

A Novel Approach for Teaching Statics

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Abstract

The Engineering School at Virginia Commonwealth University is brand new. We embody a "seamless" philosophy to enhance interdisciplinary teaching and research. In addition to the traditional emphasis upon the physical and the engineering sciences, we stress business, interdisciplinary training, communication skills, and interpersonal skills, in every required engineering course. Engineering Concepts (EGR 102), taken by all engineering students during the second semester of their freshman year is an example of such a course.

While studying statics, the students are exposed to the use of computer software, communication skills, teamwork, business, and computer programing. These topics are therefore made relevant to engineering. In the beginning of the course the students complete four open-ended laboratory assignments, which illustrate vector addition, 2-D equilibrium, friction and moments. The students develop a spreadsheet module as part of each laboratory experience. The students will complete a design project, where they will analyze a structure and explore design alternatives. At the end of the course, they will write a Windows-based computer program to analyze an engineering structure. Business issues are explored as the students complete the design project and develop their computer program.

This paper discusses the structure of the course, the logistics required to organize the course, and evaluates the success of the "novel features". This paper discusses the first two iterations of this course.

I. INTRODUCTION

The need to reform engineering education has been apparent for the last decade. The National Science Foundation in a recent call for proposals (Action in Engineering) has identified

several needed changes. These include,

- 1) active project-based learning inside and outside of the classroom,
- 2) horizontal and vertical integration of subject matter,
- 3) introduction of mathematical and scientific concepts in the context of engineering, and
- 4) the broad use of information technology.

This means eliminating the traditional mode of instruction, where lectures are typically combined with a series of assignments and examinations which require little more than rote memorization or repetition.

The National Science Foundation states that we as educators need to recognize that the students are not being served well by our method of instruction¹. Much of this dissatisfaction and disinterest in engineering occurs during the first two years of an engineer's education when they are exposed to the scientific concepts they will apply during their careers. These courses are typically taught in the traditional manner. Ninety percent of engineering majors who switched to a non-engineering major, and seventy five percent who persevered, described the quality of teaching as poor overall. Seniors about to graduate in engineering made it clear their experience in these introductory courses had given them a shaky foundation for higher level work. Two causes of this are a lack of student-teacher dialogue and ineffective use of instructional technology¹.

Consider point number two above, Bloom, a noted educational specialist, identified a hierarchy of six educational levels, each higher level being more rewarding². The typical course experience as described earlier focuses on the lower learning levels and are not appropriate for college students. We feel that college

students should perform at the fourth level, Analysis (breaking down a problem into parts and solving it), and by the time they graduate at the fifth level, Synthesis (tying together distinct concepts).

Educators also must be aware that non-technical skills are an integral part of an engineer's education. Employers have identified the following characteristics as required of successful engineers, strong technical capability, persuasion and communication skills in a variety of media, the ability to lead or work as a team member, and a thorough understanding of the non-technical issues that affect engineering decisions. John Kucharzki - CEO of EG&G, when speaking to the American Society for Engineering Education raised these issues in his 1997 plenary address. He indicated that he as a CEO and potential employer, wants engineers to have the non-technical skills listed above, but does not want technical competence to be sacrificed. This requirement from industry is important to consider in light of recent demands to reduce the number of courses required of engineering students. Thus, requiring additional courses outside of engineering is not an option.

Our goal was to create an introductory statics course, that required the students to perform at a learning level appropriate for college students, and that met the needs identified by NSF and employers as discussed earlier.

II. THE COURSE

To meet these challenges we designed a course with the following "novel" features.

- 1) Assignments which required analysis and explanation.
- 2) A series of open ended laboratory assignments.
- 3) A series of computer assignments to complement the laboratory investigations and allow the students to master the programs in an Office Suite in discrete steps.
- 4) A design project, where the students had to prepare a technical report, and a poster.
- 5) A computer project requiring the students to develop a Windows program that integrates

engineering analysis and simple business decisions.

The course as taught during the spring 1998 semester, incorporated a five-week business component (to be reduced to two-weeks), which will serve as a pilot for a full semester engineering business course, to be introduced in the Fall 1998 semester. Our plans for the future evolution of the course will be explained at the end of the paper.

The schedule of topics was as follows.

Phase 1 Fundamentals (5 weeks) - explores the basic relationships required in statics; vector manipulation, 2-D force equilibrium, 3-D force equilibrium, and moments. Five self-directed laboratory assignments were used to illustrate these concepts. To complete these assignments the students had to use computer drawing tools, word processors, and spreadsheets.

Phase 2 Applications (5 weeks) - requires the students to build on the fundamentals as they explore the in depth analysis of many common structures. This is done in two stages, 1) support reactions, and 2) internal reactions (trusses and structures). The students are required to complete a design project which requires the preliminary analysis of a structure, alternative design, and the development of a spreadsheet module to analyze this system. This is presented in visual and written form.

Phase 3 Computer Programming / Business - requires the students to write a user friendly Windows based program to analyze a static structure. This program will also allow the user to make business decisions. In addition to programming fundamentals, the students are introduced to elements of micro economics, net present value, fixed and variable costs, and supply and demand. Their program will allow them to make a "bid" which satisfies their client and company.

A. Assignments

We felt it was inappropriate to assign a large number of "one-step" drill problems. This is not

representative of tasks which the students will encounter in the real world. A recent review article based on twenty-five years of studies³, concludes that merely presenting drill problems in class and requiring the students to do large numbers of them for homework is not effective. Every assigned homework problem and every test question was a multi-step problem. This required the students to work at the "Analysis" level.

We selected the homework problems from the most challenging problems within each chapter of the text⁴. These were collected and corrected. The students were encouraged to attempt other problems in the texts as part of study and review. During the summer, the students completed these easier problems as in-class team exercises. It was hoped that as the homework problems became more complicated students would make use of the software available in the laboratory. However, the problems as written often only required a single answer and software utilities were not required. During the summer a series of analysis exercises were developed. The timely and successful completion of these exercises required the use of a computer.

To make the homework assignments a worthwhile learning experience we did not emphasize getting the correct answer, with a minimum number of calculations. We tried to get the students to learn and master a method of solution. This was, 1) drawing an accurate free body diagram, 2) writing the force/moment balance equations in correct form, 3) using the force and moment balance to determine a system of linear equations describing the system, and 4) solving this system of equations. The grading reinforced this, students earned 2/3 of their credit for method. Linear algebra was introduced (Cramer's Rule, Gaussian Elimination, and Inverses) to show the students how to solve simultaneous linear equations.

Recognizing that freshmen might have difficulty solving multi-step problems without guidance, a series of hints was available on-line. These hints a) told the students how to attack a multi-step problem, and b) asked prompting questions for each step. Such had

been done previously⁵.

B. Laboratory Assignments

The laboratory assignments served three purposes; 1) to physically demonstrate the concepts introduced in class, 2) to teach the students how to use a personal computer Office Suite by requiring increasingly complicated documents, and 3) to teach the students how to prepare a technical report. To complete these laboratories the students were given little more than an apparatus and a hypothesis. The students had to set up a spreadsheet to compare their experimental findings with their hypothesis. The spreadsheet tables, appropriate equations, and drawings had to be incorporated into a single document.

Many of the students have never been challenged in this manner, and a set of laboratory guidelines was made available on-line.

There were five laboratory activities, an introductory exercise and four experiments.

Lab 0 - Introduction to Lab: The students were given hypothetical data where the distance of a block of wood undergoing constant acceleration was measured as a function of time. They were to determine the force applied to the block and compare it with a "reported" result. This lab illustrated technical graphing (to determine acceleration), multi-step problem solving, and challenged them to account for "supposedly" bad data.

Lab 1 - Vector Addition: The students were given a block of wood which slid on a track as shown in Figure 1, thus its motion was constrained to one direction. There were two cables attached to front of the block which could be oriented at various angles. Using these cables and three scales the students were to demonstrate vector addition.

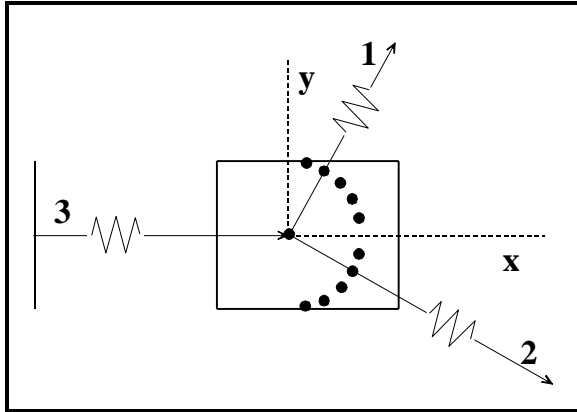


Figure 1: Diagram of Experimental Apparatus for Vector Addition Laboratory.

Lab 2 - 2-D Force Equilibrium: A mass was supported with two cables as shown in Figure 2, and the students were to predict the tension in each cable.

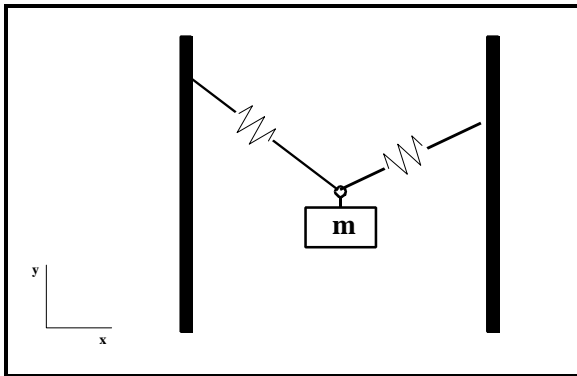


Figure 2: Experimental Apparatus for 2-D Equilibrium Experiment.

Lab 3 - 3-D Equilibrium: The students were given an upright pole held into place by three cables. They were to adjust the tension of the cables until the pole was vertical and check their results.

Lab 4 - Moments: A very unstable structure as shown in Figure 3, was built. This structure consisted of an upright column (1.5 in)², 4 ft. high which had either two or three moment arms (4 ft. long) The students would hang weights on the arms, and determine if the moments balanced mathematically when the structure did not tip over.

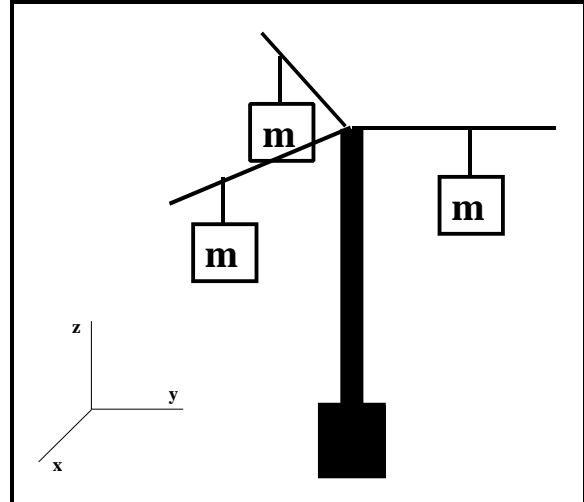
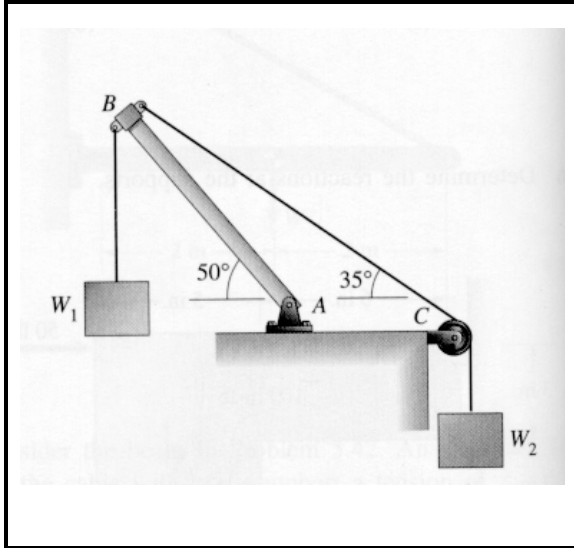


Figure 3: Laboratory Apparatus for Moment Laboratory.

C. Design Project

During the second part of the course the students completed a design project. One of the eight possible projects is shown in Figure 4. The students must conduct a preliminary analysis of the structure where they determine the support reactions and internal loads. They then must evaluate at least five design changes and make a recommendation. The project is presented as a poster and a 3-5 pg. technical paper. In their paper the students were required to explain their analysis. They were told that saying “the program predicted”, or “the equations say” is not acceptable.

In the third portion of the course the students wrote a Windows Program to analyze this structure, construct a parts list, prepare a bid, and determine the profit to their “employer” if the bid is accepted. This multiform module was presented as a paper and an oral presentation.



Project 3 (Based on Problem 5.54⁴): The crane as shown is required to lift loads by a distance of 5'. This is done by changing the angle at A. As shown the crane is being used to support a load of 1000 lbs. Can the design be changed to allow for loads of 5000 lbs to be supported? Consider the change necessary in W_2 to increase the height of the mass. You may also change the distances shown on the diagram.

III. DISCUSSION

A. Assignments

For the more challenging assignments to be a successful learning experience for the student, some sort of dialog must take place both as the students are doing the assignment and after it is submitted. The internet tips, organized on a problem-by-problem basis, help for the former. While faculty-student dialog is always preferable, students are not always working on homework while we are in our office. An assessment scheme was developed that encourages the student to submit the homework. Each problem was graded on a three point scale, up to two points were awarded for method, and one point for the correct numerical answer. Frequently this meant awarding a student little or no credit for a hastily prepared assignment, even if each answer was correct. At the beginning of the course, the homework grades were low, but they quickly improved. After in-class problems

were introduced the instructors addressed this in class, by saying "I can't follow your work" as students requested help with hastily prepared solutions. This can only be successful if the teaching assistants who were assigned to the course are appropriately trained and supervised.

It was also necessary to create a well prepared set of solutions based on those provided by the author. For solutions to be useful they must illustrate the correct way to set up the problem, and include an explanation as to why what was done was done. Many textbooks (and solution guides), take time honored "short-cuts" when solving problems. This may involve not including vector components in force/moment equations, doing a free-body diagram by inspection, and not including units in the steps of a calculation. Photocopying the solutions provided to the instructor, and making them available to the student, is not sufficient⁶.

While requiring the students to solve more in-depth problems requires more work on the part of the teaching staff, the discussions in class have shown that the students are learning from them. Perhaps as many as ten percent of the students show continued resistance to this approach. Complaints include, "I got the right answer - that's important", and "Give us easier problems to get us started". Our responses are, "Catching a fish feed's you for a day, learning to fish feeds you for a lifetime", and "You need to take responsibility for your own learning".

B. Laboratory

Each of the experimental apparatus were constructed quickly using hand tools and stock lumber. An orientation exercise is necessary if the students are to use the Office package in the lab. By reading the lab reports, one could quickly see if the student grasped the fundamental concept being illustrated. The students had to understand the direction and sign of a vector to get meaningful results in Labs 1 and 2. To complete Lab 4 they had to correctly add three cross-products. These laboratory experiments provided a visual demonstration for students, who have a hard time visualizing vectors. As the term

progressed, students were observed questioning their data and calibrating the scales, without instruction. The writing and computer proficiency of the students improved as a result of these exercises.

Many students found the labs enjoyable, and “less mickey-mouse” than those in other courses.

C. Design Project

The design project excited the students. Many stayed until 5PM the day before break to work on the project, which was due three weeks later.

It was noted that the instructors must spend time in class explaining how to a) create a poster, b) prepare a technical report, and c) prepare an oral presentation. The reports were excellent, and the students were able to explain their results as we had hoped.

D. Student Response and Performance

We placed five questions from a sample Fundamentals of Engineering Examination on the final examination. Seventy percent of the students answered three or more questions correctly.

The grade distribution on many exams is bimodal, approximately two thirds of the class perform well, and one-third poorly. The “studio” approach seems to have increased the number who perform well, but the results are not conclusive.

Many students state the course is too fast paced, requires too much work, or is atypical. However, virtually every student admits to learning a lot.

E. Future Plans

The course will be taught in a computer classroom in the Spring of 1999. During the summer a set of notes are being prepared to ensure uniformity among the various sections. This is necessary as few instructors have taken a course which includes such a wide variety of

topics.

IV. REFERENCES

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