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Using sports in engineering to teach mechanics of materials

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ABSTRACT: Active strategies that also interest and engage students in the learning process can be used to promote learning in educational settings. In an effort to interest and introduce students to engineering principles through a familiar context of sports, a multidisciplinary team of academic staff and students from two universities and a county college developed a set of hands-on modules. Experimentation in one such module allowed for students to explore mechanics of materials at an introductory level. At a four-year university, this module is one of several covered in a freshman introduction to the engineering course. The students conducted four module experiments. After this guided instruction, the freshmen work in small teams to develop their own experiments. In an engineering materials course at a two-year county college, students perform the mechanics of materials experiment, as this is the topic of the course. Students later brought in other products to test a section or material sample. The purpose of this article is to explain the module and its incorporation into each of the courses, to evaluate students' attitudes and interests in the sports in engineering topics, and to determine the perceived level of usefulness of the materials for the students in their learning and determine student level of outcome achievement.

Keywords: Active learning, mechanics experiment, student interests and abilities

INTRODUCTION

The world of sports provides an exciting, every-day platform to study multidisciplinary engineering principles and most students can relate to sporting activities in some way or another, either as a participant or spectator. A large portion of the United States population over the age of six undertakes frequent exercise or participates in recreational sports. For example, according to a 2007 report by the Sporting Goods Manufacturers Association, over 100 million people over the age of six walk for fitness. Over 75 million of these walk frequently, defined as walking on more than 50 days per year.

The *Big Three* team sports in the United States are football, basketball and baseball. Lacrosse, rugby and field hockey are on the rise among team sports and badminton, racquetball and tennis are showing participation gains among the racquet sports [1]. Similar statistics exist for sports and recreational activity in the European Union [2], Australia and other English-speaking countries [3]. Participation in sports activities even in non-organised fashion is high world-wide [4]. Due to the popularity of sports, studying technology and its effect on sports and sports performance provide a good way to teach science and engineering theories and engage students in their learning. *Studying some of the dynamic effects contained in sports, we can introduce all of the dynamic systems that we are trying to teach our students. Students tend to tune out when studying the same old greasy gearbox* [5].

Inquiry-based, active learning is central to learning unlike passive methods. In general, research shows that inquiry teaching produces positive results; examples in the sciences and engineering have been summarised [6][7]. Also, inductive methods promote transfer of learning to other contexts [8]. Further, student engagement and interest in material influences learning and motivation to learn, which has been well studied and summarised [8-10]. Grounded in learning sciences and research, as well as the notion that many students may have a limited background of applications of engineering, the team of academic staff wanted to engage students and promote student learning through the widely familiar context of sports.

Academic staff at two universities and a county college developed a set of modules for teaching engineering from an applied, hands-on point of view [11]. Inductive approaches from Vygotsky's social constructivist learning perspective described by Leach [12], and engineering experiment examples provided models for module development [13-14]. These ideas were combined with the key features of the undergraduate engineering programme to include multidisciplinary education through collaborative laboratory and course work; teamwork as the necessary framework for solving complex problems; incorporation of state-of-the-art technologies throughout the curricula; and creation of continuous opportunities for technical communication, when implementing the modules in the curriculum.

This article discusses one module in the set, which is mechanics of materials in sports and sport equipment. The module and its implementation at a four-year university and two-year college are described. The research questions asked are: 1) Does integration of sports interest students in engineering? 2) Do students find the sports materials interesting and useful in learning? And 3) Do students meet learning outcomes using sports modules and how does this compare with their self-reported ability when tested? Assessment methods, results and discussion are presented.

EDUCATIONAL MODULE - MECHANICS OF MATERIALS

A wide variety of elastomers and foams are used in sporting equipment such helmets, kneepads, golf and tennis balls, shoe soles and athletic field surfaces. Materials used in sports are chosen according to properties, such as elastic modulus and durability to meet the demands that a given sports component will be subjected to in play. This was the basis of the module developed and summarised here [15].

The *objectives* are that students: 1) Conduct experiments to compress a sample of foam or elastomer and measure force and deformation; 2) Use the concepts of stress and strain along with Hooke's Law to compute a modulus of elasticity; and 3) Compare elastic moduli for a variety of materials and associate properties with their function in specific sports applications.

In the laboratory, students used a universal testing machine (MTS 831.10 or Tinius Olson) to apply a prescribed displacement history and compressively loaded different materials, including silicon elastomers. TestStar software enabled the students to program a monotonic displacement history and collect force, displacement and time data, which were exported to Excel. The students were then taught the concepts of stress, σ, strain, ε, Hooke's law and modulus of elasticity, E, see Equations 1, 2 and 3:

$$\sigma = \frac{F}{A_s} \quad (1)$$

$$\varepsilon = \frac{\delta}{L} \quad (2)$$

$$\sigma = E\varepsilon \quad (3)$$

where F is the applied force, A_s is the surface area, and L is the original length. The students measured the dimensions of the samples needed to compute stress and strain using the force and displacement data. They were required to plot stress versus strain and determine the modulus of elasticity, which is the slope of the curve. A representative data set is plotted in Figure 1. An analogy was also made to springs and spring constants, which the students had studied in science or physics.

Determining the modulus of elasticity of the material allowed for comparisons to be made among materials independent of their size and shape. The students compared the modulus to various other engineering materials such as steel, aluminium, rubber and wood, discussed particular applications for this material and why they were appropriate.

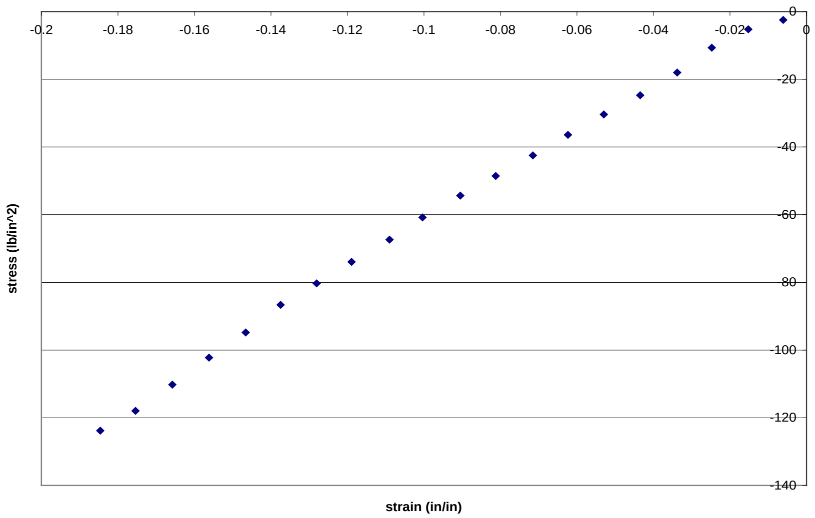

Figure 1: Example stress - strain data for a silicon elastomer sample tested to 20% strain.

METHODS

Implementation of Module in Two Courses

The module was one of several used in an Introduction to Engineering course for first year students at the four-year university. This course is used to introduce students to the science and art of design by evaluating the work of practicing engineers. The students are placed in multidisciplinary teams to learn scientific principles as well as cost, manufacturing, safety, environmental considerations and intellectual property impact engineering design.

During the first part of the course, the students learned these through experimentation in the module, which was followed by an assignment and laboratory report. After conducting several experimental modules, the students in teams developed research questions of their own, choosing experiments related to the topics that were studied in order to answer those questions. In the latter part of the semester, the students conducted their experiments, analysed data and wrote semester final reports, which also included professional issues be addressed.

At the county college, the mechanics of materials module was used in a second-year engineering materials course, which is traditionally lecture-based. With new, bench-top universal testing available, the students were also able to conduct experiments. As the students were introduced to the concepts of stress, strain and Hooke's law, they were given various elastomer samples as mentioned, as well as more typical testing of metal dog-bone samples. The students were particularly interested and brought in a variety of their own products, such as an old pair of boots from which they cut samples to test.

Assessment Methods

In order to answer the first two research questions, surveys were used. The students were given anonymous pre- and post-surveys on the first day of class and at the end of the semester, where they were asked about their level of interest in engineering and sports in engineering. The survey was designed on a 5-point Likert scale and was used to determine, if any changes occurred in the group during the course of the semester after working on sports engineering modules and projects.

After completion of the module, the students were given a survey with questions for them to rate their ability to complete the educational learning objectives and their interest in the material. This survey allowed to evaluate the student interest in this particular module and their perception of how well (or not) it contributed to their learning of the material. The survey consisted of 5-point Likert scale questions and open-ended written responses.

In the Engineering Materials course at the two-year county college, three examination questions that required students to calculate stress and strain using mechanics theory presented in the module was analysed. In the Introduction to Engineering course at the four-year university, a group laboratory report was used for assessment where students conducted stress, strain and modulus calculations, plotted and interpreted data.

In the reports, the students answered follow-up questions regarding use of materials in sports applications based on properties and comparison of mechanical properties of other common materials. The assessment results were used to evaluate, if students reached an appropriate competency level compared with the objectives and to compare the overall student perception of their learning to actual performance on assessments.

RESULTS AND DISCUSSION

Students' interest in engineering materials related to sports as a group at the two-year college increased slightly, while level of interest in engineering materials, in general, slightly decreased between the beginning and the end of the semester (Table 1a). While neither difference is significant based on an unpaired student *t*-test, together the trends suggest a positive nature of learning materials in the contexts of sports, rather than in an abstract or less relevant context.

At the four-year university, student interest in engineering related to sports increased during the semester (Table 1b); and the results are statistically significantly different $p < 0.01$. The fact that the students undertook several sports modules and conducted further experimentation on engineering in sports throughout the semester was likely to have been a contributing factor to students' increased interest in this area. Comments from the students were favourable towards projects and experimentation of sports in engineering, while one student did express concern that relating engineering to sports *took the fun out of sports*.

Table 1a: Average results of survey responses for the mechanics module.

Question	2 year pre	2 year post
What is your level of interest in engineering materials?	4.22 (SD 0.808)	3.94 (SD 0.998)
What is your level of interest in engineering materials related to sports and sporting activities?	3.50 (SD 1.200)	3.73 (SD 1.163)
	N=17	N=15

Table 1b: Average results of survey responses for the mechanics module.

Question	4 year pre	4 year post
I am interested in engineering related to sports and sporting activities	2.94 (SD 0.443)	3.14 (SD 0.949)
	N=14	N=14

Overall, students at both institutions agreed that they were interested in engineering related to sports. While the second year students at the two-year college rated this higher than the first year students at the four-year university, there are some differences to note in the courses and environment.

First, the questions were not exactly the same, which may have contributed to bias in how students interpreted or answered the questions. Also, students in this course were conducting an experiment directly relevant to the course subject matter and most were considering continuing studies in civil or mechanical engineering, compared with the university students who were in the first year from many majors that were less relevant to the module concepts (i.e. Electrical and Computer Engineering).

These second year county college students may have been more likely to consider continuing in engineering based on self-reported information of future plans compared to some first year students, yet this would be a point for further investigation.

The responses to the questions regarding students' perception of how the modules contributed to their learning of the material, interest in the module, difficulty and usefulness of handouts were favourable at both institutions, with all scores above neutral (Table 2).

The results show that while the freshman university students as a group believed that the module contributed more to their ability to understand how to determine quantities and properties, this may be due to the fact that these students were required to prepare a full laboratory report in teams. In doing so, the students met to discuss the analysis and write the report, further reinforcing the concepts.

Students from the county college were generally more interested in the experiment itself and as a way to learn these principles. Since students from the two-year college are sophomores, who have taken some introductory engineering courses and many of whom are most interested in mechanical or civil engineering, they may have found more relevance in this topic.

Students from the four-year university may be declared as chemical, civil and environmental, electrical and computer or mechanical engineering students, so those that would not be taking mechanics may have been less interested. Overall, all the students found the experiment and assignment relatively challenging and appropriate (score 3 out of 5) and the handouts to be useful or very useful [16].

Table 2: Average results of survey responses for the mechanics module.

Question	4 year	2 year
How did the module contribute to your understanding of material properties? (1 no idea, 5 concept is clear)	4.3	4.2
How did the module contribute to your ability to determine stress and strain from force and displacement data?	4.1	4.0
How did the module contribute to your ability to compute elastic modulus?	4.1	3.8
How interesting was the subject material (1 dull, 5 interesting)	3.7	4.0
How interesting was the experiment (1 dull, 5 interesting)	3.3	3.7
How interesting were the analysis and results as a way to learn engineering principles (1 dull, 5 interesting)	3.6	4.0
Please rate the difficulty of the experiment (1 much too easy, 5 much too difficult)	4.3	3.3
Please rate the difficulty of the assignment (1 much too easy, 5 much too difficult)	3.2	3.4
Please rate the handout (1 useless, 5 very useful)	4.1	4.1
	n=11	n=10

For the two-year county college, type of examination questions and average results for each are presented in Table 3. The first two questions were covered in the module and average results suggest a least competency by the students on the concepts of stress and strain. The third question was a two part question involving true stress and strain, so was slight more advanced compared with the other two questions. This may explain why the average results were lower for this question as well.

First year students (n=16) at the four-year university wrote laboratory reports that included engineering calculations, graphical representation and interpretation of data. All students (n=16) achieved the course objectives with a minimal level of competency of at least a 67%, while half of the students (n=8) achieved a high level of competency of at least 87%.

Table 3: Question type and average results.

Type of Question	Average
Calculate engineering stress given load and geometry	71%
Calculate engineering strain given geometry, gage length and final gage distance	74%
Part 1 – Calculate engineering stress and strain Part 2 – Calculate true stress and strain	63%
	N=16

Results are positive, suggesting that a majority of students met the required learning outcomes. Further, students also believed that the modules contributed to their ability to understand concepts such as stress, strain and modulus, although slightly more so than they were able to actually exhibit their abilities on assessments. A limitation of the findings is the fact that group work in the Freshman course limits individual student evaluation, although group activities and learning from one another can be an effective mode of learning. Also, without further statistics and breakdown of the examination question scores from the two-year college Engineering Materials course, only generalisations can be made from the averages.

CONCLUSIONS

Since participation in, and even viewing of sports activities are relatively common among students, this familiar context of sports provides a platform for hands-on laboratory experiences to promote learning of engineering concepts with undergraduate students. This article described a mechanics of materials module that was used in courses at both a four-year university and two-year college with positive results. Survey responses from students indicated increased interest in sports and engineering, interest in learning the course material through this sports related experiment and a belief that this was useful in the learning process.

Assessments also have some correlation in that students were able to achieve learning objectives, yet their perceptions of learning were slightly higher than actually demonstrated. This module may easily be used in, or adapted for, Introduction to Engineering courses that are common in Engineering programmes, traditional Mechanics of Materials courses, Mechanical Engineering or Materials Engineering laboratory courses or as experiments and demonstrations for K-12 students.

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