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Expose Mechanical Engineering Students to Biomechanics Topics*

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To adapt the focus of engineering education to emerging new industries and technologies nationwide and in the local area, a biomechanics module has been developed and incorporated into a mechanical engineering technical elective course to expose mechanical engineering students at ONU (Ohio Northern University) to the biomedical engineering topics. In this module, lectures have been offered focusing on the introduction of biomechanics concepts and the correlation between the human body and engineering systems. Application of engineering theories in the biomechanics field was discussed through reviewing research papers and a hands-on project, which requires the design of different structures simulating the human body using an advanced structures set. This module helps to increase diversity and gives a broader application of the engineering theories and skills. It also helps to prepare engineer students at ONU in the healthcare industry. In addition, it offers opportunity to increase the number of women engineers who pursue traditional engineering programs like mechanical engineering.

Keywords: biomechanics module, mechanical engineering curriculum, advanced structures set

Introduction

Biomedical engineering has emerged as a discipline in universities with engineering programs offering students the opportunity to apply engineering theories and techniques to the medical field. Biomedical engineering is a wide field including a variety of sub-disciplines, such as tissue engineering, genetic engineering and medical devices. Most universities having a separate biomedical engineering major are large scale research universities. Primarily, undergraduate institutions like ONU (Ohio Northern University) face a number of challenges when it comes to developing a vibrant biomedical engineering program, especially when the institution is not affiliated with a large research hospital. The T. J. Smull College of Engineering at ONU, formally established in 1903, has five majors in three departments: civil, mechanical, electrical and computer engineering, and computer science. Each program is strictly undergraduate. Given the small class sizes (about 30 students) and faculty focus on teaching responsibilities, it is impractical to create an entire track of courses for a specialized concentration in biomedical engineering. This fact, however, does not diminish the need for the undergraduate engineering students at ONU and similar institutions to be exposed to biomedical engineering topics and concepts as a part of an undergraduate mechanical engineering curriculum.

Due to the highly interdisciplinary characteristics of the biomedical engineering field, mechanical

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engineers are needed in many aspects, such as medical implant and device design, material testing and simulation for clinical applications. The mechanical engineering curriculum at ONU is strong in mechanics analysis, fluid mechanics, finite element analysis and material testing. However, the traditional courses mostly focus the application of the engineering principles on traditional industries, such as automotive and aircraft industries. The human body, as a complicated living system, still seems esoteric to mechanical engineering students at ONU. In this study, a biomechanics module has been developed and incorporated into a senior technical elective course on biomechanics, biomaterial and medical devices. The course has been taught for students in the College of Engineering at ONU in the spring quarter of 2010.

The time duration for the biomechanics module is about four weeks. The objective of this module is to introduce the biomechanics topics to upper level mechanical engineering students. The module focuses on applying the engineering theories to the human body, such as the circulatory system. In this module, eight lectures have been given on the basic concepts of biomechanics. Two sessions were discussion and review of relevant research papers. Students also finished a hands-on biomechanics project, in which structures of the human arm, leg and back have been built and the forces exerted by muscles were measured for different configurations. The project allows students to discover similarities between the human body and other engineering structures. This module would bridge students' engineering knowledge and problem-solving skills using mechanics analysis on the human body.

A number of positive outcomes are expected from this module including the opportunity to increase the number of women engineers who pursue traditional engineering programs like mechanical engineering. As the world becomes increasingly technological, changes in engineering education are necessary to attract more students in engineering to keep America's leadership in technology field (National Research Council, 2003; Heckel, 1999; US Labor Department, 2009; Borrego, 2003; National academies, committee on prospering in the global economy of the 21st century: An agenda for American science and technology, 2005; Engineering Workforce Commission, 2009; Bugliarello, 2005). This issue has been investigated widely by engineering educators and researchers and it has been reported that one solution is to attract more female students to the engineering field (Sanoff, 2005). However, only 10% of the female high school students are interested in engineering majors, because they often think that engineering is a purely technical field with no relevance in society (Sullivan, 2005). Female students in particular are attracted by careers that offer social and environmental impact (Sanoff, 2005; Wolcott, 2007), and have traditionally represented a high percentage of the total number of bachelor degrees awarded in environmental (44.2%) and biomedical (40.7%) engineering. Relatively, a few of the bachelor's degrees in mechanical engineering (13.1%) are awarded to women (American Society for Engineering Education, 2006). The potential for a career in healthcare field will attract new students, especially female students seeking a career which "helps society" (Seymour & Hewitt, 1997), to traditional engineering majors, who otherwise might not consider a degree in mechanical engineering. The project developed in this module will be used as a demonstration for outreach programs at ONU, such as Camp GEMS (girls in engineering, math and science). It is hoped that this early exposure to the biomedical projects will spark the interests of some of these students, especially females, in engineering majors.

This topic also helps to prepare engineering students at ONU in the healthcare industry. According to the ten-year projections by the US Labor Department, biomedical engineering will be the fastest-growing occupation by 2018 (US Labor Department, 2003). The Midwest healthcare industry is an emerging industry field while the Midwest healthcare start-ups have received large investment during recent years (Wilson, 2008;

Ganeshan, 2007). Ohio ranked second in the Midwest for the investment for biomedical start-ups by the Midwest Health Care Venture Report 2008, assembled by the Mid-America Healthcare Investors Network and BioEnterprise (2008). It can be expected for Ohio to follow the steps of states like California where the healthcare industry thrives and has become vital to state's economy. Adapting the focus of engineer education to emerging new industries and technologies nationwide and in the local area should help increase diversity and give a broader application of the engineering theories and skills. Engineer faculty who are interested in this field can also gain related biomedical knowledge through teaching and research activities with this integration.

Enrollment

The college of engineering at ONU, with an approximately 470 undergraduates, offers bachelor degrees in five accredited programs: civil, mechanical, electrical and computer engineering, as well as computer science. The university is currently on a quarter system, with ten-week instructional periods. One reason for the creation of the module was to expose mechanical engineering students at ONU to the biomedical engineering topics. Prior to the offering of this module, no similar topics had been offered within the college of engineering. The module was incorporated into a senior technical elective course offered in the spring quarter of 2010. A total of 13 senior engineering students enrolled in the course. Prior to enrolling in the course, students had completed most of the mechanical engineering curriculum at ONU, including mechanics analysis, fluid mechanics, finite element analysis and material testing.

Textbook Selection

Textbook selection was a major difficulty when developing this module. Given the limited background of engineering students on biology and limited amount of time, the author found relatively a few textbooks which could be used for a general introduction to bridge the students' engineering knowledge and problem solving skills using engineering analysis on the human body. Most books either assume an extensive background in biology, or focus on a limited subset of topics. The textbook selected for the module was "Introductory Biomechanics, from Cells to Organisms" by Ethier and Simmons (2008). The two authors taught biomechanics in the Department of Mechanical and Industrial Engineering at the University of Toronto and they have assumed that the reader has an engineering background instead of biology. It is an appropriate textbook to use for mechanical engineering students.

Module Content

The duration of the biomechanics module is about four weeks including eight lectures, two paper review sessions and one week of class time for a project. Details of this module will be described in the following.

Lectures

While the objective of this module is to get mechanical engineering students exposed to the application of engineering knowledge in the biomedical field, instead of teaching biomechanics theory systematically, only eight lectures were offered to introduce some basic concepts and topics in biomechanics. The major purpose was to let engineering students discover the similarities and correlations between the human body (living) systems and engineering structures and learn to apply the engineering problem-solving skills in the human body.

(1) Lecture 1: Overview;

(2) Lecture 2: Hemodynamic;

(3) Lecture 3: The circulatory system;
(4) Lecture 4: Ocular biomechanics;
(5) Lecture 5: Muscle and movement;
(6) Lecture 6: Muscle and movement (continue);
(7) Lecture 7: Skeletal biomechanics;
(8) Lecture 8: Terrestrial locomotion.

Each lecture combines the biology and engineering theories. For example, for the lecture on hemodynamic, fluid mechanics theory was used to calculate the movement and deformation of blood and the forces that produce that flow. Students understood that blood is a special fluid that if shear stress applied on it less than a critical value, it acts like a solid due to the formation of rouleaux. For the circulatory system, the heart functions like two pumps. Fluid mechanics theory was applied to calculate the power of the pumps. After the two lectures, students had a discussion of the design requirements for an artificial heart from the viewpoint of engineering. In the lecture of skeletal biomechanics, the application of fracture and fatigue theories on bones were discussed. Terrestrial locomotion was introduced to show students how the statics and dynamics theories can be used to solve forces in walking and running.

Paper Review and Discussion

After the eight lectures, students were assigned biomechanics papers to review, summarize and present in class. Through the presentations and discussions of these papers, students were aware of current trends in the biomechanics field. This review process also helps them to appreciate the application of mechanics theories in the field. For example, a paper "The Effects of Tibiofemoral Angle and Body Weight on the Stress Field in the Knee Joint" was adopted for this purpose (YANG, Nayeb-Hashemi, & Canavan, 2007). This paper focuses on the study of how the tibiofemoral alignment affects the stress and strain distribution in the knee joint. Engineering mechanics analysis was applied to study the loading conditions on the knee joint and finite element analysis was used to study the local stress and strain distribution. The paper helps students understand how to solve a problem regarding a living system using statics and dynamics theories as well as finite element analysis.

Project

The hands-on project is to design different structures simulating the human body using an ASS (advanced structures set) (PASCO scientific, 2009). The ASS includes various components that can be assembled to different structures simulating the human body. Structures based on the human body would then be investigated. The angles or postures can be adjusted. The force in each muscle can be measured by devices and monitored with computer software. These structures include: (1) human back models; (2) human leg models (see Figure 1); and (3) human arm models.

The project involves students in the study of geometric configurations and structural analysis. Student teams built the assigned structures and measured forces in structural members according to different loading and structural variables, such as angles. Then, students performed mechanics analysis for the structures to get the theoretical value of the forces on muscles. The project allowed students to discover similarities between human body and other engineering structures. They observed that similar principles of mechanics can be applied to human body structures, and that the human body and biomechanics can be a part of engineering.

It should be mentioned that the use of projects to teach courses is ideal pedagogy for the proposed curriculum program development. Students can remember more from practicing and teaching others than

passively listening to lectures. Using projects also gives students opportunities to practice their engineering thinking and problem-solving skills that they already have in the biomedical field.

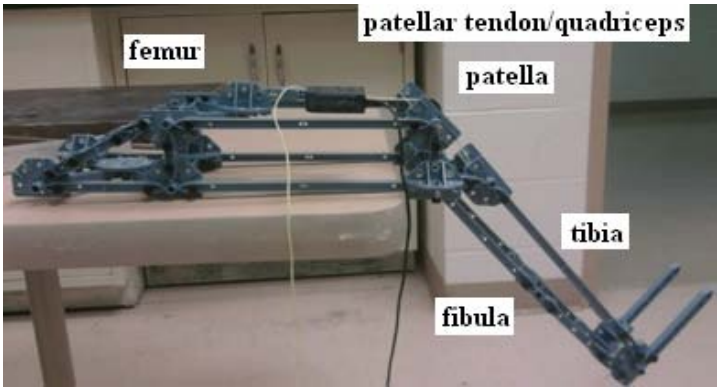

Figure 1. Human's leg assembled using ASS.

Outreach Activities

The hands-on project in the module will be used as a demonstration in the existing outreach program at ONU to attract more students, especially female students to the engineering program at ONU. ONU has an established and successful outreach program that is well-suited to the purposes of this project. Outreach activities of this proposed work related to the ONU outreach program include Camp GEMS—a four-day summer camp aiming at increasing the interests of 7th and 8th grade girls in careers related to engineering, math and science. The author of the paper will develop and conduct one activity for this camp that illustrates the biomechanics project which will be adapted to suit the abilities of middle school students. It is hoped that this early exposure to the biomedical projects will spark the interests of some female students in engineering majors.

Assessment

The expected outcomes for the module are the following:

(1) Students are to be more proficient at interpreting requirements of biomedical analysis;

(2) Students are to be more confident in solving problems in a biomedical engineering field;

(3) Students, especially the female students, find increased motivation to pursue engineering;

(4) The curriculum developed can be disseminated to engineering programs at other teaching-focused undergraduate institutions;

(5) The model can be easily implemented by engineering instructors with strong traditional engineering backgrounds, such as mechanics, but limited background in biomedical field.

The assessment for this course was conducted online at the end of the quarter. Twelve of the 13 students in the class submitted responses. Table 1 shows a summary of the quantitative responses.

From the responses above, students' attitudes towards this course can be observed. It seems that students like the style of the textbook which was written for engineering majors with limited background in biology. This is also reflected in the response for "The module enhanced my understanding of the application of the engineering problem solving skills in biomechanics filed". With the average of the outcome evaluation of 4.25 out of 5.0, the positive effect of the module can also be concluded. The module seems like to open a gate for the students to expose themselves to the application of the engineering knowledge in a different field.

Table 1

Results of the Formal Assessment for This Course

Questions	Average	Standard deviation
This course enhanced my problem solving abilities.	3.8	0.83
The homework helped my understanding of the material.	4.3	0.47
The software used in this course was useful.	4.0	0.50
The textbook was valuable in my learning experience.	4.5	0.50
The workload for this course in relation to other courses of equal credit was as expected.	3.8	0.94
The module enhanced my understanding of the application of the engineering problem-solving skills in biomechanics filed.	4.25	0.75
My overall learning experience in the course is good as expected.	3.9	0.95

A survey for the project has also been conducted. The following questions were asked in the survey:

(1) What do you like best about the project?

(2) What do you like least about the project?

(3) What specific suggestions do you have for the improvement of the project?

For question 1, students' responses are summarized as follows:

It was really interesting looking at how the body works in mechanical terms and representing that with a model to measure relationships. (four responses)

Enjoyed getting to build the model. Took me back to my Lego days. (four responses)

The ease of running the software. (one response)

While the survey was anonymous, these responses were mostly positive for the project. Most students seemed to find the project very interesting. In particular, it seems that students enjoyed building the structure. This project gave them a chance to apply the knowledge they learned in mechanics class, such as statics to the analysis of the human body structure.

While question 2 is what students like least about this project, students' responses are as follows:

The building instructions were unclear, but they were not so bad that we could not build. (eight responses)

Not knowing how the software works. (one response)

Unit conversion. Not bad, just a pain in the neck. (one response)

The amount of time given to perform the project was short. Especially for seniors who are working on capstone project in the spring. (one response)

The report. (one response)

Most students complained the building instructions for the assembly were unclear, but they were not so bad that students could not build the structures. Students thought the report was time consuming and did not like to spend time on it. However, writing the report was an essential skill for engineering students.

For question 3, students suggested to improve the project in the following ways:

Have more specific directions or a defined problem to solve. (one response)

Detailed instructions. (one response)

Make assemble easier. (one response)

Better load cell connection. (one response)

Updating the model to be more like the femur. (one response)

It would be really nice to find a model that simulated the same ideas but actually had gages that the so model would act like arm, leg, and spine with strings that could actually stay still and were easier to set. (one response)

Have more time to investigate the results. (one response)

Get new string so that it doesn't slip. (one response)

Based on the above suggestions, some modifications will be made to improve the project. While some students suggest having a defined problem to solve, next time, biomechanics problems will be defined from each structure for students to solve. For example, a statics problem can be designed to calculate the forces in muscles in the arm when holding a weight by a hand. More detailed instructions will be offered. The structure will be modified to be steadier.

Conclusions

A biomechanics module in a senior technical elective course for mechanical engineering students has been developed in the college of engineering at ONU. The module lasts four weeks, containing lectures, paper discussion sessions and a hands-on project. This module exposes mechanical engineering students at ONU to biomedical engineering topics and concepts. It helps to expand mechanical engineering students' career paths. Because it is the first biomechanics module to be offered in the college of engineering at ONU, there might be unanticipated difficulties related to its contents and format. The author will modify the module based on students' feedbacks.

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