Paper ID #36673

Development of a biomedical engineering course for high school students using a framework of student-centered pedagogy

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Development of a Biomedical Engineering Course for High School Students Using Student-Centered Pedagogy

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Abstract

Early exposure to engineering coursework can increase the persistence of students, particularly women and minorities, in STEM fields in college and beyond. Secondary school instructors have a golden opportunity to approach engineering curriculum design with a student-centered perspective that fosters engagement since many curricular resources for high school students must be uniquely tailored for students with different levels of exposure to engineering.

This paper describes the development of a biomedical engineering curriculum for high school students that integrates design thinking using the framework of student-centered pedagogical practices such as inquiry based learning, problem based learning, and open pedagogy. This approach to teaching engineering uses guided inquiry in combination with modular design projects to help students become comfortable with innovating new ideas. By its design, the course motivates student interest over longer periods of time and enables students with minimal prior exposure to engineering to engage interactively with the instructor and their peers.

Keywords

Student-centered pedagogy, design thinking, K-12 engineering education, STEM education

Introduction

The factors influencing the recruitment and persistence of students in engineering fields have been intensely investigated by a wide range of stakeholders to understand recent trends in engineering education. While the overall diversity of engineering degree programs has increased since the mid 20th century, evidence clearly shows that the numbers vary according to gender, race, and the subdiscipline of engineering[1,2]. Women were awarded 23% of degrees in engineering in 2020 and accounted for only 14% of engineering employment in 2019[2]. The exceptions to this gender disparity are the fields of biomedical engineering and environmental engineering in which women earned approximately half of all degrees awarded in 2020[2,3]. The disparities are more stark for minority students, particularly African-Americans. In 2018, African Americans were awarded 4.3% of all degrees in engineering in contrast with a representation in the US population of 13.6%[2]. Between 2008 and 2018, African American women accounted for 1.14% of bachelor's degrees awarded in engineering. One study of engineering degree trends for African American men and women has also shown that although females are more represented in biomedical engineering, the fraction of African-American women receiving bachelor's degrees in biomedical engineering declined 12% from 2005 to 2013[4].

Students often cite the clear potential for impact on society as a reason for their interest in biomedical and environmental engineering, however, there are myriad intrinsic and extrinsic reasons why students choose and persist in the field of engineering. Unsurprisingly, the important work of equipping students, particularly female and minority students, to choose, excel and persist in engineering begins years before they set foot on a college campus. One study investigating STEM pipeline persistence found that a growing interest in STEM fields as early as high school was correlated with a high likelihood of majoring in a STEM field as an undergraduate student[5]. This suggests that the high school engineering classroom is a pivotal environment for increasing exposure to STEM fields and nurturing positive attitudes toward engineering.

While traditional undergraduate engineering courses tend to have more structured curriculum, high school engineering educators often piece together specialized lessons from many different sources to create a long-term (semester or year-long) curriculum that is rigorous yet accessible for students who are new to the field of engineering. The need for curriculum development is especially pronounced for newer fields such as biomedical engineering that are rapidly changing and require frequent reviews and updates of content to stay relevant. Biomedical engineering courses also represent a unique opportunity to teach fundamental engineering concepts in an interdisciplinary way that may lower barriers to entry for other engineering fields. Adapting course curriculum specifically for advanced high school students presents the secondary school educator with a significant opportunity to develop a curriculum that is student-centered and reflects recent advancements in both technology and pedagogy.

Student-centered pedagogy

Student centered pedagogy or learner centered pedagogy can be defined as an approach to learning that enables students to become active agents in their acquisition of knowledge. Students are given a greater degree of autonomy over what they learn and how they learn and are encouraged to use their past experiences and their interactions with others to motivate their discoveries. In a student-centered classroom, less class time is spent on traditional lecture and more time is allocated for students to engage in active learning[6]. Described below are several categories of student-centered pedagogies:

Project-Based Learning

Project-based learning is one common implementation of student-centered pedagogy. In project-based learning, students actively explore a topic within a real-world context and collaborate with other students to problem-solve, analyze data, and develop an end-product[7].

Problem-Based Learning

Problem-based learning is similar to project-based learning in that students actively and collaboratively explore a topic in context. In contrast to project-based learning, students are more focused on the process of learning and developing a solution to an unsolved problem and are not required to have an end-product[7].

Design Thinking

Design thinking is a framework for innovating solutions to problems. One of the unique tenets of design thinking is that it is driven by empathy for the user. In the specific context of engineering design, the steps of the process include identifying the need, researching the problem, brainstorming a solution, selecting a promising solution, building a prototype, testing and evaluating the prototype and redesign. Design thinking has been implemented in various formats in engineering education as a type of project-based pedagogy that enables learners to actively and collaboratively solve problems with the user in mind [8].

Open Pedagogy
Open pedagogy is an approach to teaching and learning that empowers students as creators of information rather than simply consumers of information. Two of the most common implementations of open pedagogy are open textbooks and renewable assignments, however the greater mission of open pedagogy includes attributes such as openness, privacy, social justice, and accessibility[9].

Objectives

This paper describes the development of a biomedical engineering curriculum for high school students that integrates design thinking throughout the duration of the course as a form of student-centered pedagogy. This approach to teaching engineering, here termed design-based inquiry, uses guided inquiry in combination with modular design projects to help students become comfortable applying engineering principles to solve problems.

Methods

A biomedical engineering course for high school students has been offered at the North Carolina School of Science and Math since 2012 in a traditional in-person format. Each course section of biomedical engineering includes a mixture of high school juniors and seniors with a maximum enrollment of 20 students. All students at the high school are required to take one engineering or computer science course. Other engineering courses offered include Electrical Engineering, Civil Environmental Engineering, Environmental Engineering, Robotics, and Mechanical Engineering.

The semester-long Biomedical Engineering course is structured into three separate design-based inquiries focused on the subspecialties of biomaterials, biomechanics, and bioelectricity. Similarly to project-based learning and problem-based learning, students work actively and collaboratively to solve a problem in the context of the biomedical engineering subspecialties. Each design exploration is 3-4 weeks long and is preceded by 2-4 weeks of more traditional "analysis" content where students learn basic science, math and engineering principles through short lectures and inquiry-based labs that introduce or reinforce the design project. Students then walk through the steps of the engineering design process including problem definition, brainstorming and redesign with one of three outcomes:

- Ideation only without building an actual prototype
- Improvement on an existing design, product or process
- Creation of a new design, product or process

The course does not use a formal printed textbook. The course materials (including lecture slides, assignments, videos, labs) are available to students through the Canvas learning management system. Because the course is not based on a single textbook, the instructors are able to incorporate resources from diverse sources as needed to illustrate concepts and demonstrate specific skills needed for the design project. The students are assessed through formative assessments such as problem sets and labs throughout each module and through a summative quiz and a technical design project at the conclusion of each module. Students communicate their design outcomes in various formats throughout the semester including a brochure targeting potential patients, a presentation to a panel of experts, and a journal article.

In the biomaterials module, the students first learn about properties of biomaterials with a focus on bone and bone repair. The engineering content includes strength of material concepts like the stress/strain curve and the modulus of elasticity. Students review an FDA case study on the regulatory process for bringing a hip implant to market and work in groups to research biomaterial combinations (ceramic, metal, polymers) to meet a specific design criteria (i.e. hip implant for a patient with an active lifestyle). At the end of the module, the students propose their own designs for a hip implant and create brochure or other written document that describes the design process they used to create and evaluate their design.

In the biomechanics module, students learn about gait analysis and the biomechanics of walking and running. The engineering content includes kinematics and kinetic biomechanics as well as CAD design. Students collect force plate and pressure data for both barefoot and shod walking and compare their data with data collected using a 3-D printed shoe sole that they design using Onshape or other CAD software. At the end of the module, the students present a 5-7 minute presentation to the class on their shoe design and the results of their biomechanical testing.

In the bioelectricity module, students learn about electrophysiology and applications to medical device design. The engineering content includes electrical circuits, Arduino, and medical devices. Students design a project that uses biomedical equipment to collect data and apply programming approaches to analyze the data. Previous students have developed prototype devices for detecting heart signals using EKG sensors or photoplethysmography(PPG) and have developed or applied algorithms to analyze heart rate variability under different conditions. At the end of the module, the students submit a report in a journal format to present the results of their study.

Discussion and Conclusions

Based on our in-person implementation of the course, we have found that while students value the emphasis on working collaboratively and learning new knowledge and skills in context, students at the high school level who are new to design are often intimidated by design ambiguity when there is not a specific right answer to the problem or project. The biomedical engineering instructor may need to offer a little more guidance during the brainstorming and redesign phases (structured workbook, additional office hours, discussion boards, periodic team presentations over the course of the project) to help students navigate the design process in virtual environments.   Instructors should put safeguards in place to make sure students contribute comparably to the design exploration. Based on our observations, students need dedicated time within the course to redesign and receive feedback in order to gain the most benefit from the project. Studies of implementation of design thinking in undergraduate engineering programs have shown that providing opportunities to continue the project beyond the actual course increases student motivation[10]. Students who develop an interest in the Biomechanics and Bioelectricity subspecialties explored in our Biomedical Engineering course are encouraged to take the Biomechanics of Injury and Bioinstrumentation courses that are offered at our school. We encourage students who discover broader interests in topics such as electrical engineering and statics to take additional courses in engineering outside of the biomedical engineering related course offerings.

Students often get easily frustrated when faced with challenging or unfamiliar material. Previous studies have demonstrated that project-based engineering increases student engagement[11] and increases students' ability to apply conceptual knowledge of new material in diverse contexts [12]. By incorporating projects at the end of each individual biomedical engineering course module, our students may be more likely to sustain interest in the course over the entire semester. In addition, students with minimal prior exposure to engineering are more likely to engage interactively with the instructor and their peers. Student familiarity with certain aspects of design thinking such as brainstorming, presenting and working in groups helps them to stay motivated as they learn to apply more unfamiliar engineering principles to actual problems. This interactive aspect of design-based inquiry may also increase the appeal of engineering courses to female and minority students.

In future iterations of the study, we will administer a pre and post engineering design survey to assess changes in student's engineering ability and attitudes towards engineering as a result of taking this course.

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