AC 2007-1827: “MAKING STATICS DYNAMIC!” COMBINING LECTURE AND LABORATORY INTO AN INTERDISCIPLINARY, PROBLEM-BASED, ACTIVE LEARNING ENVIRONMENT.

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“Making Statics Dynamic!” - Combining Lecture and Laboratory into an Interdisciplinary, Problem-based, Active Learning Environment.

Abstract

The new U.A. Whitaker School of Engineering at Florida Gulf Coast University has been launched as a truly multidisciplinary engineering education endeavor with simultaneous development of three B.S. degree programs in bioengineering, environmental engineering and civil engineering. This interdisciplinary engineering curriculum includes eight common courses, one each semester, that all engineering majors will take. The third course in the sequence is a combined, four credit course of statics and dynamics, named Engineering Mechanics, taught in a combined lecture-lab format. This unique format provides five contact hours weekly, 2½ hours twice a week, for a total of 70 contact hours a semester. The extended meeting periods lend themselves particularly well to the lecture-lab format. There is time during each meeting period to allow students to “discover” engineering concepts in small groups using simple, and often, inexpensive physical models and measurement equipment. During each 2½ hour class at least one small group, hands-on activity is conducted. These activities include aspects of active and cooperative learning for learning problem solving techniques, with instruction and guidance from the instructor during the learning process. These activities are inexpensive and can be incorporated into a classroom of any size. Since this course is one of the eight interdisciplinary courses in the curriculum, efforts have been made to reduce the often heavy emphasis of civil and mechanical engineering in both the textbook and the typical class. Of the four authors, two are bioengineers who will be joining the faculty over the next year and co-teach this course. They have provided advice, assistance and sample problems focused in the biomedical area. These problems have been incorporated into class exercises, homework and exams. Student exam scores will be compared to similar exams from students in past years to assess whether this method improves student learning. Students will take a mini Fundamentals of Engineering (FE) Exam in statics to assess their ability to solve statics problems. A future collaboration is planned with another university to have their students take the same exam so a comparison of the two teaching methods can be made. This paper and presentation will focus on providing examples of many of the in-class activities created and tested during the first offering of this course in the fall of 2006. Lists of needed equipment and supplies will be provided. Students showed a tremendous amount of enthusiasm and excitement for the hands-on activities. They commented on how it was so much easier to see and understand the problems.

I. Introduction

A famous Native American Proverb “Tell me and I'll forget. Show me and I may not remember. Involve me and I'll understand” sums up the philosophy behind the instructional methodology described in this paper. Students often have difficulty “seeing” the problem when everything in the classroom is two dimensional, be it the textbook, chalkboard or projection screen. Actual three dimensional, real world, physical models that the students interact with during class actually involve students to improve their understanding. One can find numerous publications discussing the merits of classroom demonstrations. Richard Felder states that “They really only learn by thinking and doing, not watching and listening.” The instructional methodology
developed for this course incorporates the physical model demonstration and places it in the hands of the learner as an in-class group activity designed for students to model real problems, take physical measurements, and think about the differences between theoretical verses measured results. From studies on how people learn, students have as much as 90% retention when the student “hears, sees, talks, and does”\(^8\). Beyond the intent to increase student learning and improve retention, the small group activities helps students improve their leadership and communication skills.

II. The Transformation

Over the past 13 years the first author has taught Engineering Mechanics, commonly referred to as statics, once and sometimes twice a year. The class has always been taught with high energy in a highly interactive style with many physical models used for demonstration purposes. This method of teaching has been taught to many engineering educators over the past 12 years by the highly successful ASCE ExCEEd Teaching Workshops (ETW) and its predecessor, T4E (Teaching Teachers to Teach Engineering).\(^2\,^3\) Over the years students have had high praise for this method of instruction. Students, on teaching evaluations, have often said “Best class I have taken at this university”, “learned more in this class than any other” and “the energy and interaction help me learn.” The current challenge was to incorporate similar interactive activities into interdisciplinary, group activities for each class meeting, a goal of the school for the engineering classroom. Each lesson and its objectives were carefully examined to develop appropriate and meaningful exercises for the students.

Because of the integrated lecture-lab format of the classroom, commercially available equipment was reviewed for the hands-on activities. Existing statics classes and aides were also reviewed for current approaches used in the classroom. One source with future potential is “Hands On Mechanics”, a website sponsored by McGraw-Hill. “Its vision is one-stop shopping for educators to learn about and build physical models that will enhance the quality of the learning in their classrooms.”\(^9\) A careful search of the vendors at ASEE Exposition also revealed a number of possible tools that might be useful in teaching Statics. The most versatile turned out to be the Introductory Mechanics System by PASCO Scientific of Roseville, CA. The kit is shown in Figure 1. The system offered 15 pre-designed experiments but its variety of components provided opportunities for numerous other experiments. This kit was, by far, the most expensive purchase costing approximately $700 each. Since the plan was to have equipment for each student group, with groups consisting of 3 to 4 students, the cost of initially outfitting the course can be large. An additional list of equipment purchased for the course can be found in Table 1.
Table 1. Equipment needed per group.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Description</th>
<th>Cost (ea)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring Scales</td>
<td>6</td>
<td>2 Kg capacity</td>
<td>$5</td>
</tr>
<tr>
<td>Scissors</td>
<td>1</td>
<td></td>
<td>$3</td>
</tr>
<tr>
<td>Ruler</td>
<td>1</td>
<td>18” US and metric</td>
<td>$3</td>
</tr>
<tr>
<td>Protractor</td>
<td>1</td>
<td></td>
<td>$2</td>
</tr>
<tr>
<td>½ Wooden Yardstick</td>
<td>1</td>
<td>Holes drilled every 4 inches</td>
<td>$1</td>
</tr>
<tr>
<td>Kitchen Scale</td>
<td>2</td>
<td>Digital Kitchen Scale 10-15 lb capacity</td>
<td>$30</td>
</tr>
<tr>
<td>Wooden Blocks</td>
<td>varies</td>
<td>Children’s toy blocks</td>
<td>$25</td>
</tr>
<tr>
<td>Pliers</td>
<td>1</td>
<td></td>
<td>$4</td>
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</tbody>
</table>

III. The Execution

Since the class period was scheduled for two hours and 45 minutes with a 15 minute break, it was important to not let the students remain inactive for long periods of time. A typical class might go as follows: 5 minutes of review from previous class, 15 minutes of new material, 20
minutes of group exercise (hands-on or problem solving at the boards), 15 minutes new material, a 15 minute break, 20 minutes group exercise (hands-on or problem solving at the boards), 15 minutes of new material, 20 minutes group exercise (hands-on or problem solving at the boards), and 10 minutes to review the day’s class and preview next class.

During the problem solving/hands-on sessions the students may be asked to create their own physical model of a problem from their textbook. Using this model, they determine the forces acting on the body using available measuring devices. Next, the problem is solved using standard problem solving techniques. Finally, they are asked to compare the calculated results to the ones physically measured. Sometimes the results are very different. This then opens the door for discussions concerning engineering assumptions, modeling and so forth.

In the final version of the course for the fall of 2006, 18 different group exercises were developed. Each one will be described below. Groups usually consisted of 2 or 3 students.

1. Concurrent verses Nonconcurrent Force Systems

Attach three spring scales to metal plate from the Introductory Mechanics System as shown in Figure 2. Pull on springs and obtain static equilibrium. Sketch the line of action of each spring scale. Do they all intersect at a single point? Apply four spring scales and repeat. With three spring scales attached, have one student grip plate to prevent from rotating. Change line of action of one spring scale and have student release grip on plate. Describe what happened.

Figure 2. Concurrent verses Nonconcurrent Force Systems.
2. Measuring x and y Components of a Vector 1

Cut 3 strips of paper, each 6” x ½”. Draw x and y axis on a piece of paper. Lay one strip of paper on axis oriented 30 CCW from positive x axis. Lay other two pieces of paper on x and y axis. Draw horizontal and vertical lines from end of first strip. Measure the x and y components with a ruler. Calculate x and y components and compare results.

3. Measuring x and y Components of a Vector 2

Using three spring scales, create a problem for determining the x and y components of a force vector. Measure and record angles and forces from spring scales. Write a problem statement, including a drawing. Solve problem for homework and compare results to measured quantities. See Figure 3.

4. Determining the Resultant of Two Force Vectors

Using three spring scales, create a problem for determining the resultant force given to force vectors. Measure and record angles and forces from spring scales. Write a problem statement, including a drawing. Solve problem for homework and compare results to measured quantities.
5. Measuring x, y and z Components of a 3D Vector

Use a corner of a cardboard box to set up a 3D space. With this 3D space and 4 spring scales, measure the x, y and z components of a force. See Figure 4. Verify mathematically.

![Figure 4. Measuring x, y and z Components of a 3D Vector.](image)

6. Determine the Moment about a Point Due to Several Forces

Using the Introductory Mechanics System, set up a system that applies three forces to the balance beam. Calculate the moment about the beam balance point due to each force. Do they sum to zero? See Figure 5.
7. Equilibrium of a Concurrent Force System 1

Model a concurrent force system problem from textbook. Problem has four forces, two of which are unknown. Measure the unknown forces. Compare to mathematical results.

8. Equilibrium of a Concurrent Force System 2

Model a concurrent force system problem from textbook. This problem has three forces; one force has an unknown magnitude and unknown direction. Measure the unknown force’s magnitude and direction. Compare to mathematical results.

9. Model a Human Forearm to Determine Tension in Bicep

Using 18” wooden rule and 2 spring scales, model a human forearm and measure the tension in the bicep due to 5 lbs being held by the hand. Compare to mathematical results. See Figure 6.
10. Determine the Centroid of a Composite Shape

Trace composite shape on cardboard. Cut out shape. Punch holes at various points in the shape. Hang the shape from a point with a string. Draw the string’s line of action across the shape. Repeat several times. All lines intersect at a point, the centroid. Compare to mathematical results.

11. Distributed Load Resolved into an Equivalent Point Load

Using 2 kitchen scales and wooden ruler as a beam, apply a distributed load to beam using wooden blocks. Read from scale the support reactions. Stack same blocks on beam where centroid of distributed occurred. Read from scale the support reactions. Compare. Repeat with various types of distributed loads. See Figure 7.

12. Design and Construct a Truss Bridge

Given a specified amount of balsa wood and paper clips, a given span and given support points, design and construct a truss bridge. Bridge tested to failure in competition with other student groups. The design and construction was an out of class activity, the testing to failure was conducted in class. See Figure 8.
13. Pulley System

Using the Introductory Mechanics System create a pulley system problem. Measure the forces using the spring scales. Compare to mathematical results.

14. Machines

Create a problem with a pair of pliers. Using four spring scales measure the force exerted on the handles and the resulting force applied by the teeth. Compare to mathematical results.

15. Axial Internal Forces

Using wooden ruler and six spring scales, create a problem to measure the internal forces in an axially loaded member. Compare to mathematical results.

16. Cables Systems

Using the Introductory Mechanics System create a cable system with two point loads on the cable. Measure the angles and forces at the supports. Compare to mathematical results. See Figure 9.
17. Coefficient of Static Friction

Using the Introductory Mechanics System, determine the coefficient of static friction between a wooden block and metal ramp and a Teflon coated block and a metal ramp. Vary the weight of the block and measure the force necessary to move block. See Figure 10.
18. Friction

Model the problem shown in Figure 11. Determine additional information you would need to solve this problem and what assumptions you would have to make.

Besides these 18 hands-on, thinking exercises, group problem solving exercises were also common. Formerly the class was taught in a way that the instructor solved most of the in-class problems on the board receiving input from students as to how to go about solving the problem.
Many of these problems were now solved by groups of students working together at the boards and coming up with a solution. This made all the students active participants in the problem solving process. This also allowed the instructor to observe which students were “getting it” and those who weren’t. A comment from a student really brought it all together. “Doing these problems for the first time on the boards with other students and the instructor available for help is much better than trying to solve them for the first time all alone in my room”. One disadvantage to this method was that when the problem was solved the students did not have the solution in their notes because all the work was completed on the boards. Time was allowed for students to copy solutions into their notes or for longer complex solutions, the instructor made a solution available electronically.

The concepts of statics and dynamics are the fundamentals of biomechanics, but concepts are taught using the mechanics of the human body. Concepts of statics are applied to evaluating forces acting on the skeletal system as a whole or as individual joints. Application of dynamics in biomechanics can be seen in the athlete in motion. The principles are the same but applications are different, and depending on the engineering department of origin, mechanics is taught from the prospective of that program or professor. Since this course is required for civil, environmental and bioengineers and taught by faculty in all disciplines, examples were included to integrate problems from a biomechanics prospective into a course taught primarily for civil engineers. Examples of such problems include:

1. Tendons acting on the patella, representing force vectors
2. Lifting weights to show moments acting about a joint.
3. Calculating the center of mass of the student.

Overall, the variety of problems challenges the students to think outside of the box, beyond their individual discipline of engineering and apply learned skills to solve many different types of engineering problems. Future courses will incorporate additional homework problems and classroom activities as the bioengineering faculty arrive on campus and actively teach the course with their colleagues in civil engineering.

**IV. Assessment**

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<table>
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<tbody>
<tr>
<td>1.</td>
<td>Calculate the resultant force due to a system of forces.</td>
</tr>
<tr>
<td>2.</td>
<td>Calculate external reactions for rigid bodies in 2D and 3D equilibrium.</td>
</tr>
<tr>
<td>3.</td>
<td>Draw Free Body Diagrams for rigid bodies in 2D and 3D equilibrium.</td>
</tr>
<tr>
<td>4.</td>
<td>Determine the centroid of composite bodies.</td>
</tr>
<tr>
<td>5.</td>
<td>Calculate member forces in a truss.</td>
</tr>
<tr>
<td>6.</td>
<td>Calculate internal pin reactions in a frame.</td>
</tr>
<tr>
<td>7.</td>
<td>Calculate internal forces in multi-force members.</td>
</tr>
<tr>
<td>8.</td>
<td>Calculate internal cable forces for discrete load systems.</td>
</tr>
<tr>
<td>9.</td>
<td>Calculate internal cable forces for uniformly distributed (roadway) loading systems.</td>
</tr>
<tr>
<td>10.</td>
<td>Solve static dry friction problems.</td>
</tr>
</tbody>
</table>

**Table 2. Course Objectives.**

At the end of the course, students were surveyed on how well they thought they had achieved the course objectives (Table 2). The same survey was given to students who took the course from the same instructor in prior years (at a different institution) with the benefit of the hands-on group
activities. Results of those surveys are in Graph 1. In most cases the students taking the course with hands-on group activities rated their ability to accomplish the objectives slightly higher than previous classes.

Graph 1. Student Self Assessment of Course Objectives.

The students were surveyed about what they thought about the group activities to assist in augmenting future instruction of this course. The following questions were asked:

1. How have small group activities helped you understand new concepts introduced in class?
   **Student responses:**
   “A lot, they help me see that the things we measure actually happen”
   “It helps to work through the problems instead of just being shown how to do them”
   “They helped me learn the concepts better but sometimes other people confused me”
   “Get everyone putting in ideas”
   “They have helped me visualize how the concepts work in real life”
   “They provide a physical model for concepts”

2. Give one specific example of something you learned from the group that you probably would not have learned working alone.
   **Student responses:**
   “The hands-on activities help me to understand the concepts”
   “They just see things faster than I would see on my own”
   “How forces act on a point by pulling on the springs”
   “During reviews, learn a lot about little things in a long problem”
   “The distribution of a load, I would have just assumed you were right otherwise”
3. Give one specific example of something the other group members learned from you that they probably would not have learned otherwise.

**Student responses:**
- “I explained zero force members to them”
- “Probably nothing”
- “Moments at points”

4. Suggest one change the group could make to improve its performance.

**Student responses:**
- “working together more”
- “it’s perfect how it is”
- “better participation”
- “pretty good as is”

These comments suggest that the group activities were beneficial to the student’s learning. Students teaching students. For the in-class exercises, the group activities were fairly unstructured and groups were changed often so students worked with all members of the class at one time or another. Out of class group activities were more structured. Students would probably benefit from more guidance on how to work in teams.

Besides the student surveys, student took a 30 question, 60 minute practice FE exam after completing all statics lessons. All 13 students took the exam. They scored a 59% overall. Their grade in the course was not dependent on how well they performed on the test. Their only motivation was the instructor’s request to take the test and to do their best. By doing their best, they would have a reasonable indicator of how they might perform on the actual FE exam. One benefit from having students take these practice FE exams is that they will be familiar with the format and style of the exam when they actually take it for real. Overall grade for these students in the course was an 89%. The instructors will continue giving this practice FE exam and compare these results to results from the actual FE exam when they take it.

V. Conclusions.

The merits of active learning and cooperative learning are touted in the literature for the improvement in student learning and gained skills. The hands-on activities developed for this course were constructed based on the learning outcomes for each module. Additional evaluation is needed to determine the effectiveness of student learning and active engagement as suggested by Michael Prince in his review of the research in active learning.  

Although time and further assessment will tell as to the success of this model of teaching, it is obvious from the immediate feedback of the students that this is a preferred methodology of teaching over the traditional separate lecture lab format. By having an integrated lecture-lab format with continuous active participation of the students, immediate reinforcement of the engineering principles provided during lecture is offered. “Students learn best when they are actively involved in the process. Researchers report that, regardless of the subject matter, students working in small groups tend to learn more of what is taught and retain it longer than
when the same content is presented in other instructional formats. Students who work in collaborative groups also appear more satisfied with their classes.”

Bibliography