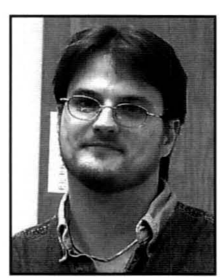
BIOMEDICAL AND BIOCHEMICAL ENGINEERING FOR K–12 STUDENTS

SUNDARARAJAN V. MADIHALLY AND ERIC L. MAASE
Oklahoma State University • Stillwater, OK 74078

One problem facing the United States is a declining number of students interested in an engineering major.[1] Between 1992 and 2002, the percentage of high school students expressing an interest in engineering decreased significantly.[2] In addition, U.S. students demonstrate a lack of preparedness in math and science.[3] To address these issues, a number of programs have been initiated throughout the country in which high school teachers are retrained, or students are exposed to science and engineering through summer outreach programs.[4-7]

The College of Engineering, Architecture, and Technology (CEAT) at Oklahoma State University (OSU) has developed a multidisciplinary, weeklong, resident summer academy for high school students called REACH (Reaching Engineering and Architectural Career Heights). The primary goal of REACH is to provide factual, experiential information to all participants, increasing their knowledge in the various fields of engineering, architecture, and technology. Another goal involves increasing the number of students from underrepresented groups studying these disciplines. The academy is designed to help students make individual career decisions, with the intention of attracting them to engineering careers. Participants are primarily junior or senior high school students. In the 2005 program, nearly 70% of the 30 students (18 female and 12 male) were from groups under-represented in engineering, architecture, and technology (such as females, Hispanics, and Native Americans).

Each academy begins with a recreational activity such as rock climbing or camping so that participants get to know each other. Afterwards, participants get exposure to engineering



***Eric L. Maase** is an adjunct lecturer of chemical engineering at Oklahoma State University. He received his B.S. in chemical engineering from the University of Maryland, his M.S. in chemical and petroleum engineering from Colorado School of Mines, and his Ph.D. from Oklahoma State University in 2004. His research interests are teaching methods, computer modeling, thermodynamics, and bio-related engineering.*

***Sundararajan V. Madihally** is an assistant professor of chemical engineering at Oklahoma State University. He received his B.E. from Bangalore University, and his Ph.D. from Wayne State University, both in chemical engineering. He held a research fellow position at Massachusetts General Hospital/Harvard Medical School/Shriners Hospital for Children. His research interests include stem-cell-based tissue engineering and the development of therapies for traumatic conditions.*

disciplines including civil and environmental; architectural, electrical, and computer; technology; biosystems and agricultural; mechanical and aerospace; industrial; and chemical and biomedical/biochemical. These disciplines are taught using a modular approach by instructors from each specialty. Hands-on projects are tailored to high school students. During the week participants are also exposed to the engineering industry through a plant tour. At the conclusion of the week, students give a presentation describing their experience at the academy in front of their peers, parents, and teachers.

TABLE 1
Bioengineering Module Schedule

Initial Survey
9:00 -10:00 — Overview and Introduction
10:00 -11:40 — Experimentation
10:20 -10:50 — Lab Tour I
10:50 -11:20 — Lab Tour II (15 students)
11:45 - 1:15 — Lunch break
1:30 - 1:45 — Wrap up the experiment
1:45 - 2:00 — Prepare for the presentation
2:00 - 2:45 — Presentations (5 min each group)
2:45 - 3:15 — Summarize/questions
Final Survey

This paper focuses on use of a new module at the 2005 academy, in which students were introduced to biomedical and biochemical engineering. This was the last module in the series. The primary goal was to expose students to various activities in bioengineering. Additional goals included teaching students good research methodology and presentation skills. The activities for the day and scheduled events for the module (Table 1) included an introductory presentation, a laboratory tour, and experimental work. In these activities, both deductive and inductive learning styles were used[8-13] to maximize teaching effectiveness and successful completion of the module goals.

STUDENT PRE-ASSESSMENT

After being informed about the scheduled events for the module and their activities for the day, students were asked to complete a one-page survey (Figure 1). Of 10 questions on the survey, two were about interest in a bioengineering career or attending medical school. The eight remaining questions required students to self-assess their confidence levels of knowledge in various topics: biological (basic biology and molecular biology); medical (biochemistry and biotechnology, human physiology, immunology, and genetics); and engineering (fluid mechanics, statics, and electrical circuits). Results of the first two questions showed that 19 of the students expressed interest in medical school and 10 in a bio-based engineering. In the self-assessed confidence level in biological, medical, and engineering topics (Figure 2), average values varied from 36% (±25%) to 56% (±26%). The only significant difference in confidence levels between male and female students was in the engineering sciences. In the more specific bio-related engineering questions on the uses of corn syrup and enzyme-dependent degradation of biopolymers, the average confidence level was 33%. In questions on the awareness of prosthetic devices and tissue engineering, 12 students could name various prosthetic devices and nine had some knowledge of tissue engineering.

2005 BioModule REACH Pre-Survey

Name: ________________________ What is your long term career goal?

Please provide appropriate replies to each of the following questions.

1. Have you thought of going to medical school? *YES or NO*

2. Have you thought of becoming an engineer with focus on biotechonology? *YES or NO*

3. What is the confidence in saying you know Basic Biology and Molecular Biology?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know
Courses taken:

4. What is the confidence in saying you know Biochemistry and Biotechnology?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know
Courses taken:

5. What is the confidence in saying you know Human Physiology Immunology, Genetics?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know
Courses taken

6. What is the confidence in saying you know Fluid Mechanics, Statics, and Electrical Circuits?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know
Courses taken

7. How much do you know about the corn syrup added in the many of the juices you drink?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know

8. How much do you know about enzymes and degradation?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know

9. Do you know any prosthetic devices that one of your friends or relatives use? List.

10. Do you know a new field called Tissue Engineering? YES or NO

Figure 1. *Pre-assessment survey form.*

PRESENTING AN OVERVIEW AND INTRODUCTION TO BIOENGINEERING

After completion of the survey, the next event initially appeared as an introductory presentation. But its intent instead was as a tool to initiate conversation with the students.[14] The presentation began with a discussion of five major topics in bioengineering, *i.e.*, physiologic systems modeling, prosthetic devices, tissue engineering, drug delivery, and biotechnology. Using an interactive presentation approach, instructors drew attention to practical applications students could have observed in society and asked students to provide their knowledge and awareness of the topics. Further, students were encouraged to ask questions. This approach was beneficial in that instructors were able to make students comfortable while providing new information on biomaterials and bioengineering.

The discussion on modeling physiological factors included two examples. The first involved measuring lung volumes and modeling thoracic forces. The example was Lance Armstrong's success in Tour de France competitions, thereby connecting students with a real-life event. The other example involved modeling the dialysis process, and students were informed they would see an entire dialysis unit during the laboratory tour.

In discussing prosthetic devices, the need for artificial organs was introduced by a chart describing the deficit of available donors. To encourage participation, students were asked about their knowledge of individuals with artificial limbs, hearing aids, pacemakers, and contact lenses (the most likely device with which an audience member would have direct experience). Further, they were asked, "How do they work?," and "What is the need?" This was done to overcome possible student reluctance to participating in the discussion. The final portion on prosthetic devices dealt with artificial heart valves, covering the progression of research and use from mechanical valves to bioprosthetic valves, and the difference with tissue-engineered valves.

The basic concepts in tissue engineering were then introduced using examples of currently available artificial skin products and their manufacturers. After exposing students to other identifiable products, the question posed was: "How do we engineer such products?" In order to show the engineering principles, controlled drug delivery devices were considered. Questions such as: "What happens when a person takes Tylenol?," and "Why does that person need to take pills repeatedly?," served as a basis for pondering better drug-delivery methods. Further, figures of nicotine patches initiated a discussion on the importance of biological factors (half-life, absorption, and metabolism) vs. physiochemical factors (dose, solubility/reactivity/pH, stability) in drug delivery. In addition, characteristics of traditional oral dosing (cyclic concentrations) and more desirable constant (continuous) drug delivery concepts allowed a short discussion of chemical diffusion.

Drug delivery served as a link to discussing digestive physiology and enzymes. To introduce this topic, randomly selected students were asked to read the content list on several empty soft drink containers. The most common ingredient, high-fructose corn syrup, was identified on all containers. Students were asked about the need for corn syrup, creating some discussion on the sweetness, solubility, and production cost of the syrup. This led to discussion on reactor design and the chemical process for obtaining corn syrup. A comprehensive engineering process diagram for complete corn wet milling was presented,[15] emphasizing the importance of acid hydrolysis or enzymatic degradation. The discussion concluded by introducing a specific experiment students would conduct examining enzyme (and acid) degradation of starch.

HANDS-ON EXPERIMENT

For a hands-on experiment, students were asked to study enzyme-mediated or acid hydrolysis of potato starch. Students

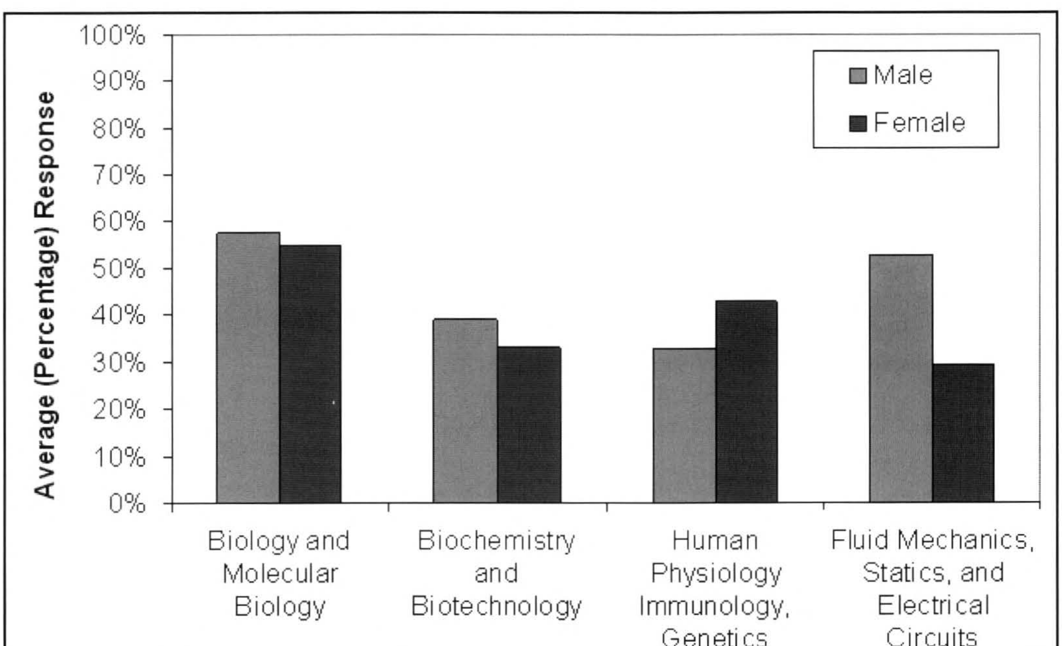


***Figure 2.** Student pre-assessment: science and engineering knowledge by gender.*

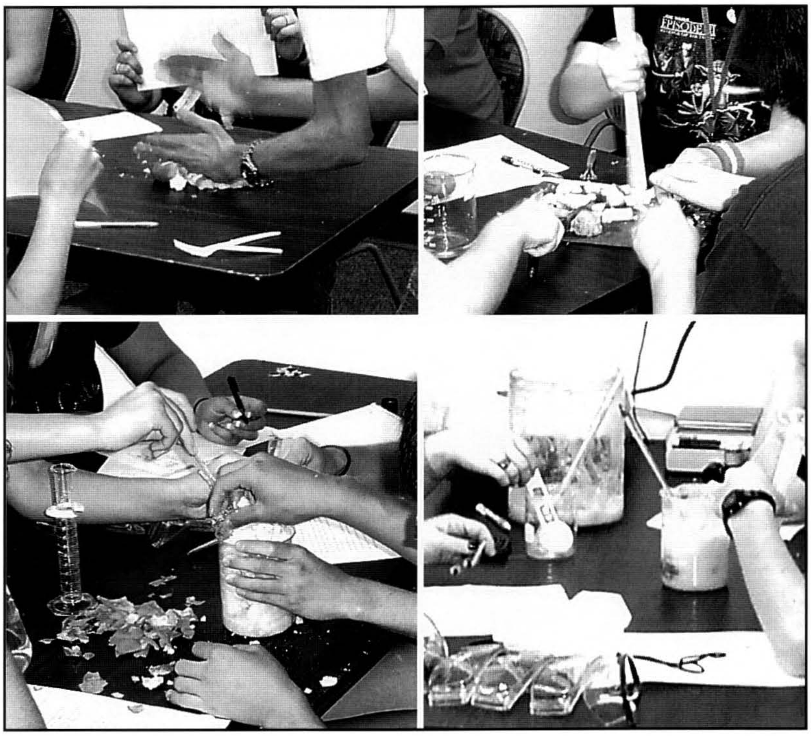


Figure 3. *Different groups pulverizing potatoes.*

were split into groups of five. Each group was pre-selected to be from differing high schools, and balanced by gender with three females and two males. The low-budget experiment is straightforward, as students either mash cooked potatoes or cut raw potatoes to place in a water bath. Enzyme (α-Amylase) or acid is added, and the solution is mixed, maintaining a constant temperature. In presence of the enzyme or acid, starch hydrolyzes to smaller sugars. The presence and amount of starch in a sample can be measured using the iodine-clock reaction—in which the abundant presence of starch is indicated by the fast appearance of blue color; reduced presence delays the appearance of blue color; and complete degradation of starch into glucose is indicated by the loss of blue color. Digestion and saliva reactions having already been discussed in the overview, the background consisted of a short (one-slide) presentation on the importance of carbohydrates (*e.g.*, immediate source of energy for the body), and various sources of carbohydrates, including rice, corn, wheat, and potatoes. Other information included types of sugars (granulated sugar, maple sugar, honey, and molasses), and more specifically, simple sugars (fructose and fruit sugar) and double sugars (sugar cane, sugar beet, maltose or malt sugar, and lactose or milk sugar).

The experiment was conducted so that students had to take an active role in developing and clarifying experimental procedures.[16] A brief experimental protocol, with instructions regarding volumes of water, directions to use the enzyme or acid, and the solution temperature, was provided to students. The detailed protocols with complete instructions were deliberately not given while critical directions were provided. Furthermore, although each team had the same experimental task, each group was given a unique experimental condition, so that the influence of temperature, mixing, and substrate-size on reaction rate could be discussed. Variables included the amount of potato used, whether it was baked or unbaked, mashed or cut, the temperature (30 °C, 50 °C, or 70 °C), and either enzyme or hydrochloric acid. Potatoes were purchased from a local supermarket, while α-Amylase (enzyme) was purchased from Sigma Aldrich Co. An iodide-clock reaction kit was from Universe of Science, Inc. Experiments were conducted in 500 mL or 1000 mL conical flasks and each group was equipped with a hotplate/magnetic stirrer, thermometer, and pH strips. Each group was told to record initial potato weight and solution pH, and to take samples at regular intervals to measure starch content. Baked potatoes needed to be mashed, and unbaked potatoes cut into small pieces using a kitchen knife.

Students enjoyed this part of the work as an easy means of team participation (Figure 3). Each group had 20 minutes to get experiments under way before laboratory tours began.

LABORATORY TOUR

Each experimental group was split, with half of the class (15 students) accompanying an instructor on a laboratory tour while the other half stayed to continue experimentation. After the first tour, the students exchanged places. Each laboratory tour was scheduled for 30 minutes.

In the laboratory tour, students were taken to an undergraduate instructional laboratory containing various unit operations. While emphasis was given to a packed bed reactor containing a resin enzyme, other equipment included a heat exchanger skid, bioreactor assembly, dialysis, absorption column, and a two-phase flow pipe assembly. A demonstration running a two-phase flow of water and air was conducted, including discussion of computer interfaces and control valves. Students liked the demonstrations, and asked a number of questions regarding the computer interface.

ORAL PRESENTATIONS

After a lunch break, during which experiments continued, the students returned to conclude their experiments. Each group was asked to present the experimental observations/outcomes as a team. They were given 10 minutes preparation time. During this recess, they were told the presentation should be a group effort, all members should be respectful to other group members, and the audience should ask questions. Each group was allowed five minutes to present its report, including question-and-answer sessions.

In the first group, the two male members monopolized the presentation, with the three female members only participating during the question-and-answer portion. The initial group also provided no introductions of group members or motivation(s) for experimental work. Prior to the beginning of second presentation, instructors gave immediate feedback on presentation strategy and reminded the students about the required equal participation from all group members. This method of immediate feedback to influence presentation behavior was followed for all presentations. Further, instructors solicited additional critiques from the audience so the entire class could become a source of feedback on presentation style and effectiveness. The instructors ensured their remarks were neither admonishing nor overly negative.

Subsequent group presentations continued to improve. The second group correctly followed initial instructions by introducing all team members, and allowing them to actively participate. Presentations from each group improved overall, but students had difficulty adequately reporting experimental results. Furthermore, none of the teams mentioned conclusions and recommendations for future investigations. Interestingly, one group that performed the experiment similar to another group reported that significantly more starch remained in their solution, but failed to make any comparison with the other team. Neither group initiated any discussion or questions of the results. Instructors had to ask students for possible explanations of the differences between each outcome.

EFFECTIVE PRESENTATIONS, EXPERIMENTAL PRACTICE AND PROCEDURE, AND CRITICAL THINKING

After the presentations, an overview of what needed to be included in the presentation was discussed. Some of the points addressed included:

- *Why did you do this experiment?*
- *What was your experimental set-up?*
- *What were your results?*
- *What conclusions can be drawn?*
- *What future plans would you suggest?*

The students were commended for excellent performance in explaining their setups so the discussion would be viewed positively rather than as criticism. Using the completed experiments as a guide and while their own presentations were still fresh, a discussion on the attributes of an effective presentation was initiated. Using questions stated above, the instructors introduced a general presentation format including introduction, methodology, results, conclusions, and recommendation sections. Although this presentation outline is not robust, it does incorporate many features of an effective presentation.[17] The students seemed to enjoy participating in a discussion of effective presentations from the unique perspective of devil's advocate, with a recent presentation from which to consider specific needs, individual shortcomings, and desirable improvements.

The instructors also opened a general discussion on appropriate experimental practices and procedures. Specific questions included were:

- *Why did the pH drop in the experiments where acid was used?*
- *What happened to the pH of the solution?*
- *What happened to the temperature?*
- *Did it take a long time at the end of the experiment?*
- *Did you keep track of time it has been sitting in the container?*
- *Did the viscosity of the slurry create mixing problems?*
- *What happened when you added potatoes to a pre-measured volume of water?*
- *What problems arose?*

These questions allowed discussion of the criteria necessary for good experimental procedures, the problems that may occur in experimental setups, and necessary data to provide adequate and sufficient information for experimental analysis. In addition, there was an opportunity to emphasize the ethical aspect of reporting. One of the teams had forgotten to include a magnetic stirring rod, and thus their solution was not well mixed, resulting in less degradation of starch than expected. They were honest about it, and the other teams thought that was a humorous mistake. This allowed a discussion of how no experiment is really a failure, every experiment provides information, and, in this specific case, mixing matters a great deal.

Other aspects of the experiment encouraged critical thinking. Some students spilled excess water from their beakers because they did not account for additional volume when adding potatoes. In other experiments, uniform heat distribution was an issue. These complications were built into experimental protocols, and the students needed to identify, overcome, and otherwise consider these issues to accomplish their experimental work.

Together with the hands-on experiment, students were shown a 5 liter bioreactor with a jacketed heater and controllable agitator during the laboratory tour. Explanations were given about how bioreactors work. Reexamining these factors after their experiments emphasized the differences and similarities between the two setups, and the need for engineering design of equipment.

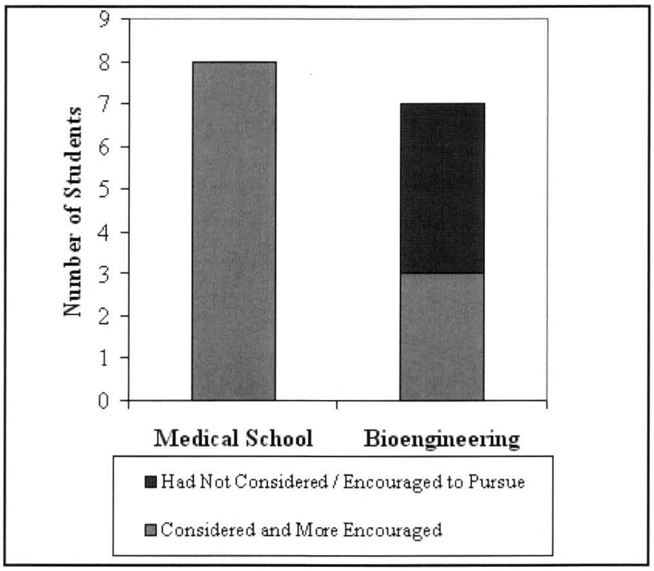


Figure 4. *Module effect on students' perceptions of available career options.*

2005- BioModule REACH Outcome-Survey

Name: ______________________ What is your long term career goal?

Please provide appropriate replies to each of the following questions.

1. Did the module encourage you to consider attending medical school? *YES or NO*

2. Are you more interested in becoming an engineer focusing on biotechonology? YES or NO

3. What is your confidence level in saying you understand the importance of corn syrup?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know

4. What is your level of understanding of the concepts behind controlled drug delivery systems?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know

5. What is your confidence level in saying you understand the need for prosthetic devices?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know

6. What is your confidence level in saying you understand how to properly present experimental data?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know

7. How much did you like the introductory lecture?
○ 10% ○ 30% ○ 50% ○ 60% ○ 70% ○ 90% ○ 100% ○ Don't know

8. How much did you enjoy the laboratory tour and did you learn anything?
○ 0% ○ 20% ○ 40% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

9. How much did you like the experiment? YES or NO
○ 0% ○ 20% ○ 40% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

10. Please name the topic you most enjoyed in this module.

Figure 5. *Post-assessment survey form.*

PROBLEMS AND RECOMMENDATIONS

At the end of the module, a general discussion was initiated asking students to comment on their experiences during the module. Principal comments included:

a) Confusion from switching of operators taking care of experiments

b) Need for proper equipment to mash potatoes or cut them into small pieces

c) Desire to have an experiment where the product is a take-home substance (not some form of potatoes that are discarded)

d) Better experimental information and more specific experimental protocols

e) A prize for the best performance to motivate their work

With each suggestion, the instructors provided immediate feedback and an explanation of the current module structure in order to elicit further group discussion. For example, team splitting can cause confusion due to lack of communication, but may not necessarily be a problem. It is very common in industrial practice to have three continuous shifts, and personnel must effectively communicate between shifts. One way to promote communication may be to include a 10-minute break between the tours with specific instructions given to update group members regarding experimental status.

In order to save time, one could use a household food processor to mash or chop the potatoes. The incomplete nature of the experimental protocols has already been mentioned, and the students were provided some reasoning for the lack of information. Their reactions were noted on this approach in future classes.

The suggestion of a prize for the best group was interesting, as the students had been conditioned over the previous week by many of the REACH faculty to expect such forms of praise. While considering the suggestion, the current module seems best served by not including prizes as a form of reward. Overall, the students enjoyed the desired give-and-take interaction encouraged by the instructors, and were open in their suggestions for improvements.

OUTCOME ASSESSMENT

To understand the effectiveness of the module on student learning, an outcome assessment was provided (Figure 5), similar to the pre-assessment survey. To measure the main objectives of the module, *i.e.*, the influence on students' perspectives of careers in bioengineering and medical engineering/science, the first two questions in the pre-assessment were repeated. Out of 30 students, a large number (~2/3) had already expressed interest in attending medical school (pre-assessment data). Therefore, no specific conclusions could be drawn regarding an increase in the student desire, awareness of medical school, or career options (Figure 4). By comparison, an increase in student awareness of bioengineering as a career was observed, as four students indicated a new interest in the bioengineering field. This suggested that the module was successful in introducing bioengineering.

Students were also asked to rank their confidence in the importance of corn syrup, for which the overall confidence doubled (Figure 6) with a large group of students indicating more than a 70% confidence level. When asked about their confidence in drug delivery and prosthetic devices, the average was 63% (± 13%) and 76% (± 20%), respectively, for each category. Further, students indicated a 74% (± 22%) confidence level in experimental data presentation. Without a pre-assessment question regarding their abilities in data presentation, however, the effectiveness of this aspect of the module could not be assessed, although one student did mention that this portion of the module was his/her favorite experience.

The final assessment questions gauged overall interest in the introductory presentation materials, laboratory tour, and hands-on experiment, for which responses were ~50% (± 28%). A follow-up, open-ended question asked for students' favorite experience during the day, with responses grouped into six general categories (Table 2). Surprisingly, nearly 53% indicated the lecture materials as their favorite events (one student noted that the afternoon lecture on effective presentations was the most interesting, and said it included information that he/she had never been shown or heard previously).

The introductory materials are likely the most interesting, simply due to the interactive nature of the presentations in relation to identifiable products and aspects of importance in students' lives. While drawing conclusions regarding differences between male and female responses is indeterminate given the small sample population, the overall nature of students' responses indicated both significant interest and engagement with instructors and presented materials. Further, a larger number of female students than male students indicated the experimental portion was the most enjoyable topic. The trend was opposite the previous response to the specific question, in which male students ranked their enjoyment of the experiment at 54% compared to female students at an average of 47%.

SUMMARY

The module introduced K–12 students to the field through interactive presentations, discussions, experimental procedure (hands-on work), and a tour of working engineering laboratories. The presentation was designed to encourage students' questions while presenting five major aspects of the bioengineering field. Within each primary topic were

TABLE 2
"What was the topic you most enjoyed?" by category and gender

Category	M	F	Total	%
General Lecture	2	1	3	10
Prosthetic Devices	2	4	6	20
Artificial Organs	4	3	7	23
Experiment	2	6	8	27
Lab Tour	1	1	2	7
No Response	1	3	4	13

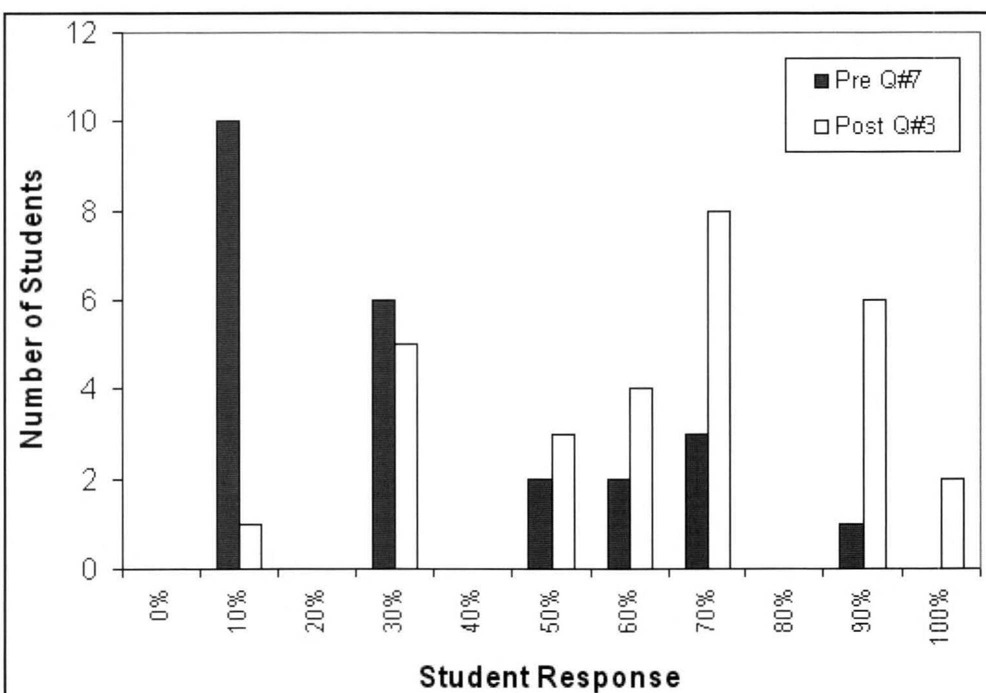


Figure 6. *Student responses to "Importance of Corn Syrup."*

secondary investigations that delved into both scientific and engineering aspects. All topics incorporated design aspects to draw on personal experiences with bioengineering products, processes, and research. Students enjoyed the presentation style and topics, and were able to connect much of the material to their own experiences and knowledge. Based on the immediate responses, the overall module was successful in influencing their interest in bio-based engineering. To better understand the effectiveness of the module, however, long-term follow-up studies are needed examining the students' career choices. The assessments also need to be redesigned to more effectively measure module features and goals.

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