

## **AC 2007-2216: NEW INQUIRY-BASED CURRICULA FOR BIOENGINEERING EDUCATION**

### **Julia Ross, University of Maryland-Baltimore County**

Julia M. Ross is Chair of the Chemical and Biochemical Engineering Department at the University of Maryland, Baltimore County. Her technical research interests are in the area of cellular engineering. In particular, her work focuses on bacterial adhesion to physiological surfaces. In addition, she maintains an active research program in curriculum development with a focus on workforce development.

### **Greg Russ, University of Maryland-Baltimore County**

Gregory Russ graduated Magna Cum Laude in 2006 with a BS degree in Chemical Engineering from the University of Maryland, Baltimore County. He is currently pursuing a MS degree in Chemical Engineering with a focus on Engineering Education, also from UMBC. He is a member of several prestigious honor societies, most notably the engineering honor society, Tau Beta Pi.

### **Carolyn Parker, George Washington University**

Carolyn Parker is an Assistant Professor and lead faculty member to the Secondary Education Program in the Graduate School of Education and Human Development at the George Washington University. She holds a BS in Biology, MA in Teaching and PhD in Curriculum Instruction and Science Education. Dr. Parker's research interests are in the achievement of women and underrepresented groups in science/technology.

### **bruce jarrell, University of Maryland-School of Medicine**

Bruce Jarrell is Senior Associate Dean and Professor of Surgery at the University of Maryland School of Medicine. He has been an active teacher of medical students and residents of surgery since 1980 and has received the Clinical Teacher of the Year numerous times. He received his undergraduate degree in Chemical Engineering from the University of Delaware.

### **John Raczek, University of Maryland**

John W. Raczek is a Web Developer in the Office of Medical Education at the University of Maryland School of Medicine. His work focuses on developing software systems for education with an emphasis on simulation.

### **Taryn Bayles, University of Maryland-Baltimore County**

Taryn Bayles is a Professor of the Practice of Chemical Engineering in the Chemical and Biochemical Engineering Department at UMBC, where she teaches, the Introduction to Engineering Design course, among other Chemical Engineering courses. Her research interests include engineering education and outreach, and has received funding from NSF in excess of \$3.6M over the last four years.

# New Inquiry-Based Curricula for Bioengineering Education

## Abstract

The **INSPIRES** Curriculum (**IN**creasing Student **P**articipation, **I**nterest and **R**ecruitment in **E**ngineering and **S**cience), funded by the National Science Foundation, is being developed in response to the need to introduce, recruit, and retain more students to STEM-related fields. The first module in the curriculum, “Engineering in Health Care: A Hemodialysis Case Study,” has been completed and is available for adoption. The curriculum is designed to be very flexible to accommodate student learning at a variety of levels, from high school to undergraduate. At the start of the curriculum, students are introduced to a hemodialysis patient and her doctor through a professionally produced video segment. The purpose of this segment is to provide societal context for the module topic. Following the video, the students go through a series of hands-on activities, demonstrations and a web-based tutorial that teach about the engineering design process and principles of engineering, such as mass transfer and fluid flow, that are essential to hemodialysis systems. Next, the students are issued a challenge to design, build and operate their own hemodialysis systems via another video segment. Before moving into the actual design project, students have access to a web-based simulation that allows them to adjust parameters (such as flow velocity, flow direction, membrane pore size and surface area) to observe how each affects the efficiency and cost of a hemodialysis system. After the students successfully complete the computer simulation, the patient and doctor (via video segment) discuss their visions of hemodialysis for the future and reiterate the challenge to design and build a hemodialysis system that meets performance criteria. Using the simulation results in conjunction with their understanding derived in the tutorial, student groups then proceed through the engineering design process and build their own prototype system to remove “waste” from “blood”. The curriculum ends with an inspirational video of engineering and medical students discussing why they chose their particular fields of study.

To date, the “Engineering in Health Care” module has been tested in a number of high school classrooms, and engineering summer camp, and with undergraduate chemical engineering majors. In this presentation we will demonstrate the curriculum module and will present and evaluate student learning, interest and attitude data.

## Background

The need to recruit more students into engineering fields in the U.S. is urgent. Although increased employment opportunities for engineering careers are forecast for the future, national enrollment in engineering disciplines has been declining<sup>1,2</sup>. These diverging trends are likely to create a shortfall of trained engineers in the U.S. in the near future<sup>1,2,3</sup>. While women and minorities comprise an increasingly large percentage of the total workforce, representation in engineering careers remains low at nine and four percent respectively<sup>1,2</sup>. In order to alter the enrollment trends, more students must be attracted to engineering careers and be prepared to pursue engineering study at the college level. To meet this challenge, new innovative high school curricula are needed. Indeed, the recent report entitled “Rising Above the Gathering Storm” issued by the National Academy of Sciences, National Academy of Engineering, and

Institute of Medicine highlighted the need to develop rigorous new K-12 curriculum materials in science and mathematics as a highest priority action<sup>4</sup>. New curricula must be accessible to all high schools and must inspire greater numbers of women and minorities to choose engineering careers. The **INSPIRES** Curriculum is being developed with these goals in mind.

## Curriculum Goals

Many high school students have little understanding of what engineers do. This often results in a lack of awareness of the opportunities available to students who study engineering. Therefore, one important focus of the **INSPIRES** Curriculum is to increase student awareness of engineering careers. The “Engineering in Health Care” module highlights biomedical engineering, an area with significant appeal to female students (biomedical engineering leads all engineering disciplines in the percentage of degrees awarded to women) yet very limited exposure in high school.

The **INSPIRES** Curriculum uses engineering design challenges and problem-based learning strategies to increase technology literacy as defined by the International Technology Education Association. The curriculum targets national standards for technology education that relate to engineering design as well as key skills that we believe are foundational for success in the study of engineering. The focus is on transferable skills that will apply not only to any engineering discipline but also to areas outside engineering. These core critical thinking skills are listed below.

- The ability to work effectively in teams and communicate technical ideas both orally and in writing
- The ability to solve open-ended problems
- The ability to synthesize what is learned in science and mathematics courses and apply the knowledge to real world problems
- The ability to think creatively with respect to the solution of an open-ended problem
- The ability to describe the natural world using mathematics
- The ability to view and analyze a complex system as a whole

The Engineering in Health Care module links the curriculum exercises (learning about and designing a hemodialysis system) directly to the solution of a real-world problem (the need to treat a teenage patient with kidney failure). This linkage helps students understand the relevance of the skills that are being developed and provides a tangible application.

Although originally designed for high school students, the curriculum is flexible enough for use in a range of age groups and skill levels from high school to undergraduate. The material contained in the module leaves room for adaptation by the instructor and the level of difficulty can be adjusted by going into as little or as much depth as desired. Although the module is designed so that it can be taught as a stand-alone program of study, it is also possible to adapt it into a more extensive program or to only use components of the module where they are applicable.

## “Engineering in Health Care” Module Description

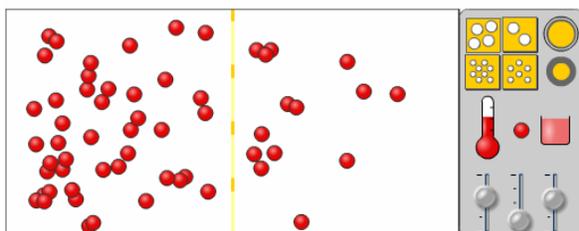
The **INSPIRES** Curriculum will ultimately consist of five stand-alone inquiry-based learning modules, each targeting a unique societal need or problem. “Engineering in Health Care: A Hemodialysis Case Study” employs a variety of classroom activities (including hands-on experiments, demonstrations, web-based tutorials and interactive computer simulations) to introduce engineering design and decision-making processes as well as basic engineering concepts. Many of the included activities require students to work in groups, thereby promoting teamwork, creativity and leadership skills. The Engineering in Health Care module differs from other available “kits” on the market in that it represents a comprehensive four week curriculum unit (assuming high school class periods of 45 minutes) that utilizes multiple pedagogical strategies to target a wide array of learning styles.

Curriculum effectiveness and student progress are evaluated using assessment rubrics integrated into the module. Baseline interests, attitudes and knowledge are established by having students complete questionnaires and assessments prior to beginning the module. Students also have the opportunity to demonstrate their ability to work as part of a team and to apply the engineering design process during a short, 45 minute pre-module design activity. The results of these pre-assessments are compared to similar evaluations given to the students after module completion.

Students are introduced to hemodialysis via a professionally produced video segment of a teenage dialysis patient and her doctor. The video provides societal context for the concepts presented in the module, bridging the gap between fundamental principles and ‘real-world’ applications. Students then explore the principles of dialysis, mass transfer and fluid flow with a series of hands-on activities. The goal of these activities is to get students thinking about the scientific topics relevant to hemodialysis and to get them actively involved. Next, students go online where they are issued a challenge to design and construct their own hemodialysis system using everyday materials. The system must be both efficient and inexpensive. Before beginning this task, the students complete an online portion of the curriculum module to learn background information and the engineering principles involved in hemodialysis. Interactive animations allow the students to visualize how each principle relates to hemodialysis system design. The students also perform an online mathematical simulation in which the parameters



Membrane Diffusion w/ Parameters



that affect the design are adjusted to determine the optimal parameter settings for achieving maximum efficiency at low cost. After completing the simulation, the patient and doctor (via video segment) discuss their visions for the future of hemodialysis and reiterate the design challenge and the goals of the project. Then, using what they have learned from the tutorial and simulation, the students work in groups to design, construct, test and evaluate the performance of the prototype they create.

After finishing the exercises described above, the students complete post-module assessments and questionnaires that complement those taken prior to starting the module. The students also participate in another mini design challenge that assesses how their use of the engineering design process has evolved.

## Results

To date, the “Engineering in Health Care” module has been tested with both high school students and undergraduates. Since spring 2005, 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 five additional schools in the greater Baltimore-Washington, D.C. area. Cumulative data including new data from ongoing high school trials will be incorporated into the final manuscript. In addition, the curriculum was used at Virginia Polytechnic Institute and State University during summer 2006 at an engineering camp for high school girls called C-tech<sup>2</sup>. Twenty-eight girls attended the camp and participated in the trial. At the undergraduate level, “Engineering in Healthcare”

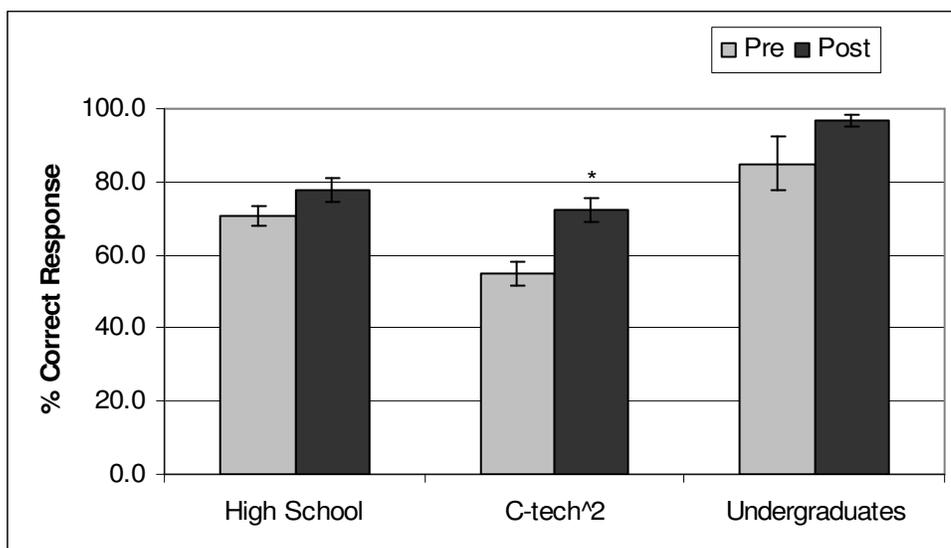


has been tested with juniors in the Biotechnology and Bioengineering Track at UMBC.

To measure student learning, online assessments were given prior to and after use of the curriculum module. The assessments consist of multiple choice, matching, and brief constructed response (BCR) type questions and evaluate learning of both scientific and engineering design concepts.

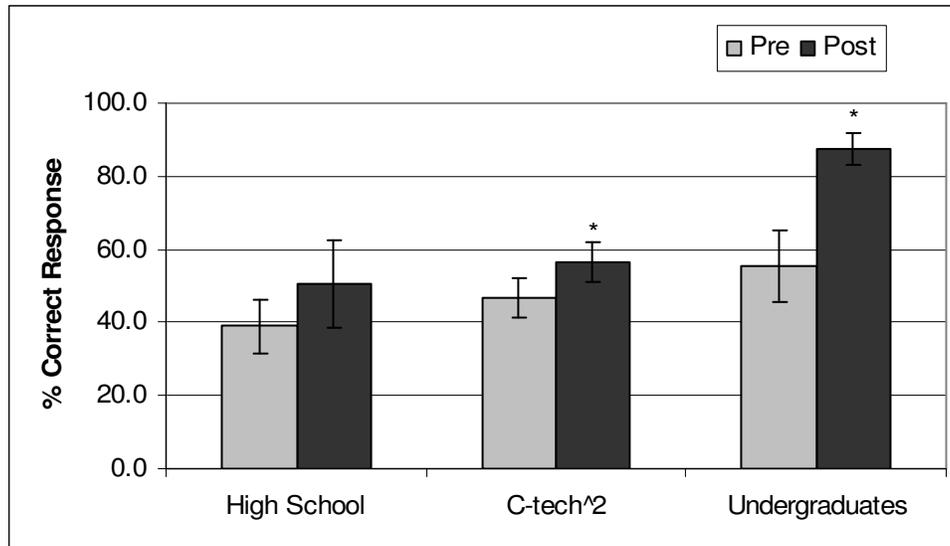
In “Engineering in Health Care”, scientific concepts include a range of topics, some of which are likely covered in previous high school courses (e.g. molecules, membranes, solutes) and others that are more specific to hemodialysis (e.g. diffusion, concentration gradient, dialysate).

Figure 1 shows student scores on scientific content questions both prior to and after use of the curriculum module. Only the C-tech<sup>2</sup> data show a statistically significant improvement in scientific content knowledge. Not surprisingly, the pre-assessment scores for undergraduate engineering majors are higher than for high school students. By the junior year in college, all undergraduates in the study had passed a course in fluid mechanics and were co-enrolled in heat and mass transfer at the time of module use. While overall improvement for high school students was not statistically significant, large increases appeared on questions related to topics specific to the curriculum module. For example, when asked to define hemodialysis and dialysate, the percent of high school students correctly answering the questions increased by 39.1% and 30.5% respectively from pre-test to post-test. Further analysis of these two problems revealed that 100% of students who answered the hemodialysis question incorrectly on the pre-test, answered this question correctly on the post-test and 70% of the students who answered the dialysate question incorrectly on the pre-test answered this question correctly on the post-test. These early results suggest that the online delivery of complex technical content is feasible and may lead to significant student learning.



**Figure 1: Student learning of scientific concepts presented as mean assessment scores  $\pm$  standard error of the mean. \* designates  $P < 0.05$ .**

In addition to assessing scientific content knowledge, understanding of the engineering design process was also investigated and results are shown in Figure 2. Preliminary data demonstrate that student knowledge of design concepts improved from pre- to post-test, with the mean score increasing 11% for C-tech<sup>2</sup> participants and 32% for undergraduates. The apparent increase for high school students is not statistically significant. Interestingly, the increase in understanding of the design process was much larger for undergraduate students compared to students still in high school. This result may be due to the fact that the undergraduate curriculum up to the junior year at UMBC does not focus on engineering design. Therefore, although the undergraduates have been exposed to the concepts of engineering design, they have had little previous experience with design before using the curriculum. The curriculum is particularly effective in helping students understand the iterative nature of the design process with 80% of students scoring higher on this question in the post-assessment. The fact that improvement in scores was observed for both C-tech<sup>2</sup> and undergraduate students indicates that the module may be effective in teaching an understanding of the design process over a range of age groups and skill levels.



**Figure 2: Student learning of engineering design concepts presented as mean assessment scores  $\pm$  standard error of the mean. \* designates  $P \leq 0.05$ .**

Upon completion of the curriculum, questionnaires were used to assess high school student perceptions about 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. Undergraduates were not asked to complete this questionnaire since they had already chosen engineering as a field of study.

**Table 1: Student responses to Post-Module Questionnaire. Top number indicates high school data, bottom number indicates C-tech<sup>2</sup> data.**

Statement	% Increased	% Decreased	%Same
My interest in pursuing a career in engineering or technology has:	18.2%	13.6%	68.2%
	59.3%	18.5%	22.2%
My confidence in successfully studying engineering or technology has:	27.3%	18.2%	54.5%
	66.7%	3.7%	29.6%
My knowledge of engineering or technology fields has:	54.5%	4.5%	40.9%
	85.2%	0.0%	14.8%
My understanding of design constraints has:	36.4%	4.5%	59.1%
	85.2%	3.7%	11.1%
My understanding of the engineering design process has:	36.4%	9.1%	54.5%
	85.2%	0.0%	14.8%
My confidence in my engineering or technology skills has:	27.3%	9.1%	63.6%
	51.9%	3.7%	44.4%
My understanding of career opportunities in engineering or technology has:	27.3%	4.5%	68.2%
	77.8%	0.0%	22.2%

Data reported in the post-module survey demonstrate notable increases in student interest, understanding and confidence toward engineering. Increases were significantly higher for C-tech<sup>2</sup> students versus average high school students. This result may be due to the fact that C-tech<sup>2</sup> targets students who already have an interest in engineering. Alternately, since C-tech<sup>2</sup> is exclusively for women, the higher scores may be due to a differing response to the curriculum between young women and men. It is also possible that the less positive results for high schools are due to instructor variability and in the particular implementation at each site. This question will be investigated further as additional students are involved in field trials.



Instructors who have used the curriculum have been asked to provide feedback on their experience. The C-tech<sup>2</sup> instructor was particularly impressed as quoted below.

“The module is thorough and effective giving student participants an authentic and complete overview of engineering--it's more than cars and bridges. The online interactive tutorials really help students learn the science and math concepts, which they later apply in their designs of the hemodialysis system, while the hands-on engineering challenges help to impart an understanding of the engineering design process.”

## Conclusion

Since 2005, the **INSPIRES** Curriculum “Engineering in Healthcare” module has been implemented into several high school technology education classes, a summer engineering camp for high school women, and a university undergraduate level engineering course. All classes provided a diverse demographic pool. The results so far have been highly encouraging. In each environment, significant increases have been observed in scientific content knowledge, engineering design understanding or student-reported interest and attitudes toward engineering careers. These preliminary results suggest that the content is accessible to a range of age groups and skill levels. One goal of the **INSPIRES** Curriculum is to recruit and retain greater numbers of women and minority students in engineering fields. Data from the C-tech<sup>2</sup> testing in particular suggest that the “Engineering in Health Care” module may significantly advance this important goal.

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