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Teaching Mechanics to Freshmen by Linking the Lecture Course to a Design Course

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Abstract

Stevens Institute of Technology recently revised the Engineering Curriculum to include an expanded design course sequence, having a design course each semester to form a *Design Spine*. The Design Spine allows development of many of the "soft skills" demanded of engineering graduates, as embodied in ABET EC Criteria 2000, by evolving them over the four years of the design sequence. Examples include effective team skills, project management, communications, ethics, economics of engineering, etc. It is also a means to enhance learning, as each of the design courses is linked to engineering courses taught concurrently. Students see this strong linkage for the first time in the second semester of the freshman year when they take Mechanics of Solids concurrently with Engineering Design II. Mechanics of Solids is a four-credit lecture/recitation course that integrates the topics of statics and strength of materials courses that were taught separately in the previous curriculum. In the two-credit Engineering Design II course, students undertake a series of four experiments and two design projects to reinforce concepts from the mechanics of solids lecture course through hands-on experience. The main objectives of this approach include integration of design and other engineering practice skills (according to ABET EC Criteria 2000) into engineering mechanics and improved teaching of engineering mechanics to freshmen. The main components included in this integrated teaching approach and a preliminary assessment of its effectiveness so far are presented.

I. Introduction

Under the guidance of the ABET engineering criteria 2000, recent trends in engineering education have led to increased integration of design and other important engineering practice skills (e.g. multidisciplinary teamwork, project management, communications, ethics, economics of engineering, etc.) into the engineering curriculum. To integrate design and other components into the mechanics courses, various methods have been used by several institutions ranging from simple modifications (such as including one or more design projects) to a complete restructuring of the engineering mechanics courses. The approach adopted at the University of Washington[1] combines a variety of both new and old techniques, which include design projects, group work, basic competency exams, computer-assisted tools, hands-on experiences and student presentations. At the University of Missouri Rolla[2], the design content is integrated into the sophomore and junior level mechanics courses through practical group design projects. In the new curriculum being developed at the University of Maryland[3], the integration of statics and mechanics of materials is centered around a single design project which is enhanced with demonstration experiments and computer tools.

Recently, Stevens Institute of Technology revised the Engineering Curriculum to include an expanded design course sequence, having a design course each semester to form a *Design Spine*[4,5]. The Design Spine allows development of many of the "soft skills" demanded of engineering graduates, as embodied in ABET EC Criteria 2000, by evolving them over the four years of the design sequence. It is also a means to enhance learning, as each of the design courses is linked to engineering courses taught concurrently. Students see this strong linkage for the first time in the second semester of the freshman year when they take Mechanics of Solids concurrently with Engineering Design II. Mechanics of Solids is a 4-credit lecture/recitation course that replaced separate Statics and Strength of Materials courses from the previous curriculum. In the two-credit Engineering Design II course, students undertake a series of four experiments and two design projects to reinforce concepts from the Mechanics of Solids lecture course.

II. Objectives

In the new curriculum at Stevens, the integration of statics and mechanics of materials into a single lecture course supported by a design laboratory is implemented with emphasis on the following objectives:

1. Integration of design and engineering practice into engineering mechanics
2. Providing a smooth transition from the introduction to engineering design course offered during the first semester[5]
3. Integration of statics and strength of materials as a more effective way of teaching engineering mechanics
4. Providing 'hands on' experience as a more effective learning tool
5. Teaching of other 'soft skills' based on ABET 2000 criteria
6. Stimulating student interest in the subject of engineering mechanics
7. Improving the retention rate for the engineering freshmen.

The main aspects of the approach needed to achieve these objectives are described in the following sections.

III. Integration of Statics and Strength of Materials

In the traditional engineering curriculum, the subjects of statics and mechanics of materials were taught in separate courses. While statics is related to mechanics of rigid bodies and strength of materials deals with mechanics of deformable bodies, both subjects are concerned primarily with bodies in equilibrium. Although teaching of these subjects in a sequential manner may provide an easier way of delivering the material especially for freshmen as they are exposed to engineering for the first time, teaching the related topics in statics and strength of materials separately is not as effective in reinforcing the students' understanding of the relationship between these topics and their role in the overall design of engineering structures.

In the new curriculum at Stevens, Mechanics of Solids is a four-credit core course[1] that is offered during the second semester along with the Design II laboratory course. The Mechanics of Solids course consists of a seamless integration of the traditional statics and strength of materials courses into a more effective course for teaching engineering mechanics in the new curriculum. It includes two 75-min lecture sessions and one recitation session per week. A set of *class problems and case studies* has been developed to discuss the major fundamental topics during the lectures. A cooperative learning approach[6] is used as much as possible especially during the recitation sessions, which involve a much smaller number of students. Design principles are highlighted as much as possible in the discussion of class problems and other case studies.

For more effective teaching of the fundamental topics and to reduce the potential risk of overwhelming the freshmen with too much material, the main emphasis throughout the course is placed on a set of selected core topics. These basic topics include free body diagrams and rigid body equilibrium in statics and the concepts of stress, strain, and deformation in mechanics of materials. These topics are integrated and discussed throughout the course through various applications of engineering mechanics. The fundamental concepts of stress and strain are introduced early in the course. These concepts are applied repeatedly within the topics traditionally included in the statics course and which are related to rigid body equilibrium and its applications to engineering structures including trusses, frames, and machines. This repeated emphasis on core topics leads to improved student learning and facilitates the transition between the various topics included in statics and strength of materials and the existing raltionships between these topics. Computer-aided tools and virtual demonstration experiments are being used to facilitate and enhance the students' physical understanding of the basic mechanics principles.

A set of basic topics was identified to develop performance and assessment criteria for the course. These topics include:

- two-dimensional equilibrium of rigid bodies with emphasis on free body diagrams as a fundamental modeling tool in engineering structures,
- analysis of engineering structures including trusses, frames and machines,
- internal forces in beams with emphasis on shear and bending moment diagrams,
- fundamental concepts of stress and strain and their role in the design of engineering structures,
- deformations in structures due to external loads including axial loads, transverse loads, bending moment and torque.

The timing related to coverage of the various topics in the Mechanics of Solids lectures is carefully designed in coordination with the Design II laboratory schedule to allow the students to have sufficient theoretical background related to the material covered in the laboratory experiments. In some cases however, new topics are introduced in the Design II laboratory before they are covered in the Mechanics of Solids lecture course. This technique was well received by the students as they had a better motivation for learning these topics once they are introduced through practical hands-on experiments. Additional topics such as friction, buckling, and stress concentration which are traditionally covered in the mechanics courses are covered

[1] By Stevens' convention for credits in laboratory courses; a two-credit course requires work to be done on a regular basis outside of the three hours per week of the scheduled laboratory periods.

entirely in the design II laboratory through a set of four simplified experiments as discussed in more detail in the next section.

IV. Integration of Mechanics of Solids Course with the Design II Laboratory

The Engineering Design II Laboratory is a two-credit course required of all engineering students during the spring semester of their freshman year. It builds upon the experiences and themes of the Engineering Design I course that was taken in the first semester of the freshman year[5]. The objectives of the course are:

1. to improve the understanding of the engineering design process
2. to increase recognition and importance of communication skills
3. to work more effectively in team situations
4. to increase self esteem and confidence in technical endeavors
5. to enhance resourcefulness in project development
6. to encourage more effective allocation of time in problem solving
7. to encourage observation of technical artifacts in the day-to-day world
8. to present design applications of computer tools
9. to learn some of the vocabulary used in engineering design
10. to provide context for and encourage learning of material in the Mechanics of Solids course that is taken concurrently with the Design II laboratory.

The instructors for the course are engineering professionals who have had substantial design experience on-the-job. Each laboratory session is staffed by one of the course instructors assisted by an undergraduate teaching assistant who provides overall logistical support to the course.

The course involves several categories of activities including:

- mini-lectures and seminars
- hands-on exercises
- demonstration experiments
- design projects
- student presentations

Each class meeting is approximately three hours in duration and, if not devoted to a single project, is typically split into three different activities of about one hour duration each. It is intended that the variety of activities will help make each class session interesting, and that successive class sessions will vary in content and style as well. In addition to the experiments and design projects, other activities that were scheduled include mini-workshops and seminars related to various aspects of engineering including management, economics, and ethics.

Most of the student activities are group-oriented, although there are a number of exercises which are submitted individually. Grading of the student performance in the course is based on the written and oral reports for the four experiments and the two design projects which are conducted as group efforts, as well as other activities including exercises, homework, and attendance.

Laboratory Experiments

The experiments illustrate the topics of Factor of Safety, Friction, Column Buckling, and Beam Bending, with and without the presence of a stress raiser. The latter experiment also exposes students to the use of strain gages. A product analysis module involves disassembly of a digital, strain-gage bathroom scale. Its operation based on bending of a steel beam, fits perfectly with the course theme. Spreadsheet software is extensively used in this course for recording and analyzing data during the experiments and the design projects.

In the first experiment, the concepts of Factor of Safety and failure and the related effects of load and material properties are introduced in terms of an uncertainty factor. One of the main reasons for the use of the Factor of Safety is demonstrated based on the variability of material properties. Examples of poor designs in the "real world" which resulted in some famous failures are presented. A simplified experiment is used to demonstrate variability of the strength of a beam due to fabrication imperfections or variation of material properties. While this is a simple experiment it is difficult to conduct it in a reasonably reproducible manner. This is a useful experience which allows the students to understand the origins of experimental error and non-reproducibility. Whereas, if the experiment was designed to be more precise, these concepts would not be so obvious and the students would tend to ignore them.

The second experiment introduces the concepts, theory and characteristics of static friction and application of particle equilibrium. It also allows further development of the concepts of experimental error and the application of basic statistical analysis. Since the topic of Friction is not be covered in the Mechanics of Solids lecture course, the basic theory of static friction is introduced before the experiment is conducted by the students. In this experiment, no specific instructions are provided to the students on how to conduct the experiment. The students are provided with a flat polished aluminum plate with guide rails (channel), one rectangular block with two surfaces made of polished aluminum and two surfaces made of plastic, a metal ruler, and a brass tube approximately 1 inch long. Using these components, the students have to design the experiment and experimental procedure necessay to determine the coefficient of static friction between various surfaces and analyze the effect of various parameters of the friction coefficient.

In the third experiment, the concepts and theory of column buckling are introduced. It allows the students to observe, measure, and analyze the buckling phenomenon. Comparison of the experimental data with theoretical computations is used to illustrate applicability and limitations of the buckling theory to real world applications. A column buckling setup is provided including operating instructions. The students are asked to measure critical loads within the elastic region that generate buckling of two different columns: a rectangular steel rod and an aluminum tube.

The objective of the fourth experiment is to study beam deflection and stress and strain distribution and concentration in a cantilever beam. Using strain measurements obtained from a uniform aluminum alloy cantilever beam with pre-installed strain gages, the flexural stress is determined and compared with theoretical predictions. On a similar beam containing a 6.4-mm diameter hole, the stress concentration factor is determined from the strain distribution near the hole.

Design Projects

In addition to the experiments described above, two design projects are included which draw upon knowledge gained in the Mechanics of Solids lecture course and build on elements of the experimental activity from the laboratory. The objective of the first project is to design, build and test to destruction a single planar truss. The truss is constructed using square brass tubing. Gussets are used to join the different members of the truss. The gussets and the truss members are attached to each other by soldering using a propane-fueled torch. The strength-to-weight ratio is used as a measure of performance of the students' truss design. Strength is determined by applying an increasing load to a joint located at the top of the center of the truss until the truss fails (i.e. undergoes permanent deformation). A sample of a truss designed by one of the groups is illustrated in Figure 1.

The second project is related to the design of a wooden hoist to meet load, deflection, minimum weight and cost constraints. This project demands that students apply knowledge gained from the Mechanics of Solids lecture course in order to analyze candidate cross-sections that can be constructed from standard wooden members. Then they select a final configuration, construct the device and measure its deflection using an attached strain gage. These measurements are then compared to theoretical predictions. In Figure 2, student members of one of the groups are shown performing an experiment with their hoist design.

Other Topics

It has been mentioned that the design course sequence is intended to be a major vehicle for developing a number of desirable competencies, the so called "soft skills", in our graduates in alignment with the goals of ABET EC2000. Engineering Design II contributes to developing these competencies in several ways.

In the area of communications, students are expected to make oral presentations using professional presentation software, typically the Microsoft Powerpoint, that is included in the bundle installed on their personal computer (required for all freshmen). Starting with the Freshman class that entered in Fall 1999, all the students have notebook computers. Written reports are critiqued by the instructors and returned to the students for correction.

There is a case study on ethics based on the space shuttle Challenger disaster and the respective roles of Thiokol engineers and management and that of NASA personnel. This introduces the ethics thread in the design sequence and it is also used to illustrate some team dynamics issues. This case study is used later in the curriculum in a more in-depth manner. The technical issues involved in the Challenger O-ring failure also fit well with the general emphasis of the course.

A module on Project Management introduces students to issues of defining customer requirements and translating those into metrics that can be used in design. Basic concepts of House of Quality and Quality Function Deployment (QFD) are introduced. An introduction to Microsoft Project is also included to build on the project management concepts that the students learned from the first design course. In the latter, they developed Gantt charts for their design projects.

The thread on Engineering Economy is introduced in this course as well. This thread is developed throughout the design course sequence. It should be noted that students explore some preliminary ideas on costing during the first semester Freshman design course, Engineering Design I. The introductory Engineering Economy module focuses on the time value of money, interest rates and the determination of Present Value (PV) and Net Present Value (NPV). A homework assignment requires the use of spreadsheet analysis for determining NPV for a proposed commercial venture linked to the second design project, a shop hoist. The exercise asks students to examine the effect on NPV of increased development time and costs in bringing the product to market and also the consequent sensitivity of NPV to unit price as a result of potentially being able to charge more for the product because of the increased development effort. In this way students learn how design and economics issues go together, a trend which is be reinforced throughout the design sequence.

V. Assessment

So far, assessment of the effectiveness of this integration has been conducted through student and instructor feedback and from student evaluations at the end of the course. In spite of the emphasis on fundamental topics only, the diversity and amount of concepts involved in the integrated Mechanics of Solids lecture course still represents a challenge to the average freshman. There was a highly positive feedback from the students on the integration of the Design laboratory with engineering mechanics course as well as the diversified skills that were covered in the laboratory. A more comprehensive assessment based on carefully defined sets of course performance criteria and assessment performance criteria are planned. This will be conducted through a variety of means, including web-based assessment surveys of the students, as we implement within the next year the Stevens Assessment Plan to meet ABET Criteria 2000 requirements.

VI. Conclusions

Using an integrated approach, the new mechanics lecture and laboratory design courses at Stevens Institute of Technology are developed to allow the students to understand more clearly the role of mechanics in the design of engineering structures. Although the diversity of concepts involved in the integrated lecture course may present a challenge to the average freshman, repeated emphasis on fundamental concepts throughout the course leads to improved student learning, facilitates the transition between the various topics included in statics and mechanics of materials, and it illustrates the existing relationships between these various topics. Furthermore, other important topics as defined by the ABET 2000 criteria have been implemented in the associated design laboratory course to enhance the engineering practice skills early on in the students' academic career.

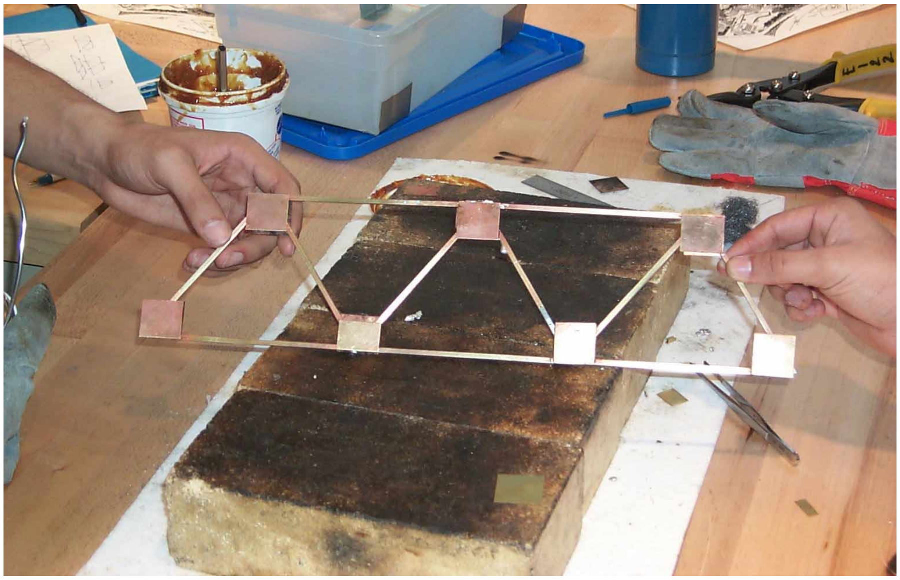

Figure 1. Student design of a planar brass truss

Figure 2. Student design of a wooden hoist

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