Session 2793

You can't do a thing if you can't build the swing: Modeling and Reality in Mechanics of Materials

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Abstract

This paper presents the results from the integration of lab experiences and classroom materials in a junior level Mechanics of Materials class at the University of Memphis. Previously, the class content and laboratory content were disjointed and offered no sense of continuity between topics and potential applications. This produced students who might have passed both the class and laboratory successfully but who had no real sense of where the learning integrated into their overall engineering experience. In an effort to address these concerns, faculty from the Mechanical Engineering and Civil Engineering Departments at The University of Memphis worked together to design and propose a more reality-based curriculum within the existing course parameters. With the introduction of a limited-scale design project, information developed in the lab was critical to the completion of the design project that applied engineering content to real-time application. Supplementary and supporting information is provided along with project results to make these ideas easily adaptable to any engineering design course.

Introduction: Curricular Problems

As any reputable engineer knows, understanding the problem is critical to proposing successful solutions. The problems in this case were complex and longstanding. Primarily, there was a problem of redundancy. Before the fall semester of 2002, both the Mechanical Engineering and the Civil Engineering departments at the University of Memphis presented separate Mechanics of Materials classes to juniors in their respective departments. Students from each department were allowed to register for either class to satisfy departmental graduation requirements. Material covered by both departments had a significant overlap but with emphasis on problems more typical to each discipline. Each department had a laboratory course loosely linked to their class. It was not unusual for students to take the lecture portion of the classes in one semester and the lab portion at a later time.

A secondary problem involved the disconnections between the laboratory experiences and the course content. The laboratory experiences in each department were usually very simple demonstrations illustrating stress and strain relationships and the failure of materials under different loading conditions. Efforts were made to make the lab experiences more meaningful through the utilization of statistical analysis of the results and through detailed lab reports, but deliverables were limited to analytical, data-driven reports.

With only one hour of credit given for the lab, students did not understand the need for the extra work that was being required. Lab reports were usually sterile documents reflecting what the students believed that the instructor wanted rather than a vehicle for a learning experience for the students.

Traditionally, Mechanics of Materials was heavily weighted towards engineering science (analysis) with few open-ended or design problems introduced. The number of topics covered in the class left little room for the extended development usually required for design problems. During the fifteen-week semester, a total of eleven topics were to be presented. Admittedly, a number of these topics were extensions of work done in Statics, but they still required a number of lecture and evaluation periods to develop the concepts.

Student Performance Problems

A review of end-of-semester faculty evaluations and individual student interviews revealed that student attitudes were negatively affected by these administrative and curricular disconnects. Evidence that students weren't learning or retaining enough course information through application-based-outcomes was obtained by a pre-semester survey. The students entering the Fall 2002 Mechanics and Materials class self-assessed their preparedness for the class and were also tested during their first week of class as to their cross-over knowledge from Statics, the prerequisite class for Mechanics of Materials. Findings included:

- 61% of the students believed that they were well prepared based on their Statics background;
- 94% of the students believed that their mathematics background had prepared then well for the class;
- Yet only 12% of the students were able to correctly solve eight of more of the Statics problems given in the Statics Evaluation Instrument the first week of the class.

The testing instrument is included as Appendix 1. Student performance on the specific types of problems from the Statics Evaluation Instrument is presented in Figure 1.

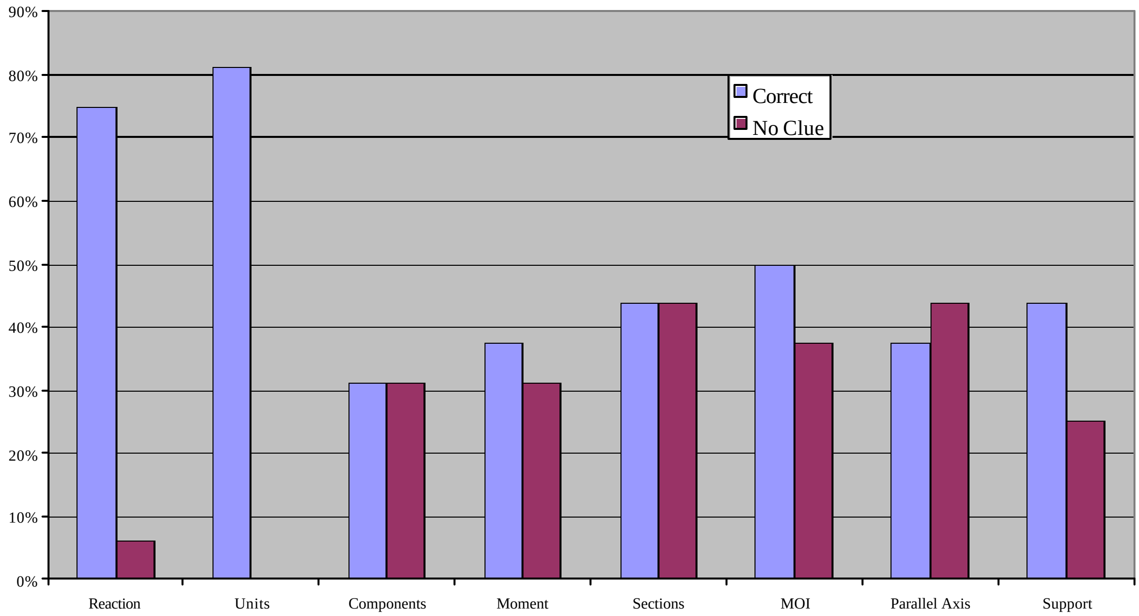

Figure 1: Results from Statics Evaluation Instrument

During class discussion regarding the results from the Statics Evaluation Instrument, the most commonly expressed opinion was that Statics didn't connect enough with the "real" world. The students perceived that the class was more like a physics or mathematics class than an engineering class. Further discussion with the students revealed that the introductory sequences in Mechanical and Civil engineering were more focused on open-ended projects while Statics was so heavily weighted to analysis (engineering science) that it was not as connected to "real engineering" as their previous experience had been. These results came as a significant shock to our faculty.

Solving the Problems: Curricular Solutions

In an effort to solve these problems and promote student interest and motivation for Mechanics and Materials, faculty from both the Mechanical Engineering Department and the Civil Engineering Department collaborated to design an innovative design-based approach which was piloted in the Fall semester of 2002.

The first problem of redundancy was relatively simple to solve. A decision was made to alternate the classroom sections of Mechanics of Materials between the Mechanical and Civil Engineering departments. In the fall semester of each academic year, the Civil Engineering faculty would teach the course and in the spring semester, the Mechanical Engineering faculty would teach the course. Each department would maintain their own lab sections, but the topics taught in the classroom sections would be brought into closer topical agreement. A close review of the labs were undertaken to determine if the laboratory classes could also be combined but there was less agreement on this so each department will continue presenting their own lab sections.

Redesign of the Laboratory Experience

Following this review, the problem of laboratory/course material disconnects was examined, and the Civil Engineering faculty made the decision to include a design assignment as the terminal assignment in the lecture class. This decision was made after a careful review of relevant literature regarding current successful practices in teaching design. A common yet important reason for including actual design experience in the laboratory/class sequence requires a design-based assignment that will allow students to begin to link theory with action. In doing so, it is strongly suggested that these assignments offer students the following three opportunities:

- To learn design skills in incremental steps from beginning to end;
- To allow time for observation of each step of design;
- To allow time for reflection of each step

One innovative approach to integrating design experience into course content involves the use of "reverse-engineering" projects, as described by Wood, Jensen, Bezdek and Otto[1]. This approach has been used successfully at The University of Texas, MIT, and The United States Air Force Academy, and it is unique because it looks at design from an alternate point of view: deconstruction. Why is this important? Because, according to Hodge and Steel[2], a student's ability to design is a crucial part of his/her engineering education. So crucial, in fact, that it the authors describe it as "design, above all else, defines the difference between an engineering education and a scientific education".

Using the concept of reverse engineering as a pedagogical approach provides students with a chance to learn design from careful study of a product. Instead of facing the sometimes insurmountable task of creating something from a plethora of theories and concepts, students can take a product apart, study the components, reassemble the product, and in doing so, learn each step incrementally as developed in both Otto[3] and Ingle[4]. Again according to Woods, et al[1], instructors familiar with this system state that using reverse engineering "eases the transition from the analytical courses students have taken previously to the open-ended nature of the design courses they are currently taking".

With these pedagogical ideas in mind, we elected to proceed with a combination of reverse-engineering design examples as a background for a student-based design assignment.

Curricular Re-Design to Integrate Design with Content

The scope of the design would be limited by the work that the students had done previously in this class alone, and therefore, it would be limited to the selection of the material and the form of the material to achieve the design goal. In addition, if possible, the laboratory was to be utilized in support of the design. This would create a tighter linkage between the course work and the lab work. In addition, the Civil Engineering students had a background in this type of design from design projects presented in the Civil Engineering Foundation sequence.

The design problem presented in the pilot semester is presented in the following example. Students were asked to work in groups of three to design and propose a wooden playground swing set. Examples from commercial vendors were presented and discussions were held in class to select the critical elements in the swing designs.

A simple set of constraints was developed and a simplified loading and support system was created with the following specifications:

- Materials for the design were to be available from local hardware suppliers and design costs were to be developed from actual materials costs.
- Material properties were to be generated from the lab class as a client of the lecture class. Samples of the materials for the swing were to be provided by the lecture class and tested by the lab class.

An example of the design criteria is included in the Appendix 2.

With the idea of more closely connecting the lab class and the lecture class, it was proposed that the lab class act as the testing laboratory for materials selected by the lecture class for their design project. In order to reinforce the communication skills, all communications between the lab class and the lecture class were to be formal memoranda. No students were common to both the lecture and lab classes in the Fall 2002 semester. The lecture class was tasked with making a formal client request to the lab class for testing of the materials. The lab class in return, was to locate ASTM standards for testing the materials, perform the testing, and return the results of the testing back to the lecture class for utilization in the design.

Early, it had been proposed that the utilization of problems supplied in the text with a more design-oriented approach would solve the problem of connectivity of the class to actual engineering design work. After a review of the problems, it was decided to use a limited number of these to illustrate techniques, but the "real" world connection was still lacking. Students were still working on paper exercises without a feel for the impact that their results would have on an overall design. It was then proposed that the students undertake a design and build project for the class.

If the lecture and labs had been connected, this would have most likely been the avenue that would have been followed. However, with the lab class completely disconnected from the lecture class, it was not possible to have a build experience available to the lecture class within the parameters of the time available or the available equipment. Since we are an urban university with a high population of working students, available time for non-credit lab experiences is not readily available. This disconnection eliminated the design and build project for the lecture. Yet the common example available through the deconstruction provided some assistance in developing a design project with reasonable expectations.

The next alternative considered was to utilize the lab as an agency for the lecture design project. The lab section would test materials that were to be utilized in the design. This alternative would allow an expansion of the connection of the lab topics to lecture materials as well as a opportunity to perform physical analysis of materials which were going to be incorporated into a design. This is the alternative that was selected for implementation in the fall semester of 2002.

Fall 2002 Example Design Project Parameters

The design project was limited by the materials locally available and by the relative inexperience of the students. Students would be asked to generate alternatives, perform analysis, and then select designs based on cost and safety factors. Since all the analysis tools were to be generated by the students, no commercial packages were to be used; the problem was limited in scope and was presented with a number of simplifying assumptions. After a number of possible problems were considered, it was decided that the design of a playground swing set would be appropriate.

The playground swing set selected was to support four swings hung from a center member by chains. Supports for the center member were to be A-frame supports with one leg of the A-frame modeled as a fixed-end support and the other leg as a roller support. The connection between the center member and the A-frame was to be modeled as a free pin and the crosspiece of the A-frame and the support members were also connected with free-pins. The number of A-frames used for the design was up to the students. Students were allowed to select the spacing between the swings based on their review of actual playground equipment and manufacturers catalogs. All hardware and materials for the design had to be available at local hardware outlets.

Design constraints were the maximum deflection of the center member at any point and a factor of safety for the design. After discussion with the students, a load that could be expected on each swing was provided to the students.

The students were to purchase hardware pieces and lumber segments that they proposed be used in their designs. All materials were to be purchased by the groups out of their own funds. The expectation is that the materials cost for testing will not exceed $25. It has noted that this may present a financial hardship on some students and that funds be provided for the project. While this may be the case in rare instances, it is typical in the department to have students purchase materials from their own funds within limits. The lecture/design students would then make formal requests to the lab section for testing of the mechanical properties of these materials. This is where the problems developed in the fall class.

Results

The lecture students were presented with the design problem with six-weeks remaining in the semester. While they had not yet been presented with bending analysis of beams, they were to choose materials that they thought might be usable in this type of design. They were also limited in their design to wood for the member of the swing set. Since the available material at local hardware outlets is limited, it was expected that the geometric design of the center member would be the critical part of the design.

At the same time that the lecture students were presented with the design problem, the lab students were tasked to begin developing a set of procedures for materials testing based on ASTM standards. In particular, they were tasked to locate and prepare a testing methodology for testing wood. When these procedures had been collected, a trial run was to be made in preparation for the sample submitted by the lecture class.

When the procedures had been collected, it was discovered that two pieces of testing equipment had been broken during a remodeling of the labs during the preceding summer. The equipment was unable to be repaired with the short time frame left in the semester so alternative methods of testing were tried to no avail.

Without the critical connection between the lab and the lecture, the instructor required the students to locate materials information on their own. No testing of the materials was done so the design exercise reverted to a paper exercise.

Even with this failure to have a "real" world experience, the students responded favorably to the addition of the design project and many regretted the missing component. All of the students were able to locate material properties for the wood used in the project but only 60% were able to locate properties for the metal connectors used to support the swings and to connect the frame pieces. Most generalized to material properties without considering the form of the connector under consideration.

Student Performance Solutions

At the completion of the class, the students were again surveyed about the class and asked to evaluate their performance with the following results:

78% of the students felt that they have an adequate knowledge of the fundamentals of Mechanics of Materials that would allow then to utilize that knowledge in the future work in Civil and Mechanical Engineering. This compared to 82% of the students who achieved a final grade of C or higher in the class.

Compared to the 61% who felt that Statics had adequately prepared them at the entry to the class, when given the same question at the end of the semester, only 46% felt that their Statics preparation was adequate.

73% of the students felt that their math preparation was adequate compared to 94% at the beginning of the semester

56% of the students responded that the design project increased their understanding of Mechanics of Materials

24% of the students expressed a desire to have more design problems included in the class, no student expressed a desire to have the design problem eliminated

85% of the students expressed a desire to have a closer link between the lab class and the lecture class

Future Plans

While the utilization of the swing design is considered as a marginal success at best, the response of the students in both the lecture and lab class was such that the experiment will be attempted again during the Fall 2003 semester. With a longer planning horizon, hopefully the mechanical difficulties will no longer be a problem. The lessons learned from the utilization of the reverse engineering will be more fully developed and extended to other design problems. The selection of a design problem will be more limited in scope and will have segments as each topic is considered in the class. The use of readily available materials was a positive and is actually a continuation of work done in the Civil Engineering foundation sequence.

In addition, based on student responses, the structure of the lecture portion of the class is currently under review. Is has been proposed by the authors, but not yet adopted, that two one hour lecture sessions and one three hour recitation session replace the current three one hour lecture sessions. Also based on those students exit reviews, Mechanics of Materials support is being added to the engineering tutoring services on an as needed basis.

Biblography

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Biographical Information

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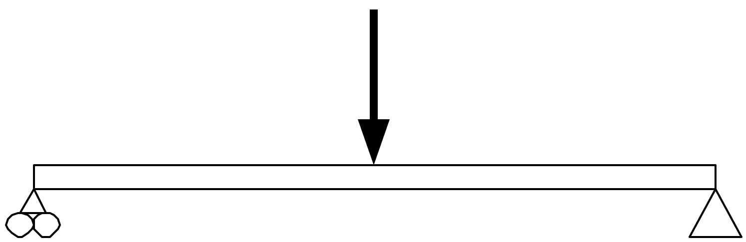
Appendix 1

STATICS EVALUATION

For all the following problems, assume that the system is in equilibrium and will continue to stay in equilibrium.

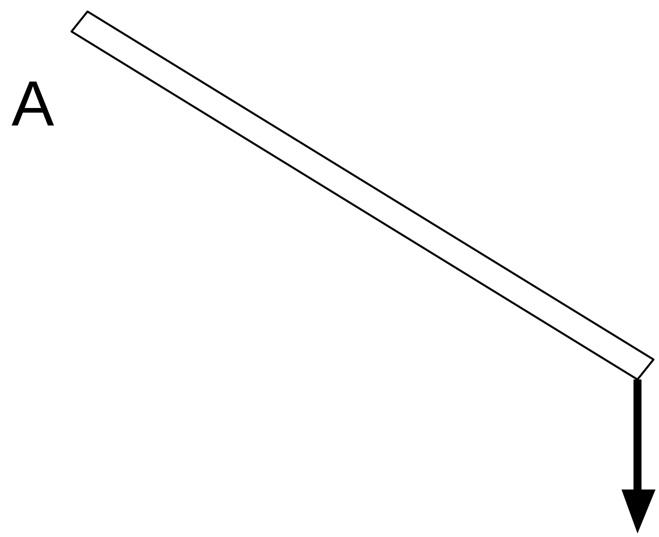
1. For the figure shown below, if the force being applied at the middle of the beam is moved closer to the left end of the beam, you would expect the reaction at the left end of the beam to



   a. Increase
   b. Decrease
   c. Remain the same
   d. Not a clue

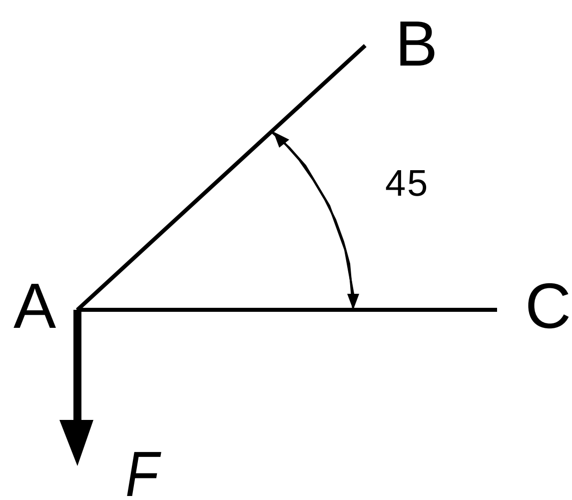
2. All of the following are units of force except
   a. Newtons
   b. Kilograms
   c. Pounds
   d. Not a clue

3. In the figure shown below, the support at point A would have to be



a. A free pin
b. A roller
c. A fixed-end support
d. Not a clue

4. In the support shown below, the magnitude of the force carried by member AB is



a. Greater than the magnitude of F
b. Less than the magnitude of F
c. Equal to the magnitude of F
d. Not a clue

5. If a two-dimensional force has a magnitude of 25 force units and one component of that force is 20 force units, what is the magnitude of the other component of the original force along an axis perpendicular to the axis of the 20 force unit component?
    a. 45 force units
    b. 10 force units
    c. 15 force units
    d. Not a clue
6. The force F generates a moment M about a point P. A moment arm from P to the line of action of the force is given as R. The magnitude of the moment M can be calculated by
    a. F/R
    b. R*F
    c. R*F*sin(angle between the moment arm and the force)
    d. Not a clue
7. The method of sections depends on
    a. All the forces at a connection adding up to 0
    b. All the moments at a connection adding up to 0
    c. All the members of the truss being in compression
    d. Not a clue
8. The minimum moment of inertia of any shape is
    a. About the base of the shape
    b. About one edge of the shape
    c. About the centroid of the shape
    d. Not a clue
9. The parallel axis theorem allows us to calculate the moment of inertia of a shape about any axis using
    a. $I = \hat{I} - Ad^2$
    b. $\hat{I} = I + Ad^2$
    c. $I = \hat{I} + Ad^2$
    d. Not a clue
10. A fixed end support provides
    a. A reactive force and a reactive moment
    b. A reactive force
    c. A reactive moment
    d. Not a clue

Appendix 2
Design Criteria

Your firm has been chosen to do the preliminary design and material selection for a children's playground swing set. The main structural members of the swing set are to be made of wood, the type and quality of which will be a part of your design process. The swing set will be traditional A-frame ends with the swings hung from a top piece. All analysis should be based on static loading and should not consider any dynamic situations. An end view of the swing set is shown in Figure 1.

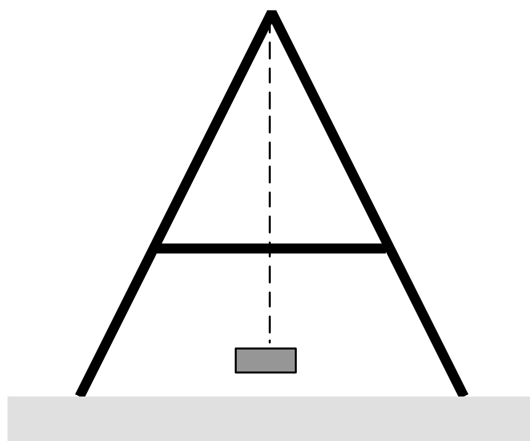


Figure 1. End View of Swing Set

The currently identified constraints are:

1. Four swings must be able to be attached to the swing set.
2. Two chains from the top member of the swing set support each swing.
3. Hooks that pass through the top member and are bolted with a washer and nut are used to connect the chains.
4. One ground support at each end of the swing set may be considered as a fixed end support while the other support at each end may be modeled as a roller.
5. All connections other than the support connections with the ground may be modeled as pins.
6. All connections other than the chain connections may be considered as lag bolts with washer and nut connections.
7. The design load on each swing is 300 pounds.
8. The safety factor is 2.5 for the design.
9. The maximum deflection in the top beam should be no more than 0.5 inches at the worst-case condition.

You should select three alternative designs for this project and perform an analysis based on Mechanics of Materials for each design. Spacing of swings, height of swing set, and spacing of ground supports should be typical. Connectors and all other materials should be specified in each alternative analysis. Material costs should be obtained from local hardware vendors and should be included in your report. You should select on design as your selected alternative and support the selection with your analysis. Be sure to include diagrams of all your alternatives as well as a detailed analysis of how you make your analysis.