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Work in Progress: Learning from Two Little Blue Lines: Introducing Biomedical Engineering by Reverse Engineering a Low-Cost Diagnostic Device

Dr. Mary Staehle, Rowan University

Dr. Mary Staehle is an Associate Professor and Undergraduate Program Chair of Biomedical Engineering at Rowan University. Before joining the faculty at Rowan in 2010, Dr. Staehle worked at the Daniel Baugh Institute for Functional Genomics and Computational Biology at Thomas Jefferson University and received her Ph.D. in chemical engineering from the University of Delaware. Her research is in the area of biomedical control systems, specifically neural regeneration. Dr. Staehle is also particularly interested in biomedical and chemical engineering education.

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In-class demonstrations and outreach activities that introduce students and/or educators to Biomedical Engineering can be challenging to develop, expensive to implement, and inflexible in complexity. Several low-cost modules that introduce biomedical engineering concepts to K-12 students have been described previously (e.g. Lambeth et al., 2015; Madihally and Maase, 2006; Sherwood and Klein, 2003). Here, we have developed a flexible module that utilizes the reverse engineering of over-the-counter, low-cost diagnostic devices – early pregnancy tests – to introduce various aspects of Biomedical Engineering. Early pregnancy tests have been suggested for collegiate-level in-class activities previously (Evenson 2013), and considerable research has been dedicated to the development of paper-based analytical devices for diagnostics and molecule detection (e.g. Martinez et al., 2010; Scala-Benuzzi et al., 2018), but we are unaware of any previously published modules that couple these for the introduction of biomedical engineering.

Module Overview

Participants are first introduced to the concept of Biomedical Engineering as the cone of opportunity between medicine and engineering, and they are asked to brainstorm areas of work or innovations in the field. These responses are then classified as medical devices, healthcare engineering, tissue engineering, regenerative medicine, rehabilitation engineering, neural engineering, medical imaging, diagnostic devices, etc. In the next phase of the discussion, participants are asked to list known diagnostic devices, and in the subsequent discussion, the facilitator directs the discussion to include the identification of engineering challenges associated with the development and implementation of these devices.

For the hands-on activity, student groups are given sealed packages containing early pregnancy tests and asked to use their senses and insight to determine how these diagnostic devices work. These early pregnancy tests were purchased at a local "dollar store" and are very simplistic and easy to disassemble. Higher-level students/participants are challenged to determine molecular mechanisms involved, whereas less-experienced students/participants are asked to hypothesize a general methodology.

After approximately 5 minutes, we continue the discussion with a YouTube video showing the actual mechanism and then discuss other potential applications for at-home diagnostic devices, the engineering challenges associated with their development, and ethical considerations of alternative applications (e.g. cancer tests). Advanced students are also challenged to use their new-found knowledge of paper-based diagnostic devices to reverse engineer an at-home marijuana urine testing kit, which has the opposite antibody binding and reporting patterns.

Implementation

We have implemented this module successfully with both high school students and high school STEM teachers. In this preliminary assessment of student perceptions and attitudes, we ran the

module within a day-long STEM conference for high-achieving high school students selected to participate in a state-run program. Ninety students registered for the program, 51 female and 39 male, representing 81% of the counties in the state of New Jersey. These students were diverse (15% African American, 15% Hispanic/Latin, 35% Asian, 35% Caucasian), ambitious, and all identified as interested in STEM fields. Although specific data is not available for this group, most students indicated informally that they were high school juniors or seniors.

Students were allowed to self-select among multiple parallel tracks, and the 30-minute module was presented twice by the same facilitator to a total of 33 students. (Attendance at the program was adversely affected by inclement weather. Original registrations for the module were capped at 50 and were fully subscribed.)

Following the activity, each student participant was asked to complete a short 13-question survey about his/her experience. The survey contained 10 Likert-Scale questions, 2 fill-in-the-blank questions, and one open comment box. Likert-Scale questions were quantified as 5=Strongly Agree, 4=Agree, 3=Neutral, 2=Disagree, 1=Strongly Disagree. All errors stated are 95% confidence intervals around the means. The Rowan University IRB approved this study, and participants were provided an explicit opportunity to refrain from completing the survey. No identifying information was collected, nor were any rosters of attendees generated or collected. Therefore, all assessment is anonymous and in aggregate.

Preliminary Assessment of Student Attitudes and Perceptions

Students reported a large increase in their awareness and understanding of the field of biomedical engineering. When asked whether they knew what biomedical engineering was prior to the workshop, the average response was 3.8±0.3. Ninety-seven percent of students agreed or strongly agreed that the workshop increased their awareness of the field of biomedical engineering (average score 4.6±0.2), while 94% (average score 4.5±0.2) agreed or strongly agreed that the workshop increased their knowledge of the field of biomedical engineering.

There is also some increase in their likelihood to consider biomedical engineering as a career option/college major. The reported intent to consider biomedical engineering as a career option or college major prior to the workshop was quite neutral (3.2±0.4). When asked whether the workshop made them more likely to consider biomedical engineering as a career option/college major, the average response was 3.7±0.4. Interestingly, of the 18 respondents who indicated that they Strongly Disagreed, Disagreed, or Neither Agreed nor Disagreed with the statement “I was considering Biomedical Engineering as a career option/college major before today’s workshop”, 11 responded to the follow-up question about likelihood to consider biomedical engineering after the workshop with Agree or Strongly Agree. It is important to note here that since the students self-selected for the workshop, there is likely some predisposition to an interest in biomedical engineering or medicine that may have been kindled by increased awareness and comprehension rather than radical shifts in thinking, but the perception shift following a 30-minute module is encouraging nonetheless.

To determine whether the perception shift toward increased likelihood to consider biomedical engineering following the workshop was specific to biomedical engineering or extended to other

engineering disciplines, the students were asked whether they were considering engineering (any discipline) as a career option/college major before the workshop and whether the workshop changed those considerations. Average responses for intent prior to the workshop were 3.9±0.4, and students also responded that the workshop made them more likely to consider engineering (3.9±0.3). This is likely because they felt the workshop gave them a better understanding of engineering in general (4.0±0.2).

From the facilitator perspective, one concern with this activity is the participants' uneasiness when asked to manipulate an early pregnancy test; this is of particular concern with adolescents. The students surveyed in this implementation of the module were asked, "When [the facilitator] first pulled out the early pregnancy test, I felt ___." Several examples were provided (excited, intrigued, nervous), but respondents were free to write any emotional response in the blank. Approximately half of the students selected intrigued. Other responses included: confused, amused, amazed, curious, interested, surprised, excited, shocked, uncomfortable, and enthralled. These responses do not capture the squirming observed by the facilitator, but rather point to the more rationalized responses the students hoped to exude when self-reporting after the activity. This suggests a respect for the beneficial learning experience obtained in the activity. Respondents also claim that after the activity, they felt that early pregnancy tests were: clever, interesting, useful, intelligently-designed, simple but ingenious, incredible, efficient, elegant, economical, cool, innovative, intricate, mystical, and fascinating.

Finally, the participants were asked whether they could see how the activity related to biomedical engineering (4.6±0.2), and whether they enjoyed the activity (4.5±0.2). These results are the most encouraging because they indicate that students learned about an aspect of biomedical engineering (design and development of low-cost diagnostic devices), enjoyed and respected the activity (even when reverse engineering an early pregnancy test!), and translated that into a greater appreciation of the field of biomedical engineering.

Conclusions

Taken together, the early assessment results from implementing this outreach module suggest that the module is effective in affecting positively the attitudes and perceptions of biomedical engineering in high-achieving high school students. Anecdotal evidence from additional implementations suggest that this is not unique to high-achieving high school students; high school teachers that completed the activity also provided similar feedback. The module is inexpensive, scalable, and easy to implement in various locations, and with various audiences, and can be customized to fit the background and interests of the facilitator.

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