2006-1167: INTRODUCING BIOMEDICAL AND BIOCHEMICAL ENGINEERING FOR K-12 STUDENTS

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Biomedical and Biochemical Engineering for K-12 students

Abstract.

One of the problems facing the United States is the declining number of students expressing an interest, or majoring, in engineering. The percentage of twelfth grades expressing an interest in mathematics dropped from 73% to 61% between 1990 and 2000. There is also the recurring problem of the lack of preparedness among US students in math and science. To address these issues, a number of programs have been initiated throughout the country where either high school teachers are retrained or students are exposed to science and engineering through summer outreach programs. The College of Engineering, Architecture, and Technology (CEAT) at Oklahoma State University (OSU) has also developed a multi-disciplinary weeklong resident summer academy for high school students called REACH (Reaching Engineering and Architectural Career Heights interested in engineering, architecture, or technology. Through module-based instruction, students are introduced to various engineering fields.

This report describes one of the new modules used in the 2005 academy where students were introduced to biomedical and biochemical engineering principles and practice. This was the last module in the series. The primary goal was to expose the students to various activities carried out in bioengineering. Additional goals included teaching students good research methodology and presentation skills. The activities for the day and the scheduled events for the module included an introductory presentation, a laboratory tour, and experimental work. The approach taken in presenting biochemical/biomedical engineering is described along with the effectiveness of the approach. Pre- and post-assessment surveys found that the students were interested in the materials presented, actively involved in the experimental procedure, and the module successfully increased the students interest in the field of biochemical/biomedical engineering.

1. Introduction.

The declining number of students expressing an interest, or majoring, in engineering is one of the major problems facing the United States [1]. There is also decrease in the interest level in mathematics and sciences; in 1990, 73% of twelfth grades agreed with the statement "math is useful for solving problems" which decreased to 61% in 2000 [2]. In addition to lack of interest, there is also the problem of under-preparedness among US students in math and science [3]. To address these issues, few higher education institutions have initiated novel programs where either 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 also developed a multi-disciplinary weeklong resident summer academy for high school students called REACH (Reaching Engineering and Architectural Career Heights). The primary goals of REACH are providing factual, experiential information to all participants to increase the level of knowledge of the various fields of engineering, architecture and technology, and increasing the number of students from underrepresented groups studying those disciplines. The experience is designed to help the students make sound individual career decisions with the intention of attracting them to engineering careers. Participants are primarily junior or senior high school students. The thirty (18 female and 12 male) participants of the 2005 program consisted of nearly 70% of one or more underrepresented groups 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 the participants get to know each other. Then, participants get exposed to engineering disciplines including Civil & Environmental, Architectural, Electrical and Computer, Engineering Technology, Biosystems and Agricultural, Mechanical and Aerospace, Industrial, Chemical and Biomedical/Biochemical engineering. These are taught using a modular approach by instructors from each discipline and using hands-on projects tailored towards the high school students. During the week, the participants are also exposed to 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 piers, parents and teachers.

This report focuses on use of the new module in the 2005 academy where students were introduced to biomedical and biochemical engineering. This was the last module in the series (week). The primary goal was to expose the students to various activities carried out in bioengineering. Additional goals included teaching students good research methodology and presentation skills. The activities for the day and the 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] in order to maximize teaching effectiveness and successfully achieve the goals of the module.

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

2. Student Pre-Assessment.

After informing students about the scheduled events for the module and their activities for the day, they were asked to complete a one page survey (**Figure 1**). Out of ten questions on the survey, two asked about their interest in a bioengineering career or in attending medical school. The remaining eight questions asked the student's for self-assessed confidence levels of their knowledge of various biological (basic biology and molecular biology), medical (biochemistry and biotechnology, human physiology immunology, genetics), and engineering (fluid mechanics, statics and electrical circuits) topics. With respect to the interest in pursuing medical school or engineering school with focus on biotechnology, nineteen of them expressed interest in medical school and ten of them in a bio-based engineering. In the self-assessed confidence level in biological, medical and engineering topics (**Figure 2**), the average values varied from 36% (±25) to 56% (±26). The only significant difference in the confidence level

2005- BioModule REACH Outcome-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

between male and female students was in the engineering sciences. In the more specific bio-related engineering questions about their knowledge of the uses of corn syrup and enzyme-dependent degradation of biopolymers, the average confidence level were 33%. Regarding the awareness of prosthetic devices and tissue engineering, twelve of them listed various prosthetic devices and nine of them had some knowledge of tissue engineering.

3. Presenting an Overview and Introduction to Bioengineering.

After the completion of the survey, the next event initially appeared as an introductory presentation but was used as a tool to initiate a conversation with the students [14]. The presentation began with a discussion of five major topics in bioengineering i.e., modeling physiologic systems, prosthetic devices, tissue engineering, drug delivery, and biotechnology.

Using an interactive presentation approach, the instructors drew attention to practical applications that students could have observed in society and asked the students to provide their knowledge and awareness of the topics being discussed. Further, the students were encouraged to ask questions. The benefit of this approach was that the instructors were able to make the students more comfortable while simultaneously providing new information on biomaterials and bioengineering.

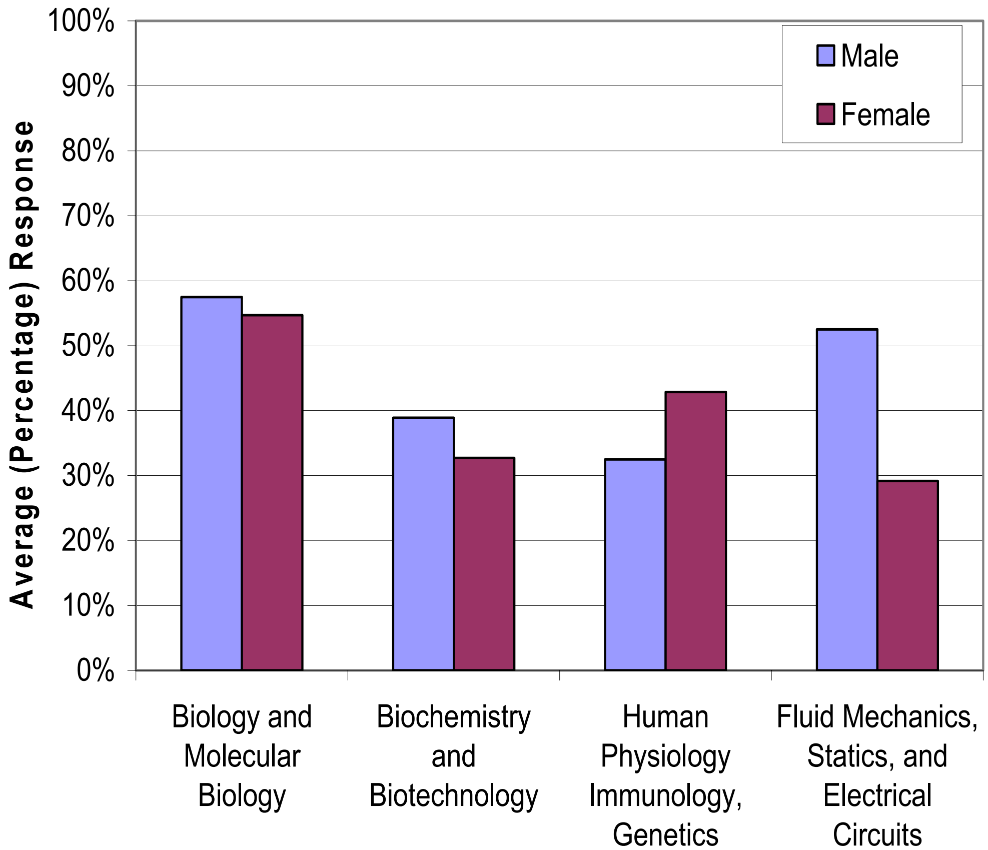

Figure 2. Student Pre-assessment: Science and Engineering Knowledge by Gender

Modeling physiological factors included two examples: first, measuring lung volumes and modeling thoracic forces. The example employed was Lance Armstrong's success in *Tour de France* competitions to connect students with a real-life event. Another example dealt with modeling the dialysis process and students were informed about seeing an entire dialysis unit during the laboratory tour.

In prosthetic devices, first the need for artificial organs was introduced by showing 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 in an effort to overcome the reluctance that students might have in participating in the discussion. The final portion of the prosthetic devices dealt with artificial heart valves, covering the progression of research and use from mechanical valves to bioprosthetics valves, and difference with tissue engineered valves.

The basic concepts in tissue engineering were then introduced with the example 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 i) what happens when a person takes Tylenol? ii) why does that person need to take pills repeatedly? served as a basis for considering better drug delivery methods. Further, they were shown figures of Nicoderm® patches initiating a discussion of importance of biological (half-life, absorption, and metabolism) versus physiochemical factors (dose, solubility/reactivity/pH, stability) in drug delivery. In addition, the characteristics of traditional oral dosing (cyclic concentrations), and more desirable constant (continuous) drug delivery concepts allowed a short discussion of chemical diffusion.

Drug delivery also served as a link to discuss digestive physiology and enzymes. To introduce this topic, several empty soft drink containers were brought to the room and randomly selected students were asked to read the content list on each container. The most common ingredient, high fructose corn syrup, was identified on all containers. Students were asked about the need for corn syrup, from which discussion continued onto the sweetness of the syrup, solubility, and production cost, leading up to 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 within the process. The discussion concluded by introducing a specific experiment they would conduct examining enzyme (and acid) degradation of starch.

4. Hands-on Experiment.

As a hands-on experiment, students were asked to study either enzyme-mediated or acid hydrolysis of potato starch. Students were split into groups of five, and each group was pre-selected to be from different high schools, and balanced by gender with three females and two males in each group. The low-budget experiment is straightforward as students take either cut raw potatoes or mash cooked potatoes and place them in a water bath. To this mixture, either enzyme (α-amylase) or acid is added and the solution is mixed while maintaining a constant temperature. In presence of the enzyme or the acid, starch hydrolyzes to smaller sugars. The presence and amount of starch in a sample can be measured using the iodine-clock reaction; abundant presence of starch is indicated by the fast appearance of blue colour, reduced starch content delays the appearance of blue colour and complete degradation of starch into glucose is indicated by the loss of blue colour. The background, having already discussed digestion (and saliva reactions) in the overview, a short (one-slide) presentation with additional basic materials on the importance of carbohydrates (such as immediate source of energy for the body), and various sources of carbohydrates including rice, corn, wheat and potatoes was discussed. Other information included was types of sugars (granulated sugar, maple sugar, honey and molasses) i.e., simple sugars (fructose and fruit sugar) and double sugars (sugar cane, sugar beet, maltose or malt sugar, 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 providing critical directions. Furthermore, each group had a unique experimental condition, although each team had the same experimental task, so that the influence of temperature, mixing, and substrate-size on reaction rate could be discussed. Variables included the amount of potato used, baked or unbaked potato, mashed or cut, temperature (30°C, 50°C or 70°C) and either enzyme or hydrochloric acid. Potatoes were purchased from a local supermarket. α-Amylase (enzyme) was purchased from Sigma Aldrich Co. An iodide-clock reaction kit was from Universe of Science, Inc. Experiments were conducted in 500mL or 1000mL 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 for measuring 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 underway before laboratory tours began.

5. Laboratory Tour

Each experimental group was split, with half of the entire class (15 students) accompanying

Figure 3. Different groups pulverizing potatoes in a group.

an instructor on a laboratory tour while remaining students stayed to continue experimentation. After the first tour, the students exchanged places. The students that had been overseeing the experiments were taken on the next laboratory tour, and returning students continued the groups' experiments. 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 as the enzyme, other equipment including a heat exchanger skid, bioreactor assembly, dialysis, absorption column and a two-phase flow pipe assembly was shown. A demonstration running a two-phase flow of water and air was conducted, including discussion of the utility of computer interfaces and control valves. Students liked the demonstrations and asked a number of questions regarding the computer interface.

6. 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 provided 10 minutes of preparation time. During this recess, they were also told that a) the presentation should be a group effort, b) all members should be respectful to other group members, and c) the audience should ask questions. Each group was allowed five minutes to present their report which included 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 nor motivation(s) for the experimental work. Prior to the beginning of second presentation, the instructors gave immediate feedback on presentation strategy and reminded the students about the required equal participation from all group members. This method of immediate comments to influence the presentation behavior of each group was followed for all presentations and the expected improvements in subsequent presentations. Further, instructors solicited additional critiques from the audience in order that the entire class could become a source of feedback on presentation style and effectiveness. The instructors ensured that their remarks were neither admonishing nor overly negative.

Subsequent group presentations continued to improve. The second group correctly followed the initial instructions by introducing all team members, and all team members actively participated in the presentation. Although presentation of each group improved, overall, while the students successfully explained their methodology they had difficulty in adequately reporting experimental results. Furthermore, none of the teams actually mentioned conclusions and recommendations for any future investigations. Interestingly, one group that performed an experiment similar to another group reported that significantly more starch remained in their solution, but failed to make any comparison with the other team, and neither group initiated any discussion or questions of the results. The instructors had to ask the students for possible explanations behind the differences between the two outcomes.

7. Effective Presentations, Experimental Practice and Procedure, and Critical Thinking

After the presentation, an overview of what needs 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 an excellent performance in explaining their set-ups so that the discussion would be viewed positively rather than as criticism. Using the completed experiments as a guide and while their own presentations still fresh, a discussion on the attributes of an effective presentation was initiated. Using the questions stated above, the instructors introduced a general presentation format should include introduction, methodology, results of work, conclusions, and recommendation sections. Although this presentation outline is not robust, it does incorporate many features of an effective presentation for reporting experimental results [17]. The students seemed to enjoy participating in a discussion of effective presentations from the unique perspective of devil's advocate and 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 discussions 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 for emphasizing the ethical aspect in 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, but 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 and others were built into the experimental protocols and the students needed to identify, overcome, or otherwise consider these issues in accomplishing their experimental work.

In concert with the hands-on experiment, students were shown a five liter bioreactor with a jacketed heater and controllable agitator during the laboratory tour. Explanations were given about how those 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.

8. Problems and Recommendations

At the end of the module, a general discussion was initiated by asking questions about the comments and concerns the students had regarding their experiences during the module. The principal comments included

a) Confusion due to 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 'mashed' potatoes that are discarded)

d) Better experimental information; more specific experimental protocols, and

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

With each suggestion, the instructors provided immediate feedback as well as an explanation for 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. As it is very common in industrial practice to have three continuous shifts and personnel must effectively communicate between shifts, a similar event here serves as an opportunity. One way to promote communication is to include a 10-minute break between the tours with specific instructions given to update group members regarding the experimental status.

In order to save time, one could use a household food processor to mash or chop the potatoes; such suggestions have merit and are items the instructors certainly will consider for future work. The incomplete nature of the experimental protocols has already been mentioned, and the students were provided some of the reasoning for the lack of information and their reactions were noted for better implementation of 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 maintained the desired give-and-take interaction encouraged by the instructors and were open in their suggestions for improvements.

9. Outcome Assessment

To understand the effectiveness of the module on student learning, an outcome assessment was made (**Fiure 4**), similar to the pre-assessment survey. To measure the main objectives of the module i.e., the influences on students' perspectives on careers in Bioengineering and Medical Engineering/ Science, first two questions in the pre-assessment

2005- BioModule REACH Pre-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%

Figure 4. Post-assessment survey form.

were repeated after paraphrasing. Out of thirty students, a large number (~2/3rd) had already expressed interest in attending medical school (pre-assessment data), no specific conclusions could be drawn regarding an increase in the student desire/ awareness of medical school/ career options (**Figure 5**). By comparison, an increase in the 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.

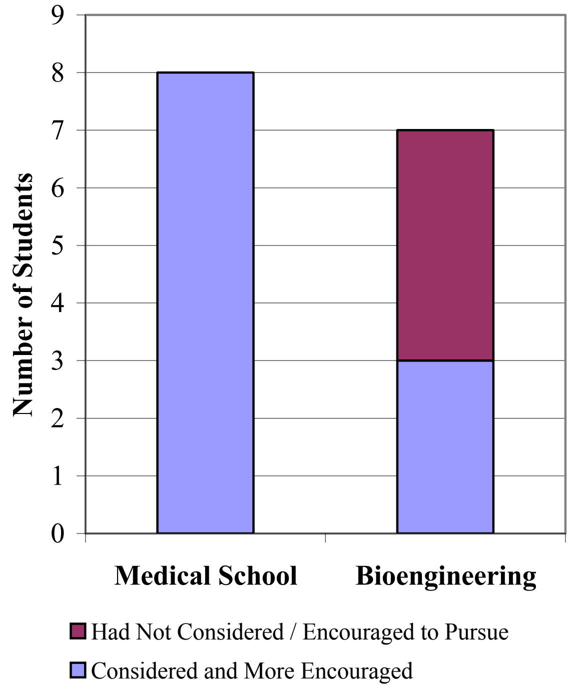

Figure 5. Module effect on students' perceptions of available career options

The students were also asked their confidence in stating that they understand the importance of corn syrup, for which the overall confidence doubled (**Figure 6**) with a large group of students indicating a greater than 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 in experimental data presentation. However, without a pre-assessment question regarding their abilities in data presentation, 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, also asked for students favorite experience during the day, with the responses grouped into six general categories (**Table 2**). Surprisingly, nearly 53% indicated the lecture materials (one student noted that the afternoon lecture on effective presentations was the most interesting, and included information that he/she had never been shown or heard previously) as their favorite events.

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%

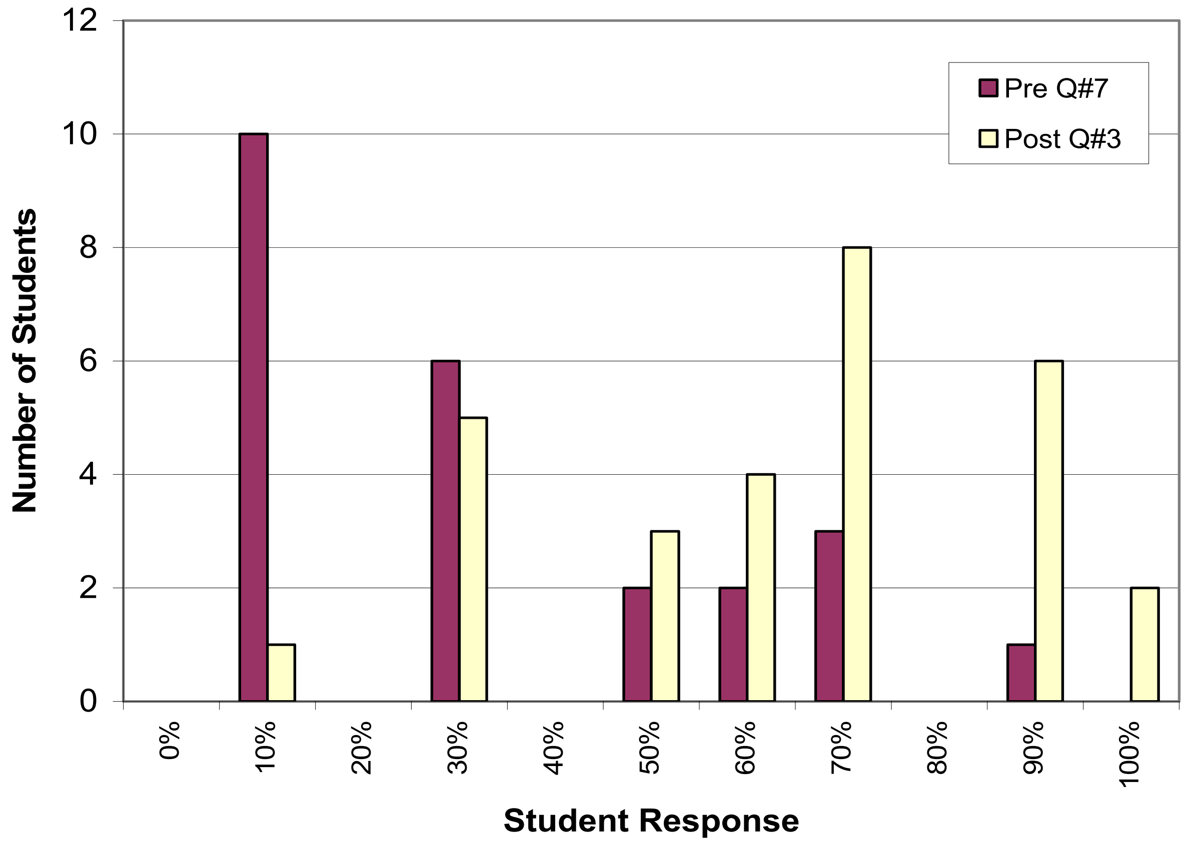

Figure 6. Student responses to "Importance of Corn Syrup"

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 the instructors and presented materials. Further, a larger number of female students than male students indicated that the experimental portion was their enjoyable topic, although the trend was the opposite of 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%.

10. Summary

The module introduced K-12 students to the field through interactive presentations, discussions, an 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 secondary investigations that delved into both scientific and engineering aspects. All topics incorporated design aspects to draw on the personal experiences with bioengineering products, processes, and research that have likely affected their lives. 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. However, to better understand the effectiveness of the module, long-term follow-up studies are needed examining the students' career choices. Further, pre and post-assessment needs to be redesigned to more effectively measure module features and goals.

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