
AC 2012-5405: INCORPORATING ENGINEERING DESIGN INTO HIGH SCHOOL STEM INITIATIVES

Dr. Taryn Melkus Bayles, University of Maryland, Baltimore County

Taryn Bayles, Ph.D., is a Professor of the Practice of chemical engineering in the Chemical, Biochemical, and Environmental 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. Joshua A. Enszer, University of Maryland, Baltimore County

Joshua Enszer is a full-time lecturer in chemical engineering at the University of Maryland Baltimore County. He has taught core and elective courses across the curriculum, from introduction to engineering science and material and energy balances to process control and modeling of chemical and environmental systems. His research interests include technology and learning in various incarnations: electronic portfolios as a means for assessment and professional development, implementation of computational tools across the chemical engineering curriculum, and game-based learning.

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

Incorporating Engineering Design into High School STEM Initiatives

Abstract

A report by the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine titled “Rising Above the Gathering Storm” specifically calls for the development of rigorous new K-12 curriculum materials to improve science and mathematics education as a highest priority action. With funding from the National Science Foundation, we have developed new curriculum modules which target the International Technology & Engineering Educators Association (ITEEA) Standards for Technological Literacy and increase involvement in STEM (Science, Technology, Engineering and Mathematics) related fields. Each module focuses on an engineering design challenge that provides real world context, is grounded in STEM content, and uses the engineering design process to design, construct and test a working prototype. The modules feature professionally produced video segments which introduce the design challenge, hands-on activities, and online segments with interactive animations and mathematical simulations. The curriculum has successfully been used in high school technology education classes over the last six years.

Our state recently received an award from the Race To the Top (RTTT) fund, a competitive grant program designed to encourage and reward states that are creating the conditions for education innovation and reform and achieving significant improvement in student outcomes, including making substantial gains in student achievement, closing achievement gaps, improving high school graduation rates, and ensuring student preparation for success in college and careers. Our state has focused its RTTT program to include STEM initiatives throughout PreK-12 to teachers looking for new curricula with a STEM focus, which in turn has fostered collaborations among STEM high school teachers. As a result, a higher percent of science teachers attended our Professional Development (PD) workshop last summer and are currently using our engineering design curricula in their traditional science classrooms. Further, one of the technology education teachers using our curriculum has partnered with physics and biology teachers to provide supplemental science lessons related to the overarching engineering design challenge. In another school, three teachers who attended the PD workshop are partnering with two teachers who did not attend the workshop to help them deliver the curriculum to their students, which has resulted in thirteen classrooms from a single high school using the same curriculum module.

Currently thirty-five classrooms at eleven different schools are using the "Engineering in Health Care: A Heart Lung Case Study" curriculum module, and more classrooms are planning to use this module in the winter or spring of 2012. Student learning data is being collected and analyzed to determine the effectiveness of using the curriculum in a variety of different settings and will be compared to the results attained in previous years of the program.

Background

The *INSPIRES* Curriculum (*IN*creasing Student *P*articipation, *I*nterest and *R*ecruitment in *E*ngineering and *S*cience) is the result of a NSF IMD project to provide new curricula for technology education. It is designed to target what we believe to be the core engineering skills and concepts that should be addressed at the high school level in order to better prepare students to pursue careers in engineering and technology. While content topics are important in building student interest and in connecting the curriculum to real life, it is the skill set development that we believe is foundational for future success in the study of engineering. We purposely emphasize the development of these *transferable* skill sets as the focus of our curriculum. We consider the following skills to be key:

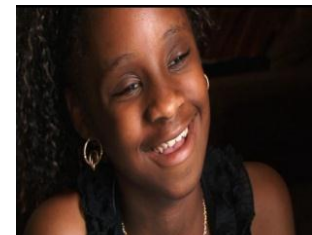
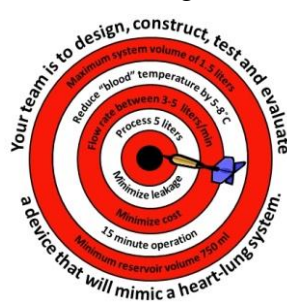
- The ability to solve an open-ended problem
- The ability to effectively work in teams and communicate technical ideas
- The ability to synthesize what is learned in science and math classes and apply knowledge to a real-world open-ended problem¹
- The ability to think creatively
- The ability to view/analyze a system as a whole.

The specific content areas covered by the curriculum were chosen to stimulate student interest in engineering and technology and to provide a real-world context. Each module is focused around an engineering design challenge, since we believe design is the foundation for understanding engineering and technology.

Professionally produced video segments introduce the students to the design challenge and provide the real-world context and constraints. The videos also provide descriptions of how the real-world components

function and what improvements must be made to further the technology. The curriculum incorporates mini-design challenges and hands-on activities to help students understand key content, which enables them to create a successful design solution. An on-line segment, which features interactive animations, provides explicit connections to STEM related

concepts. In addition, mathematical simulations are included so that the students are able to scaffold² their design decisions and determine the effects on efficiency and cost of their design. Integrated assessments and a comprehensive teacher guide, complete with pedagogical strategies, are provided. The modules are designed to be low cost and use commonly available software and materials to make the curriculum accessible to most



Rate of Heat Transfer = $\frac{T_{\text{inside}} - T_{\text{outside}}}{\Sigma R}$

Rate of Heat Transfer = $\frac{\Delta T}{m c_p}$

Select a volumetric flow rate (L/min):

Select a tubing length (m):

Select a diameter (mm):

Tubing material is held constant
Inlet temperature = 23°C
Temperature of the ice bath = 0°C

Length: short long

Flow: slow fast

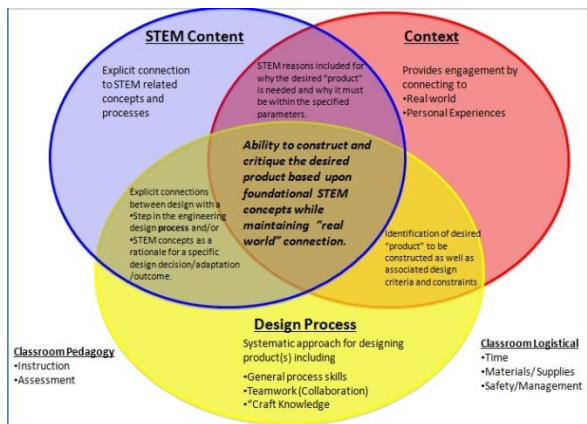
school systems. Before each of the design challenges were adopted for the *INSPIRES* curriculum, they were tested with students in college freshman Introduction to Engineering Design courses, as well as in a high school outreach evening program.



In our current NSF DR-K12 project, we have partnered with the education department and have adapted the Threaded Professional Development framework, which draws upon the latest professional development literature³⁻¹⁰. 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 teachers’ experiences;
- Focusing on subject-matter knowledge and deepening teacher content knowledge;
- Providing explicit connections between the Professional Development (PD) activities and the student outcome goals; and
- Providing connections to larger issues of education/school reforms.

The PD institute threads the use of the *INSPIRES* curriculum throughout all components – which include a content course, practice instruction, reflection, and post institute enactment. Engineering faculty model various pedagogical best practices and then teachers use these same strategies and materials as they practice-teach with Upward Bound students, – allowing the teachers to try the new curricula and pedagogical strategies in a safe environment. The *INSPIRES* curriculum is used as a mechanism to engage teachers in concrete tasks of teaching, assessment, observation, and reflection; to illuminate the processes of learning and design; and to ground the professional development in inquiry, reflection, and experimentation that are



participant driven. By focusing the curriculum on real-world context and threading both STEM content and the engineering design process, teachers and students are provided the ability to construct and critique the desired design solution based on foundational STEM concepts while maintaining a real-world connection.

In our most recent PD institute we offered an abbreviated three-day workshop (versus the previous three-week institute¹¹⁻¹² described above). This three-day workshop still used the *INSPIRES* curriculum and all of the PD best practices listed above with the exception of the ‘practice instruction and reflection’, due to time

limitations. However, the teachers were still required to design, construct, test and evaluate their design challenge (a heart lung system) – as we believe that the engineering design process is an engaging process where some problems (and therefore learning opportunities) simply cannot be predicted and must be gained from first-hand participation. This gave the teachers an opportunity to not only apply the design process, but also gave them the opportunity to evaluate and refine their knowledge of technical concepts. When problems arise during the students’ development of their heart-lung systems (when the teachers enacted the curriculum with their own students during the school year), the teachers now have the experience to be able to relate to them and help them move past the issue.



The Race To the Top

In a recent final report of the Governor’s STEM task force¹³, our Governor was quoted:

“Preparing our children for the knowledge-based economy is among our highest priorities as we seek to improve STEM training throughout the state. Even in difficult economic times, we will continue to protect the investments in education at every level, from Pre-K to college, while increasing the alignment between the needs of our partners in the business community and the curricula designed by our educators. This synergy illustrates the emerging reality that just as our challenges are interrelated, so too are our opportunities for the future.”

With this in mind, our state applied for and received an award from The Race To the Top fund, and our state’s STEM task force made the following recommendations:

1. Align P-12 STEM curriculum with college requirements and workplace expectations in order to prepare ALL students for postsecondary success.
2. Triple the number of teachers in STEM shortage areas who are prepared in Maryland programs, increase their five-year retention rate from an estimated 50% to 75% and enhance the STEM preparation and aptitudes for elementary and early childhood teachers.
3. Ensure that all P-20 mathematics and science teachers have the knowledge and skills to help all students successfully complete the college- and career-ready curriculum.
4. Provide STEM internships, co-ops, or lab experiences for all interested high school and college students to jump-start their successful transition to the workplace.
5. Increase the number of STEM college graduates by 40 % from the present level of 4,400 graduates by 2015.

6. Boost Maryland's global competitiveness by supporting research and entrepreneurship.
7. Create Maryland's STEM Innovation Network to make STEM resources available to all.

Our state's Department of Education Office of STEM Initiatives is using some of the RTTT funds specifically to develop new state STEM Standards of practice, lessons and units; to implement STEM professional development for STEM educators via the State's Educator Effectiveness Academies; allocate funds for the implementation of STEM initiatives in elementary and middle school, particularly focusing on increasing STEM interest and participation of underrepresented populations; collaborate with colleges, universities, governments agencies, businesses, and industry partners to develop e-resources for STEM teaching and learning. The *INSPIRES* curriculum has been selected to be one of the exemplar STEM curricula featured in the State's Educator Effectiveness Academies which will be presented to 1500 science teachers across the state in April/May 2012. In addition, the authors of the *INSPIRES* curriculum have been asked to help author new technology education curriculum units for the state. Also, our most urban school district has implemented a new promotion structure based on Professional Development participation (rather than length of service). As a result of these state wide initiatives, the attendance of our PD workshop was over 80% science and mathematics teachers (versus less than 10% in previous years), as compared to technology education teachers (who were targeted for the PD workshops and institutes).

Results

During fall/winter 2011-2 fifteen teachers at eleven different schools elected to use the *INSPIRES* Engineering and Health Care: A Heart-Lung System Case Study module as one of their units (with additional implementations scheduled for the winter and spring). The implementations have taken place in a wide variety of classrooms which include Technology Education, Honors Chemistry, AP Physics, Health Science and Physical Science classrooms and afterschool Science Clubs. One of the technology education teachers¹⁴ partnered with a biology teacher to teach a class on human physiology so that the students could learn about heart rate. This same teacher also partnered with a Physics teacher to provide supplemental information on how the power supplies operate the pumps which were used to circulate the fluid in the Heart Lung system. In another school one teacher who attended the three-week PD institute and two teachers who attended the three-day PD workshop partner with two teachers who did not attend PD training to help them deliver the curriculum to their students. This resulted in thirteen classrooms from a single high school using the same curriculum module. At this time each of these classrooms have completed their enactments – the results (as well as results from the spring 2012 enactments) will be reported at the annual conference and will be compared to the following results¹⁵ which were obtained for previous implementations of the same curriculum module.

Student Learning Data

"Engineering in Healthcare: A Heart Lung System Case Study" was implemented with nine teachers at local high schools during the 2010-11 academic year. To quantify learning, students were asked the same questions to examine 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. Student learning data for 357 students (of over 700 students who used the curriculum) has been collected and evaluated; the results are displayed in **Figure 1**.

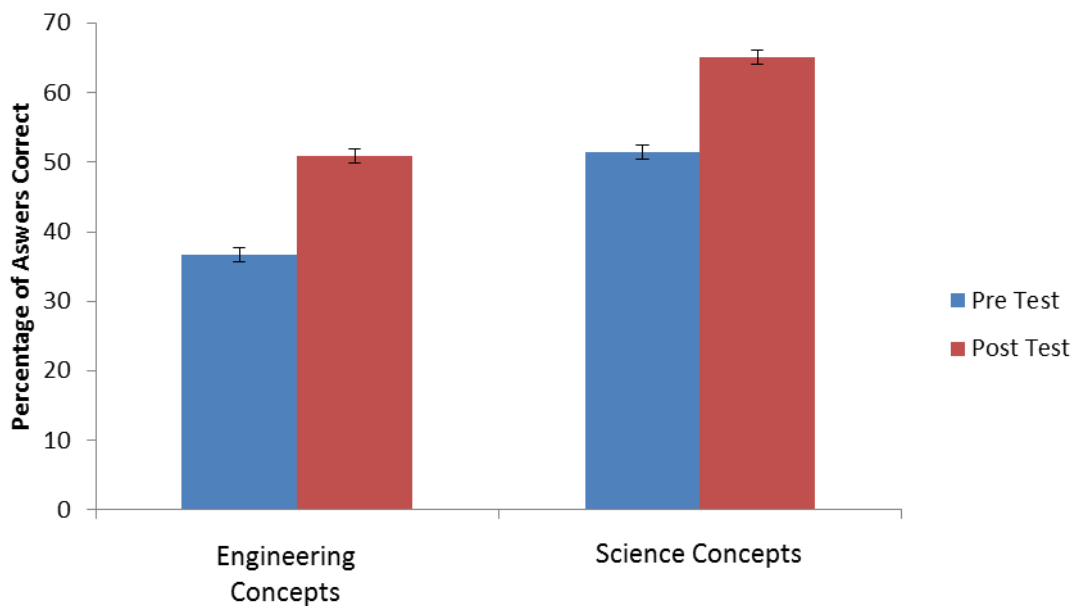
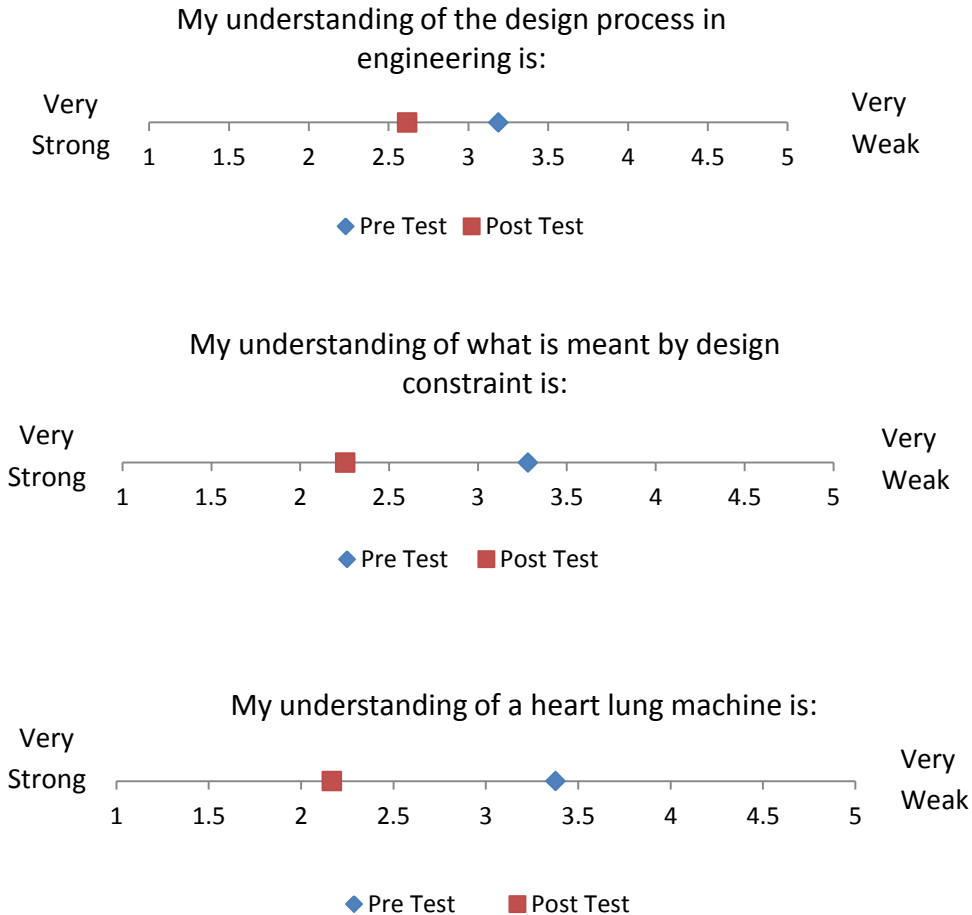


Figure 1: Student learning data from "Engineering in Healthcare: A Heart Lung System Case Study" in the 2010-2011 school year. Mean score \pm standard error for 357 Students.

Figure 1 illustrates that the engineering scores went from 36.7% ($\pm 0.85\%$) to 50.9% ($\pm 0.89\%$) and the science scores changed from 51.4% ($\pm 0.86\%$) to 65.1% ($\pm 0.92\%$). Using a two tailed t-test the p values were determined to be 1.1E-46 and 7.0E-38 for the engineering and science scores respectively, showing that there was a statistically significant improvement in students' pre and post test scores.

Interest and Attitude Data

Students were also asked to complete a 15-item Interest and Attitude Questionnaire before and after completing the modules to poll their perceptions and expectations of engineering, medicine and technology. 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

three 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: 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 rating of the hands-on demonstrations as being useful in understanding the concepts, was the highest at 71%. These results indicate that the portions of the module that 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 is promising. Early data indicate the curriculum is successful at targeting ITEEA Standards 8, 9 and 11. Teacher response to the curriculum has been enthusiastic¹⁶⁻¹⁷ suggesting a need and desire for the materials being developed. We have previously reported various challenges and lessons learned from the Professional Development institutes 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 in their understanding of the materials presented. Similar results from a different study¹⁸ 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. We will also collect and evaluate the data from the current academic year implementation and will compare this data to previous implementations to determine the effectiveness of the curriculum in different STEM classrooms. This data and analysis will be included in the ASEE annual conference.

Acknowledgements

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