AC 2008-499: INTEGRATING APPLICATIONS IN THE TEACHING OF FUNDAMENTAL CONCEPTS

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Integrating Applications in the Teaching of Fundamental Concepts

Introduction

Student retention through to the successful completion of an undergraduate degree in engineering is of increasing concern to educators, policy makers, and, of course, students. It has been estimated that only half of those entering an undergraduate engineering program go on to complete the degree.[1] This is particularly low when one considers that the bar to enter an engineering program is often higher than for other programs.[2] By 2007, Dean, Anthony, and Vahala reported that the retention of engineering students had become a major undertaking for most institutions.[3] As one of the largest engineering disciplines, awarding 21% of the 2007 engineering bachelor's degrees,[4] retention is a particular concern in Mechanical Engineering.

There are a variety of factors related to student retention, with grades and student interest being among the strongest. Grades, of course, are strongly correlated with retention but so is student interest. Studies of retention in engineering have found that over half of the students who left engineering either came to dislike studying it or lost interest in what they felt the profession offered.[5]

The use of "real life applications" in basic engineering courses is one possible way to both make the courses more interesting and to raise grades. Increasing student interest and grades has the potential to increase student retention. Integrating applications into the teaching of fundamental concepts has already been found to increase women's recruitment and retention at Carnegie Mellon in computer science[6] and at Drexel in engineering[7].

As part of an National Science Foundation-sponsored project to change the undergraduate ME curriculum to make it more attractive to a diverse student community, the use of "real life" applications to teach fundamental ME concepts was explored. A series of applications-based lesson plans—covering concepts in solids, fluids, and design—were developed by ME faculty members from eight participating universities and tested in terms of their impact on students and on participating faculty. The participating colleges and universities were Johns Hopkins University; California State University, Los Angles; Michigan State University; Smith College; University of Washington; Stevens Institute of Technology; Howard University; and Tuskegee University.

Methods

There were several criteria that the applications and lesson plans had to meet. The first was that the applications needed to be familiar to the students. As Sue Rosser explained,

> I see math classes where vectors are taught using sails and sailboats. This may work very well in [Maine]. I am originally from the Midwest, and I can tell you that there are a lot of students who have never seen a sailboat. They may never be able to understand the idea that you are talking about vectors and listen to the math. Because they are so panicked over the fact they know they are not familiar with the example, they think they can't understand what this person is going to be talking about.[8]

Earlier work on test items confirms Rosser's comment. When the same concepts were being tested, students were more apt to get a test item correct if the context of the test item was familiar to them.[9, 10]

In addition, it was expected that the lesson plans would center on the five E's: Engage, Explore, Explain, Elaborate, and Evaluate. These concepts grew out of the work of Atkin and Karplus,[11] and are the basis of the Biological Sciences Curriculum Study curriculum.

Lesson plans were developed using the following applications: Airfoils, Bottle Closures, Crushers, Engines, I-Beam Stress Analysis, iPods, Mock Trials, Cooking Sausages, Skateboards, Stapler Designs, Tennis Ball Throwers, and Wiggle Writers (vibrating motorized pens). Three existing applications—Balloons, Rockets, and Gliders—that had been developed by one of the participating professors were also included. Over the 2006/07 academic year, the applications were tested in the following four courses:

- Freshman Experiences in Mechanical Engineering (Fall, 2006)
- Introduction to Mechanical Design (Fall, 2006)
- Materials Engineering (Spring, 2007)
- Mechanics of Solids (Fall, 2007, Spring, 2007)

To explore the effects of applications, the following sets of data were collected:

Student ratings, of the applications used in their class, in each of the following areas:

- level of difficulty
- overall value
- contribution to their understanding
- student participation

Student ratings, of their courses with the applications, in each of the following areas:

- level of difficulty
- interest
- learning
- class participation
- other students' class participation

The response of students in the courses with applications to open-ended questions asking them about:

- topics included in the course that do not contribute to their mastery of the content
- course activities that increased their interest in mechanical engineering
- course activities that greatly increased their knowledge of a specific course topic

Pre, mid-course, and post interviews with participating faculty on: the impact, if any, of the applications on teaching, unintended outcomes of using the applications, their willingness to use applications again, and any impact of the applications on students.

In addition, student grades and course syllabi were collected for the courses where the applications were implemented and the same courses, taught by the same instructor, without the applications. In three courses, Freshman Experiences in Mechanical Engineering, Materials Engineering, and Mechanics of Solids, results from the standard student evaluation form were collected from both sets of courses as well.

Student data were not broken out by sex in this paper. Overall a third of the students were women; however, the percentage of women in the individual courses ranged from 7% to 100%. Seventeen of the thirty-three women in the study were in the one single sex course. For this paper, it was felt that the interaction of any sex differences with such confounding variables as percent of women in the class, course type, and institution would make the breaking out data by sex inappropriate.

Table 1 provides a list of the applications and the courses in which they were used.

Table 1: Applications and the Course in Which They Were Used

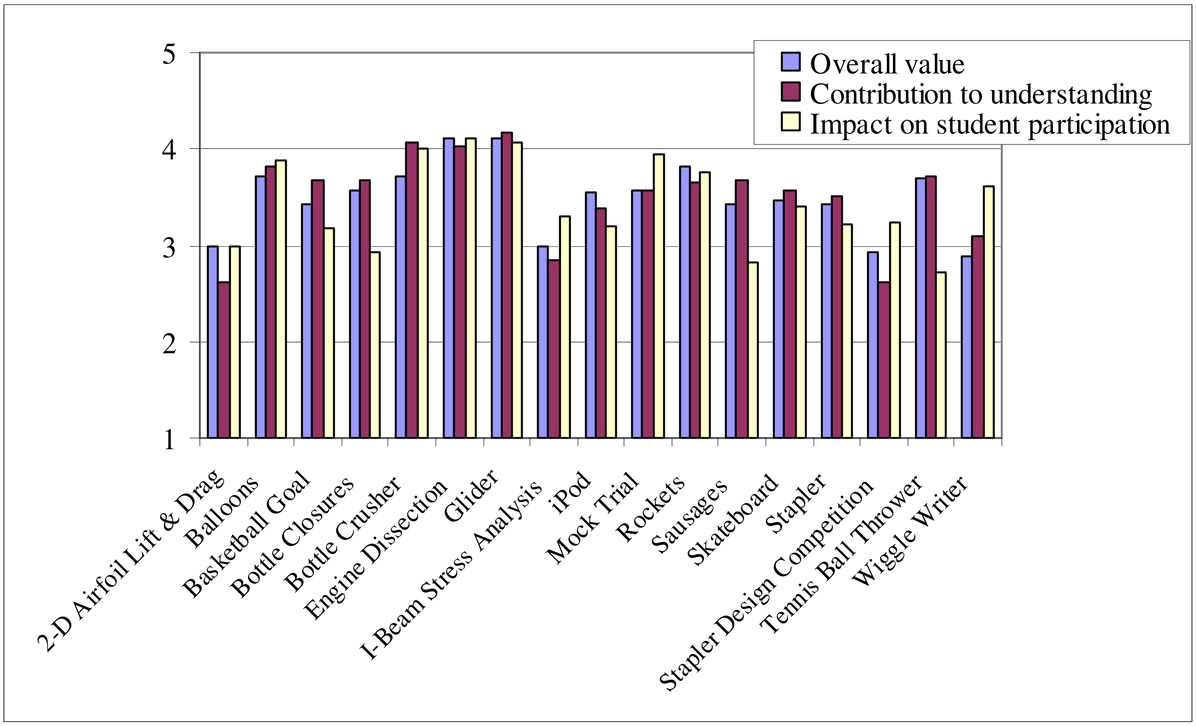
	Freshman Experiences in Mechanical Engineering (33 students)	Introduction to Mechanical Design (14 students)	Materials Engineering (16 students)	Mechanics of Solids (37 students)
Engine Dissection	X			
Mock Trial	X			
Tennis Ball Thrower	X			
Wiggle Writer	X			
2-D Airfoil Lift & Drag		X		
Bottle Crusher		X		
I-Beam Stress Analysis		X		
Staplers		X		
Stapler Design Competition		X		
Balloons			X	
Gliders			X	
Rockets			X	
Basketball Goal				X
Bottle Closures				X
iPod				X
Sausages				X
Skateboards				X

Results

Student Ratings of the Applications

As Figure 1 indicates, although student ratings of the applications varied, overall ratings were positive. Across all applications, student mean ratings of the value of the application, the application's contribution to their understanding, and the application's contribution to student participation were similar (3.5 each on a scale of 1-Very Low to 5-Very High).

Figure 1: Student Ratings of Applications (1=Very Low to 5=Very High)

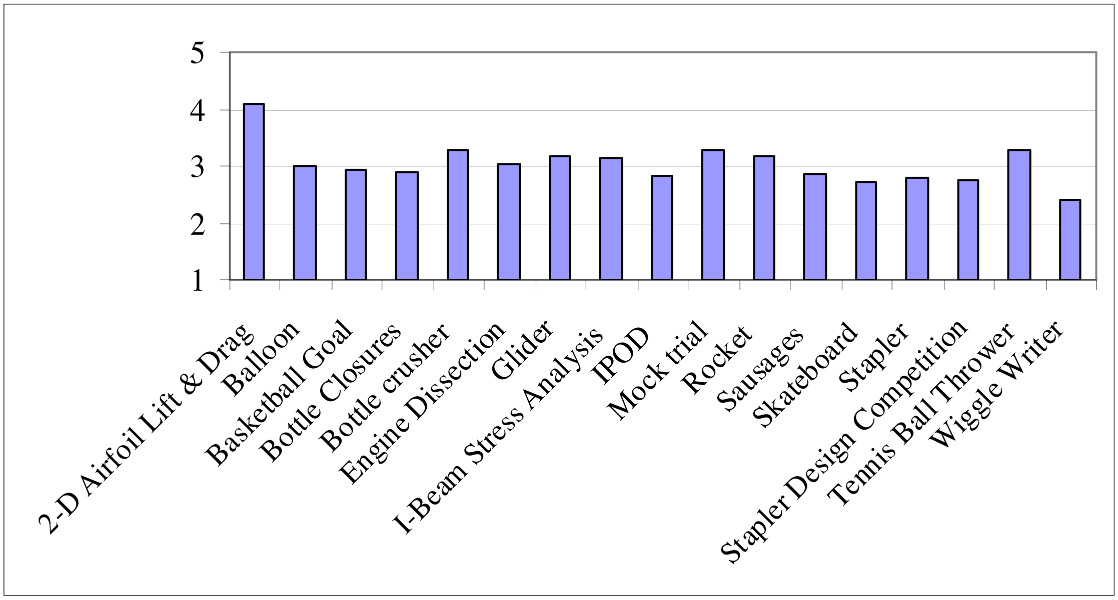


With three exceptions—Stapler Design Competition, I-Beam Stress Analysis, and 2-D Airfoil Life & Drag—students rated all of the activities as having had at least a medium contribution to their understanding. They felt three other applications—the Gliders, Engine Dissection, and Bottle Crusher—were particularly effective in contributing to their understanding. Each of these three highly rated applications was used in a different course.

Student ratings of the degree to which an application contributed to their understanding correlated very highly with their rating of its overall value (.77). Their rating of the degree to which an application contributed to their understanding was also correlated highly with their rating of its positive impact on student participation (.57).

Figure 2 provides student ratings of the level of difficulty of the applications in which they participated on a scale of 1-Too Easy, 3-About Right, 5- Too Hard.

Figure 2: Student Ratings of the Difficulty of the Applications
(1=Too Easy, 3=About Right, 5=Too Hard)



Their mean rating across applications was 3.0 (about right). Their ratings of individual applications ranged from a little easy rating of 2.4 for Wiggle Writer to hard rating of 4.1 for 2-D Airfoil Lift & Drag. There were no significant correlations between students' ratings of the difficulty of an application and their ratings of its value, its contribution to their knowledge, or its contribution to classroom participation.

Student Learning

> The applications made it real for them to learn the stuff and see [that] they can do cool, interesting creative things with them. It's not just about doing problem set after problem set and exam after exam. If they really want to learn, if it's interesting, the mind learns it better, they're receptive. Part of it is just getting their enthusiasm up and showing them what they can do.
> (Materials Engineering Professor)

Grades

One of the indicators of student learning is, of course grades. In three of the four courses there were no differences in final course grades of the students in the courses with the applications and students in the same courses taught without the applications (80 for students in the applications course vs. 81 for students in the non-applications course). In these three courses, Freshman Experiences in Mechanical Engineering, Introduction to Mechanical Design, and Mechanics of Solids, the applications used covered only a part of the course.

In the fourth course, Materials Engineering, the whole course was designed around the three applications used, Balloons, Gliders, and Rockets. Students in the applications-based Materials Engineering course had significantly higher final course grades than did comparison students in a

Materials Engineering course taught by the same instructor without applications (81 for students in the applications course vs. 72 for students in the non-applications course, $t=2.39$, $p=.029$).

Perceptions of Learning

In the Mechanics of Solids course evaluation, students were asked to rate their learning experience for a variety of fundamental concepts taught in the course. These included three areas directly related to the applications used in the course:

1. Definitions of stress, strain, mechanical properties, centroid of composite areas, and area moment of inertia
2. Systems of forces and moments
3. Determining stresses related to axial loading and bending

Students in the applications course were significantly more apt to rate their learning of these concepts as great or significant than were students in the same course taught by the same instructor but without the applications (85% students in the applications course vs. 70% students in the non applications course, Chi Square=4.08; $p<.05$). There were no significant differences between student ratings of their learning experience related to concepts not covered by the applications (67% students in the applications course vs. 62% students in the non applications course).

Applications related to Learning

Across courses, almost two thirds (63%) of the students listed activities that increased their knowledge, including the applications Engine Disassembly, Bottle Crusher, Mock Trial, 2 D Airfoil Lift and Drag, and Sausages. Others wrote about the value of labs, real life examples, and practical applications. Only 10% (9) of students felt that there were topics in their courses that did not contribute to their mastery of the content. In this context, two applications were listed, the Mock Trial and the Gliders, although one student listing Gliders felt that "the final iteration of the glider project was a bit redundant—didn't really teach new concepts. The first two iterations were really interesting, though."

Course Quality

In the Freshman Experience in Mechanical Engineering course, students were asked to rate the course in different dimensions on a scale of 1-Excellent to 5-Poor. Students in the course with the applications rated the overall quality of the course significantly better than did students in the same course taught by the same instructor without the applications (1.8 students in the applications course vs. 2.1 students in the non-applications course; $t=1.54$, $p=.03$). They also rated the instructor's teaching effectiveness as significantly higher (1.6 students in the applications course vs. 1.9 students in the non-applications course; $t=.4$, $p=.05$).

Student Interest

> I'm not sure they learn the material better in terms of how to solve academic problems, but it reinforces the concepts and makes it interesting. [T]his is the most important aspect

of this, a student who might be passive (dreaming, not interested), they pay more attention, more active learning.
(Freshman Experience in Mechanical Engineering professor)

Applications appeared to have an impact on student interest as well. Eighty-four percent of the students listed activities that increased their interest in ME. While most students listed general activities like product design and labs, also listed were the applications Gliders/Planes (7), Engine Dissection (6), Balloons (4), Tennis Ball Launcher (3), Rockets (3), Bottle Crusher (1), Mock Trial (1), and Wiggle Writer (1).

Student enthusiasm, engagement, and interest were the reasons faculty gave for continuing to do nine of the applications:

Balloons
Basketball Goal
Bottle Closures
Gliders
iPods
Rockets
Skateboards
Tennis Ball Throwers
Wiggle Writer

This increased interest is key because student ratings of their interest in the ME courses were very highly correlated (.7) with ratings of their learning. Their learning was also significantly correlated with their class participation (.5). Their ratings of their learning and of their interest were not correlated to their rating of course difficulty.

Course Changes

Faculty plan to use 13 of the 17 applications again, but were unsure about using the other four. Three of the four—Stapler Design Competition, I-Beam Stress Analysis, and 2-D Airfoil Life & Drag —were the applications with the lowest student rating. For each of these four applications, the biggest faculty concern about using them again was the time they took. There is perhaps a correlation to be drawn from these two independent observations, i.e. that applications which, due to their compactness, can be dovetailed into the delivery of the course with causing a minimal disturbance are also ones that hold the students' attention and provide maximum benefit in terms of learning outcomes.

In two of the courses—Introduction to Mechanical Design and Materials Engineering—there were changes in the delivery and assessment based on application use. Among the changes to the Introduction to Mechanical Design were:

- an addition of a homework assignment to submit an easy product invention to Staples™
- a reduction in the amount of credit given to projects (from 60% to 30%)
- an increase in credit given to student participation (from 0% to 10%)
- using an application, Bottle Crusher, as the first project

The Materials Engineering course changes included:

- an increase in credit for projects (from 10% to 20%)
- a decrease in credit for labs (from 20% to 15%)
- the addition of three design projects – Balloon, Rocket, and Gliders
- the addition of a design log and a portfolio

Three of the four instructors spoke of the changes using the applications had on their teaching:

> Any time you do something different, experiential teaching, it reveals various aspects about one's teaching. And the other thing is by getting involved with these real life applications, it reveals things about the teaching and learning styles, so it helps in that way, helps one adjust the strategy and technique used for learning. And it also reveals, maybe something that would be difficult to identify clearly, where students have misconceptions.

> [Using the applications] changed my teaching because I had to be more responsive to students being incredibly creative.

> [Using the applications meant I] talked more about how to manage projects, not just numbers.

Conclusions

Student ratings of their learning in the ME courses were highly correlated with their interest and their participation but were not related to course difficulty. Students who felt they learned more were also more interested in the course and felt that they, and others, participated more in the course. This same relationship occurred with the applications. For students, interest and learning are very tightly tied together and both are tied to participation. Other data collected about student learning and interest appear to support this. Real life applications can increase student interest and participation.

These real life applications, idealized for simple analysis, allow students to engage, explore, and explain by employing familiar materials; for example, using the cooking of sausages to better understand the Mohr's circle of stress and using skateboards to illustrate bending moments and shear stress. Applying real world applications to the teaching of fundamental ME concepts can make a difference.

References

1. Shuman, L.J., Delaney, C., Wolfe, H., Scalise A. & Besterfield-Sacre, M. (1999). Engineering attrition: student Characteristics and Educational Initiatives. A paper presented to the 1997 Annual Meeting of ASEE. http://www.engr.pitt.edu/~ec2000/grant_papers/Shuman+ASEE-99.PDF accessed January 2, 2007.
2. Anderson-Rowland, M.R. (1997). Understanding freshman engineering student retention through a survey. A paper presented to the 1997 Annual Meeting of ASEE Session 3553 http://www.foundationcoalition.org/publications/journalpapers/asee97/3553.pdf accessed January 2, 2007
3. Dean, A., Anthony, B. & Vahala, L. Addressing Student Retention In Engineering And Engineering Technology Through The Use Of A Multidisciplinary Freshman Course. A paper presented to the 2007 Annual Meeting of the

American Society of Engineering Education. 2007.
http://www.icee.usm.edu/ICEE/conferences/asee2007/papers/2218_ADDRESSING_STUDENT_RETENTION_IN_ENGINEER.pdf
4. Engineering Workforce Commission (2008). http://www2.aaes.org/ewc/members/directory.cfm accessed January 2, 2008.
5. Shuman, et al. 1999 op cit
6. Margolis, J., & Fisher, A. (2002). *Unlocking the Clubhouse: Women in Computing*. Cambridge, MA: MIT Press.
7. Fromm, E. (2003). The changing engineering educational paradigm. *Journal of Engineering Education*, 92(2).
8. Rosser, S.V. (2004). Gender issues in teaching science . In S. Rose. and B. Brown (Eds.) Report on the 2003 Workshop on Gender Issues in the Sciences (pp. 28-37). Retrieved December 29, 2006 from www.colby.edu/~bbrown/2003Workshop.html
9. Chipman, S., Marshall, S., & Scott, P. (Winter, 1991). Content effects on word problem performance: A possible source of test bias? *American Educational Research Journal*, 28(4), 897-915.
10.Linn, M. & Hyde J. (1989). Gender, mathematics, and science. *Educational Researcher*, 18(8), 17-19, 22-27.
11. Atkin, J. M. & Karplus, R. Discovery or invention? *Science Teacher* 29(5): 45, 1962.