge for this project is to build, test and evaluate a system that mimics a heart lung system. The constraints of the system are taken from requirements of heart lung machines used during open heart surgery. The heat lung system must maintain a biologically safe flow rate using the pumps which are provided to the students. The system is required to cool the "blood" between 5-8 °C during the 15 minute testing period. During the surgery, the blood is cooled to reduce the oxygen demand of the body while the heart is being repaired. The system is also required to provide a functioning 750 mL reservoir which acts as the lungs of the heart lung system, which adds oxygen to the blood and removes carbon dioxide. The total system volume of the heart lung system is not allowed to exceed a maximum volume of 1.5 L which ensures the patient has enough blood in the body to provide oxygen to vital organs throughout the surgery. The students are also encouraged to minimize leakage of their system and also to minimize system cost.



Let it Flow

"Let it Flow" is the opening mini design challenge for the heart lung module. Teachers split the class into teams of approximately four students. The students are given materials which consist of vinyl tubing ½'', ⅜'', and ¼'' inner diameter each two feet in length, plastic funnels,



plastic ties, and two empty bottles. They have 30 minutes to design, build and test a system that can transport 500 mL of water a distance of six feet with minimal leakage in the quickest possible time. This activity allows the students to start to think about fluid flow through a system and how things such as height, path of flow and tube diameter will affect the final heart lung system design.

Hands-on Activities

<u>*Centrifugal Pumps*</u>

Many students do not have exposure to centrifugal pumps, so this hands-on activity is designed to allow the students to learn how to operate different types of pumps and discover how they work. Students first watch a video which demonstrates the proper technique to connect, prime and start up various pumps. The students are split into groups and follow the instructions from the video to get an understanding of how to operate different pumps, including centrifugal pumps.

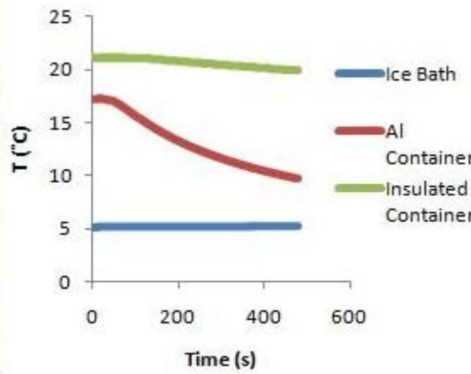
<u>*Experiencing Heat Transfer Part 1*</u>

In this hands-on activity, students learn about how contact area and temperature gradient affect heat transfer. Students first set up five different stations to prepare for this activity. The first four stations are set up by filling large plastic bowls with cubed ice, crushed ice, ice water, and cool water (~7 °C). The last station is set up with two ice packs and rubber bands and the temperature of each bath is recorded (the ice and ice pack are assumed to be 0 °C). The students then fill five identical 8 oz bottles with water and record the starting temperature of the water. For the first four stations, the students place the bottles in each bowl. For the last station, the students wrap the ice packs around the bottle with the use of rubber bands. After 10

minutes elapses, the students remove the bottles from the medium and record the water temperature. The students are then engaged in a discussion (led by the teacher) of how the rate of heat transfer is affected by temperature gradient and contact area.

<u>*Experiencing Heat Transfer Part 2*</u>

In contrast to what part one illustrates, the second part of experiencing heat transfer focuses on how different materials affect the rate of heat transfer. Students fill two different water bottles with water and record the temperature. One of the bottles is a double walled plastic bottle insulated by air and the other is a single walled aluminum bottle. Both bottles are approximately the same shape and have the same volume. The students then simultaneously immerse the two bottles in ice-water baths. After 5-8 minutes elapses, the students remove the water bottles from the ice baths and record the temperature. Following the activity another student discussion which material conducted heat more easily and reasons why.



Final Design Challenge Activity

Students are split into teams ranging from three to five people and are encouraged to use information gained from the on-line content, activities, on-line simulations, creativity and innovation to design a heart lung system which meets the design criteria. The students start off by brainstorming and collaborating amongst their team to create ideas of where to start with their project. The students decide which of their ideas have the greatest possibility for success and provide a rough sketch of their designs. The students begin with building a fluid flow circuit in which the water travels from the patient into a pump which moves the water to a 750 mL reservoir and then circulates the water back to the patient. The students are provided various types of tubing, connectors, pumps and other common materials for the construction of their design. Once the flow circuit is created, the students add in the heat transfer component of the heart lung system so that the water can be cooled 5-8 ˚C. The students test and evaluate their designs and make any

necessary refinements to make their system perform better. Once the final test is complete, the students present their results to the class.

Career Opportunities

One of the unique features of this specific module is that it gives the students some prospective of some lesser known career opportunities in the healthcare field. When students are asked what careers are available in the healthcare field they typically respond with two answers: nurses and doctors. Although doctors and nurses are typically the face you see when you go to the hospital or medical facility, there are many other individuals behind the scene that play a critical role to help doctors diagnose patients, develop medicine and vaccines or design critical healthcare equipment to enable doctors and nurses to save lives. By watching a video, students learn about two positions that are critical in the healthcare field but seldom receive recognition because they do not have face to face time with the patient: the engineer and the medical laboratory scientist. The first video entitled "Designing the Future" introduces the students to a number of college students from a variety of backgrounds who are studying engineering. Each engineering student describes how they became interested in the subject, the projects that they are working on in school and their goals and aspirations after graduation. The video also highlights the importance of teamwork throughout the design process and the need to work together and collaborate to have a successful design. The goal of this video is to give the students an idea of what engineers are like, the opportunities that are available for engineers and how each student can prepare to become an engineer. The second video entitled "The Invisible Medical Team" introduces the students to the field of medical laboratory scientist. Medical laboratory scientists do much of the background research and perform tests to diagnose patients that the doctors then use to design a treatment for the patient. This video describes many different career opportunities that the students can go into ranging from jobs in hospitals to industry to research positions in the government.

Post Assessment

At the end of the heart lung module, the students return to the online system and complete post assessments on science and engineering content and interest & attitudes towards STEM related fields.

Teacher Professional Development

Over the first five years of the INSPIRES project, the teacher Professional Development (PD) training was limited to two days. But in the past two years, with the support of a NSF-DRK-12 grant and cooperation with the education department, the PD training was extended to three weeks. This has allowed the teachers to spend more time to learn, practice and reflect. The PD is split into three distinct sessions. The morning session focused on the heart lung engineering content taught by engineering faculty and inquiry-based pedagogical facilitators (one of which is a faculty member in the education department). The teacher's content lessons followed the same curriculum path as the students, encouraging inquiry-based pedagogical methodology, which fostered interaction between facilitators and teachers and a better understanding of material[4]. The early afternoon sessions had the teachers apply what they learned in the morning by teaching the heart lung curriculum to classrooms of students enrolled in the Upward Bound Program. In the late afternoon session, the teachers and INSPIRES faculty collectively reviewed videotapes of that day's session and provided constructive criticism to improve content understanding, teaching pedagogy and curriculum delivery. A complete description of the PD program has been previously reported[5]. In designing the professional development workshop, we drew upon the latest professional development literature[6-13]. From this research base six core components of what constitutes 'high quality' professional development were found in multiple studies. These components include:

- Immersing participants (teachers) in inquiry, questioning and experimentation;
- Intensive and sustained support;
- Engaging teachers in concrete teaching tasks that integrate teacher's experiences;
- Focusing on subject-matter knowledge and deepening teacher content knowledge;
- Providing explicit connections between the Professional Development activities and student outcome goals; and
- Providing connections to larger issues of education/school reforms.

<u>**Results and Discussion**</u>

Student Learning Data

"Engineering in Healthcare: A Heart Lung System Case Study" is currently being implemented with nine teachers at local high schools. By the end of the school year, it is estimated that 700 students will participate in the module. To quantify learning, students were asked the same questions to examine the changes before and after the module. Over the years the INSPIRES team has observed that much of the student learning data was deficient due to the fact that many of the students did not complete the pre and/or post test, or that their answers were incomplete or indistinguishable in the response. The on-line system is set up in such a manner that students cannot move forward to the next question until they provide a response for each question – students have quickly determined that they can type in meaningless letters into the free response box and then be allowed to move forward. In hopes of obtaining a higher percentage of usable data, facilitators from the INSPIRES team have helped proctor each of the pre and post assessments. To date, the student learning data for 252 students has been collected and evaluated (and this represents 60 % of the students who have used this module to date); the results are displayed in **Figure 1**.

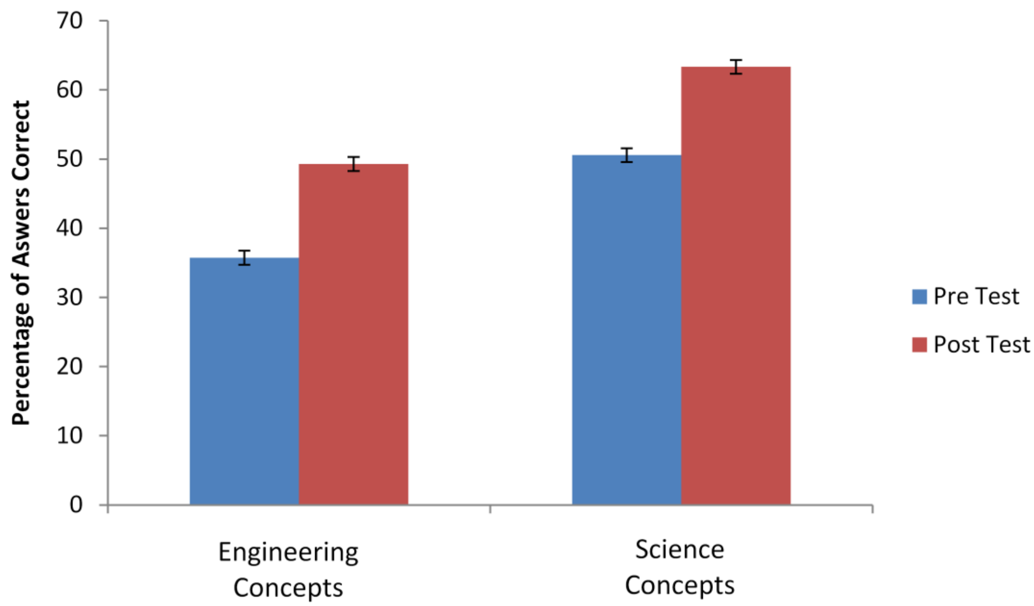
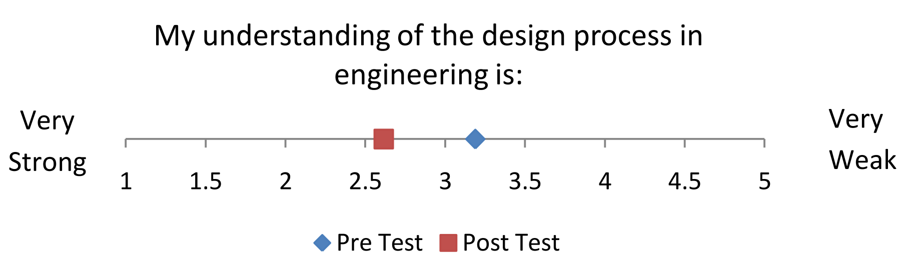


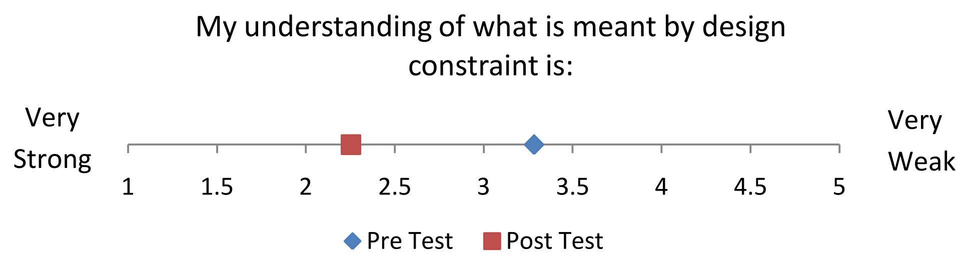
Figure 1: Student learning data from "Engineering in Healthcare: A Heart Lung System Case Study" in the 2010-2011 school year. Mean score ± standard error for 252 Students.

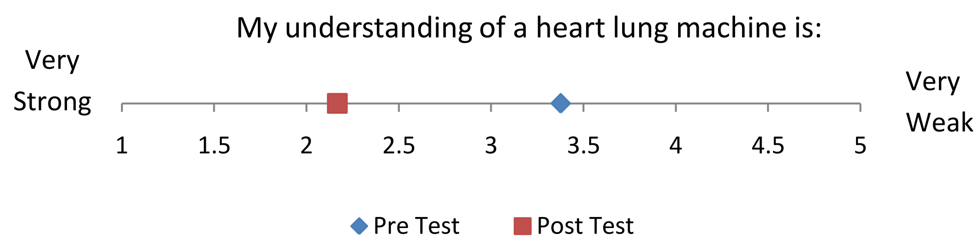
Figure 1 illustrates that the engineering scores went from 37.5% (±1.1%) to 49.3% (±1.1%) and the science scores changed from 50.6% (±1.1%) to 63.3% (±1.2%). Using a two tailed t-test the p values were determined to be 1.80375E-30 and 1.9391E-22 for the engineering and science scores respectively, showing that there was a statistically significant improvement in students' pre and post test scores. The results will continue to be updated as more data is collected from the teachers who will complete implementation over the remaining school year, and will be included and presented at the conference.

Interest and Attitude Data

Students were also asked to complete an Interest and Attitude Questionnaire before and after completing the modules to poll their perceptions and expectations of engineering, medicine and technology and consisted of 15 statements. Students were also asked to indicate their current level of understanding of a number of engineering design and content areas related to a heart lung system. Ten of these questions had statistically different results between their pre and post scores (n=139) and the results of three of these questions are provided below:







The other questions which had statistically significant different results between their pre and post scores were:

- My understanding of a mathematical simulation
- My understanding of heat transfer
- My understanding of the relationship between heat transfer, surface area & temperature
- My understanding of conduction and convection
- I consider my knowledge of engineering and technology
- My ability to accurately explain the importance of making a prototype
- My confidence in my engineering skills

Their increase in student confidence with scientific terminology related to the design process and the heart lung machine is consistent with their increase in assessment scores in these areas. Finally, students also took a Post Module Questionnaire at the completion of the curriculum unit. This questionnaire was broken into two sections. The first section asked students to indicate whether their interest or skills in certain areas increased, decreased or remained the same as compared to before using the module. Results are shown in Table 1 and are presented as the percent of students (n=175) indicating each response.

Table 1: Student responses to Part 1 of Post Module Questionnaire

	% Increased	% Decreased	% Remain the Same
My interest in pursuing a career in engineering or technology has:	20.0 %	29.7 %	50.3 %
My ability to work on teams has:	53.2 %	9.7 %	37.1 %
My confidence in successfully studying engineering or technology has:	42.2 %	14.9 %	42.9 %
My understanding of how math helps solve problems in engineering or technology has:	54.9 %	5.7 %	39.4 %
My knowledge of engineering or technology fields has:	62.3 %	5.1 %	32.6 %
My understanding of design constraints has:	59.4 %	4.6 %	36.0 %
My understanding of mathematical simulation has:	42.3 %	6.3 %	51.4 %
My understanding of the engineering design process has:	69.7 %	4.6 %	25.7 %
My confidence in my engineering or technology skills has:	46.3 %	13.1 %	40.6 %
My understanding of career opportunities in engineering or technology has:	40.0 %	7.4 %	52.6 %

Over 53 % of students reported an increase in their ability to work on a team, knowledge of how math helps solving problems, knowledge of engineering or technology fields and understanding of the engineering design process as a result of using the curriculum module. In addition, over 40 % of students report an increase in confidence in successfully studying engineering or technology, understanding of design constraints, understanding of mathematical simulation, and career opportunities in engineering or technology. The module also appears effective in increasing their confidence in their engineering or technology skills, with almost four times the number of students reporting an increase as those reporting a decrease for this category. When aligned with data from the Interest and Attitude Questionnaire, it is interesting to note that students report an increased ability to work on a team, but decreased enjoyment of working on team projects – and in the data provide below over 64 % of the students felt that their final design project was enhanced by the team approach and over 55 % of the students felt that the team experience helped them learn.

Module Effectiveness

The Post Module Questionnaire also includes a second section in which students are asked to agree or disagree with statements regarding the effectiveness of various aspects of the module. Student responses to these questions are listed in Table 2.

Table 2: Student responses to Part 2 of Post Module Questionnaire

	% Strongly Agree	% Agree	% Neutral	% Disagree	% Strongly Disagree
This inquiry-based learning engineering module has been academically challenging.	15.0 %	34.1 %	39.9 %	8.1 %	2.9 %
The use of interactive animations enhanced my learning	12.7 %	42.2 %	35.3 %	7.5 %	2.3 %
The mathematical simulation gave my team ideas of how to start the design challenge project.	15.6 %	35.3 %	34.1 %	9.2 %	5.8 %
The final team design project has been challenging.	20.3 %	34.1 %	30.6 %	13.3 %	1.7 %
The quality of our final project was enhanced by the team approach.	17.9 %	46.9 %	30.6 %	2.9 %	1.7 %
The team experience helped me learn.	17.3 %	38.2 %	28.9 %	11.0 %	4.6 %
The hands on demonstrations were useful in understanding the concepts.	25.5 %	46.2 %	21.4 %	2.9 %	4.0 %
I understand the connection between the pre mini-design activity and the overall design project.	11.0 %	40.5 %	35.8 %	9.2 %	3.5 %

This section of the Post Module Questionnaire indicates that more than 54 % of the students believe (agree and strongly agree) that interactive animations enhanced their learning, and that the team approach enhanced their final project. The majority of students also felt that the design project had been challenging and that the mathematical simulation provided ideas of how to start the design challenge. The students gave their highest rating of over 71 % believed that the hands on demonstrations were useful in understanding the concepts. These results indicate that the portions of the module which keep the students actively engaged aid in their learning and understanding of the material presented.

Conclusions

The results of the INSPIRES Curriculum: Engineering in Healthcare – A Heart Lung System Case Study module are very promising. Early data presented here indicate the curriculum is successful at targeting ITEEA Standards 8, 9 and 11. Teacher response to the curriculum has been enthusiastic suggesting a need and desire for the materials being developed. We have previously reported[14-15] various challenges and lessons learned from the Professional Development workshops and how they have impacted our curriculum Teacher's Guide. The inquiry-based learning approach appears to be effective at teaching both scientific content and engineering design knowledge as demonstrated in statistically significant improvement in pre/post tests in both categories. The online interactive animations and hands-on activities, in particular, have been well received by students and a large percent indicate that these activities have aided their understanding of the materials presented. Similar results from a different study[16] indicate that engaging students in engineering curriculum activities may diminish achievement gaps in science for some student populations.

Future Work

In the near future, the INSPIRES project will continue to implement the Engineering in Healthcare: A Heart Lung System Case Study curriculum with several other schools in the local area as well as collect and evaluate the data and will include this data in the conference presentation. Next summer, the INSPIRES project will offer two professional development workshops: a three week PD workshop similar to the ones offered for the last two years and a new three day PD workshop which provides a shorter, more concise alternative for teachers who are unable to attend the three week workshop.

Acknowledgements

The funding provided by the National Science Foundation DRK-12 program is gratefully acknowledged, as well as the participation of the Upward Bound Program and area high school students.

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