"Bridging the gap": A Strategy for Implementing Projects in First-year Engineering Courses

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Abstract

First-year engineering courses play an important role in promoting understanding among students about the practice of engineering, the roles of science and mathematics in engineering, and important engineering processes such as design and modeling. Although the Dwight Look College of Engineering at Texas A&M University had made important strides in its first-year engineering courses: introducing teams and team training, clustering engineering with mathematics and/or physics courses, and creating more active/cooperative learning environments in the engineering classrooms, there were opportunities for significant improvements. For example, students needed to see tighter integration between engineering, science, and mathematics. Students needed to understand more clearly the roles of models and analytical performance predictions in the engineering design process. To address these opportunities, a prototype of a new first-year engineering course that builds on prior curriculum initiatives is being offered in the 2004-05 academic year. The prototype is project-based in that two projects form the core of the syllabus. Further, specifications were developed to aid in tailoring projects to meet the goals of the class. These specifications include defining time constraints for students and faculty; acknowledging the range of abilities of the incoming students; satisfying the needs of downstream faculty members, course instructors, and TAs; and supporting the integration of mathematics and science. To illustrate the developed specifications, one prototype project involving construction of a truss utilizing Supermag® magnetic sticks will be presented. Since the kits contained standardized components, trusses could be assembled easily and their performance did not depend on quality of fabrication. Therefore, the engineering design process was highlighted. Students were able to make predictions of the maximum load that the truss could support within 10% of the measured performance. This paper will present specifications for suitable projects, a description of the truss project, details on the implementation, and results from the project.

Need

Engineering and science faculty members are restructuring the first-year engineering curricula to improve both retention of first-year engineering students and their performance with respect to learning engineering, science, and mathematics [1,2]. Many of the efforts are guided by student perceptions as well as faculty comments regarding projects and connectivity of concepts. Distillation of the comments identified seven issues that, if addressed, would increase student interest in the course, and hopefully, motivate them to stay in engineering. The seven issues are related to two key areas, projects and relationships between engineering and mathematics and science classes.

Issues related to projects are:

1). Students and faculty members perceive projects currently being used in first-year engineering courses as "build and see" where students proceed through trial and error with little connectivity with the sciences or mathematics [3,4]. Some programs have provided simulation tools to enable students to predict the performance of their design proposal [5,6].
2). Engineering faculty members thought that success of a project relied more on the fabrication skill as opposed to application of the engineering design process or knowledge of mathematics and science.
3). Projects did not reflect the societal roles that engineering plays.
4). Projects did not reflect a true engineering process.

Issues related to engineering and sciences are:

1). Science is perceived as discovery oriented with little use for prediction.
2). Students see mathematics and science as concept-oriented and not task oriented. Thus the ability of the students to apply concepts to specific task is not strengthened [7-9].
3). Freshmen engineering is boring since there is little in terms of active participation in building systems.

Student perceptions were distilled from comments solicited from students about their first-year engineering courses. Faculty perceptions were distilled from comments of faculty members made as the College of Engineering explored options to its current first-year engineering program.

To address these issues it was felt that two corrective measures were needed. The first was to develop projects that utilized concepts that are covered in the concurrent science and mathematics courses, better represented the engineering process, and helped exemplify engineering roles in society. Better coordination of engineering class content and activities with material in the science and mathematics classes was the second corrective measure.

The central change in the philosophy of the class was to convert the class into a ***task- or project-oriented learning environment*** [10,11] in which projects are used to motivate and guide the course content rather than being used to exemplify or supplement the subject matter. Thus, the students are introduced to a societal need and are asked to design, predict behavior, build, and

test a system that will satisfy the need. Projects then motivate topics introduced in the class, and faculty members guide students through the process of designing a system.
The paper will describe how one engineering project was developed for the renewed first-year engineering course at Texas A&M University. Another project was also developed for the course and will be described elsewhere.

Project Guidelines

Project Factors

A set of nine project factors were developed to determine whether or not a project is suitable for the course. These factors account for administrative issues as well as content issues. Administrative issues range from time line to course credit. Content issues address needs for students' skills and engineering aspects. The nine factors can be broken up into two categories, one dealing with projection selection and the other dealing with project implementation.

Project Selection:

1). The project that is chosen addresses (in a simplified fashion) a societal need that is easily recognizable and relevant to the student's major(s) [12,13].
2). Students could predict performance of a proposed design with their current level of knowledge [4,14]
3). Prediction of the behavior of the system to be built is within the scope of the course content in concurrent math and science courses.
4). The project lends itself to supporting the engineering process rather than trial and error/guess work.
5). Material presented to the students to help predict behavior of the system to be analyzed must prepare students for follow on courses in the students' chosen major(s).
6). Success does not rely on the fabrication ability of the students,
7). The project must be conducted within a suitable time period and should not require additional lab facilities,
8). Create a workload that is consistent with the credit that is assigned to the class and support the engineering graphics content of the course, and
9). Depth of training required for instructors and teaching assistants on key issues.

The first five factors can be categorized as content issues while the remaining four factors fall under administrative issues. Some factors, such as 6 and 7, are related to both content and administrative issues. As an example, factor 7 includes issues dealing with additional facilities, such as machine shops and separate laboratory classes. This point is crucial here at Texas A&M University since there are around 1,200 freshmen and it is almost impossible to provide separate laboratories for the freshmen engineering classes. Thus, all the activities must be carried out in the class itself during class times.

Engineering Process

Faculty members identified four elements of the engineering design process that they wanted students to learn:

1). Identifying need: What task is to be fulfilled?

2). Conceptual design: How might the need be fulfilled?
3). Analysis and modeling: What is involved in determining whether the conceptual design will meet the need?
4). Verifying and assessing: How can predictions from the models by confirmed through testing?

Additional Issues

Additional topics that often are not given enough attention on the selection of a project are shop training, safety, transport/storage, and disposal. Students often need significant training to gain access to departmental machine/wood shops. Safety issues range from students getting splinters and cuts to the misfiring of energy storage devices, i.e. bungee cords snapping, air tanks rupturing, and pinch points pinching. Such unsafe incidents, although they may occur infrequently, make liability issues a concern. Some projects require the students to build apparatuses that are ungainly and bulky that makes transport and storage a difficult issue. This is particularly important for the typically large freshmen classes at Texas A&M University. The last issue is disposal. Completed projects that end up in a dumpster instill a sense that there is no need to recycle materials.

Initial Project Considerations

This course was implemented as a pilot program for a class consisting of 200 students (two sections of 100 students each). The students had declared their chosen majors to be Mechanical Engineering, Civil Engineering or Aeronautical Engineering. Based on this composition it was decided to consider projects that involve force and motion transmission since these topics are directly relevant to the students' chosen disciplines. The students were divided into forty-eight teams with most of the teams consisting of four members.

Initial project ideas included a Lego® Mindstorm robot that followed a line, a mechanism similar to a wheelchair lift, and a hoisting mechanism. Analysis of these project ideas showed that students would need more knowledge of mathematics and physics than were being covered in the current classes. Each of the initial projects required knowledge of kinematics, kinetics, differentiation, and integration that the students will not have until late in the semester. Since lecture time in the first-year engineering courses is limited, engineering faculty members would be unable to provide sufficient material in the engineering lectures. As a result, students would be unable to make quantitative predictions of performance of their designs. As a result the initial project ideas did not satisfy one or more of the requirements described earlier.

Based on these considerations, it was decided that a project involving a static system (i.e., one that involved only a force transmission) would be suitable for students and within the scope of what they would learn in the first few weeks of classes in mathematics and physics.

Supermag® Truss Project

Design of a truss satisfies many of the project factors. First, most everyone has observed a truss in operation supporting a road, holding up a roof, or providing the structure support for a wing.

So the need for a truss is understood and project factor 1 is addressed [15]. The instructors could easily list societal needs that involve the use of a truss system. Students then had to design, analyze and test a truss. Connecting societal needs to tasks helps student see why engineers would need to calculate load limits. Also, students can analyze the performance of a truss using basic algebra and trigonometry without knowledge of kinematics or calculus. Force and moment equilibrium are the only physics concepts required and students would be introduced to these concepts early in the physics. So, analyzing and building a truss satisfies factors related to the required knowledge base. In addition, the graphics skills required to sketch a truss design help support the introductory graphic skills that make up a portion of the first-year engineering courses.

Types of Truss Constructions

Construction of trusses in the classroom is traditionally done by use of glued joints with wood or paper. These trusses do not conveniently lend themselves to analysis as the mode failures are many and the joints analyses are complex. Glued joints can fail under tension, shear, and moment loads making a definitive analysis of failure mode difficult. In addition, traditional glue and stick trusses can have members fail due to buckling which make predication of failure complicated and too involved for a first semester freshmen engineering course.

However, trusses that are built utilizing magnetic stick and balls (see Figure 1) do present a system that is easier to analyze. The joints in a magnetic stick truss cannot support a moment load and the sticks resist buckling loads too. The main mode of failure is due to tension, that is, the stick is pulled away from the ball.

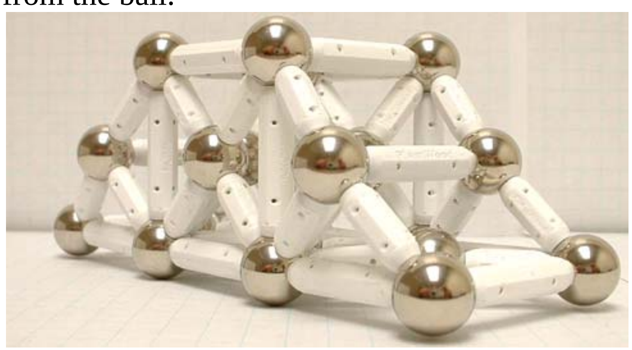

Figure 1 Supermag® Truss

Fabrication Issues

Traditional glue and stick trusses require precision and consistent cuts with careful gluing techniques. Poor assembly of a glue and stick truss again makes analysis difficult. Testing of these trusses lend themselves to a more qualitative analysis as opposed to quantitative analysis. Moreover, the students cannot try out alternative designs since the building of a wooden truss itself is very time consuming. The magnetic stick and ball truss are made from kits that contain standardized components. This removes any need for fabrication skills and also illustrates use of off the shelf components. Table 1 compares these two methods of fabrication.

The magnetic stick and ball system that was selected for this project was the Supermag® kits [16]. Figure 2 shows the three components: magnetic sticks in two lengths and one size of steel ball. The two lengths permit multiple truss designs to be generated. This kit was selected as the sticks have a small cross section and up to 22 sticks can be attached to a single ball.

Table 1 Comparison of Supermag® to Glue and Stick Trusses

	Supermag® Truss	Stick and Glue Truss
Load supported at joints	Compressive and tensile	Compressive, tensile, and moment
Fabrication: gluing	none	yes
Fabrication: Cutting	none	yes
Fabrication: immediate results	yes	no
Fabrication: Standardized components	yes	no
Ease to alter design	yes	no
Ease of testing load at joints	yes	no
Force equilibrium analysis at joint	yes	no

Since no gluing is involved students can make rapid changes to their designs and immediately observe whether the change improves performance or not. The kits that were provided to the students consisted of 36 long magnets, 54 short magnets, and 32 balls. By removing fabrication issues, difficult joint analysis, and multiple modes of failure, the truss project utilizing magnetic stick and ball components allows more time to be spent reinforcing connections between physics, mathematics, and engineering.

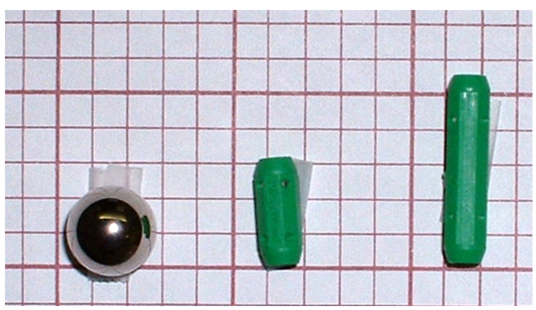

Figure 2 Supermag® Components

At this point in the development of the project factors 1 through 6 have been addressed although project factor 4 requires further explanation.

Time Issues

Project factors 7 and 8 address issues regarding the time available to cover the required material. A typical semester consists of 14 weeks with the class meeting twice a week for 110 minutes. The class has two components, one part dealing with graphics and the other dealing with engineering components or topics. With a two-credit hour class, graphics requires one hour and one hour is available for other engineering content. A project that requires extensive out-of-class time and knowledge levels above what the students learn is not fair for one credit hour. Simplifying the needs of the project and bringing the amount of work required on the project to a level of one credit creates a sense of fairness in the students. Although there are elements of the graphics that support the engineering process it should be assumed that half of the lecture time is devoted to graphics. This leaves 14 lecture periods to cover the engineering process. The lecture period consists of interactive lectures, reading assessment tests (RATS), and administrative issues. Table 2 illustrates the course breakdown and timeline for a seven-week period.

Table 2 Project and Course Timeline*

<table>
<tr><td colspan="14">7 week period
E-Engineering component G-Graphics Component</td></tr>
<tr><td colspan="2">Week 1</td><td colspan="2">Week 2</td><td colspan="2">Week 3</td><td colspan="2">Week 4</td><td colspan="2">Week 5</td><td colspan="2">Week 6</td><td colspan="2">Week 7</td></tr>
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<tr><td colspan="3">Exploratory, define need</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="8">Force and Equilibrium</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="4">Concept design</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Analysis</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">Tensile testing</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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</table>

*Note: Other topics (MATLAB, company visits, communication skills {report writing}, etc) must be included in each lecture.

Project factor 9 requires that professors, instructors, teaching assistants, and peer teachers are comfortable with material required for the project. Although it might be expected that the instructors would recognize connections between truss design and topics in the concurrent physics and calculus courses, this is not the case. In addition, if multiple sections of the class are being covered, it is imperative that time is taken to make sure that a common thread of content exists between the different sections. If the requirements and content are too different across sections students in one section will think they are unfairly treated. Projects that are overly complex can often be a challenge to professors to understand all of the nuances although they may not ask for assistance. Time must be taken to have meetings with all course instructors to promote that continuity exists across multiple sections.

Engineering Aspects

The previous discussion focused primarily on the project factors. A discussion is required that shows how the analysis of the Supermag® truss helps in satisfying the demonstration of the engineering process, project factor 4.

Identifying Need

Although part of the engineering process is establishing a need, it is important to recognize that the students are freshmen and that they do require guidance. Defining of needs comes from two primary sources, one is from daily observation by the engineer and the other is from a second party, that is, a consumer. The students were approached as if the instructors were the consumer. The teams were then looked upon as individual contractors. The need that was defined for the students was:
"Build a truss to span a gap of 4.25 in. (107.9 mm)."
Once the need was established, the next stage was to define constraints on the design. Five constraints were given:

1) Sidewalls must be parallel. Students could analyze two-dimensional trusses, but instructors thought they would have great difficulty in analyzing a three-dimensional truss.
2) Symmetric in design.
3) Must support a minimum load of 2 lbs (0.907 kg).
4) Length must be between 4.25 in. and 5.75 in. (107.9 to 146.1 mm).
5) Height must not exceed 5 in. (127.0 mm).

The constraints provided are given to establish a baseline for performance. Geometric constraints are provided to simplify modeling and testing. By requiring a symmetric design with parallel walls, the modeling for the analysis stage is greatly simplified as only two dimensional free body diagrams are required. Class discussion about the importance of these constraints is prudent because the rationale for them is often overlooked and not fully understood. Defining constraints is a vital bridge that links definition of need to development of concept.

Developing Alternative Concepts

Once specifications have been established, students require knowledge of trusses and truss analysis to develop their conceptual designs. Then, they can use the Supermag® kits to conceive and assemble many different ideas and check to see if the defined constraints are met. Once a team has decided that a conceptual design may satisfy the need they apply their graphics skills and sketch their design with enough information so that another team can construct their concept. This stresses the need for communication through drawings. Once the consumer, i.e. the instructor, has approved their concept, the students can proceed onto the analysis.

By the time engineering faculty members have presented the intent of the class, the needs of the project, the definition of the constraints, terminology of trusses, and discovery opportunities (i.e. exploration with the Supermag®), the physics course has covered the required equilibrium and force concepts. Timing of the topics presented in all three courses supports the project-based nature of the course in which topics are designed to support design and implementation of the project.

Analysis and Modeling

The analysis stage guides students through the process of developing a model and analyzing the model to determine if their proposed concept will meet the defined constraints. This stage is where the critical links between the engineering, physics, and math occur. The truss project requires that students construct a number of free-body diagrams, develop the equations of equilibrium for the overall truss and each joint, and then solve the equations to determine the load in each member. The students are told to develop a model that determines the loading of each link when a unit-load is applied to the top of the truss. Once this accomplished, the students then can recognize that they need to know the tensile load required to separate a ball from a magnetic stick.

The students used a tensile rig shown in Figure 3 to determine the load required to separate the ball and stick. This test emphasized the need for free-body diagrams and application of equilibrium of moments. Although the activity was performed in a physics lab, engineering instructors emphasized that students were performing the ball and stick test to obtain data on how something performs as opposed to typical physics experiments where students verify a theory. Faculty members wanted to stress one of the differences between engineering and science. Each team tested one stick and ball and the data for forty-two teams were compiled and made available to the students. Students could analyze the data to obtain a minimum, a mean, and a maximum value at which the stick may fail (see Table 3). Armed with this data the students were able to develop a range of loads in which their trusses could fail.

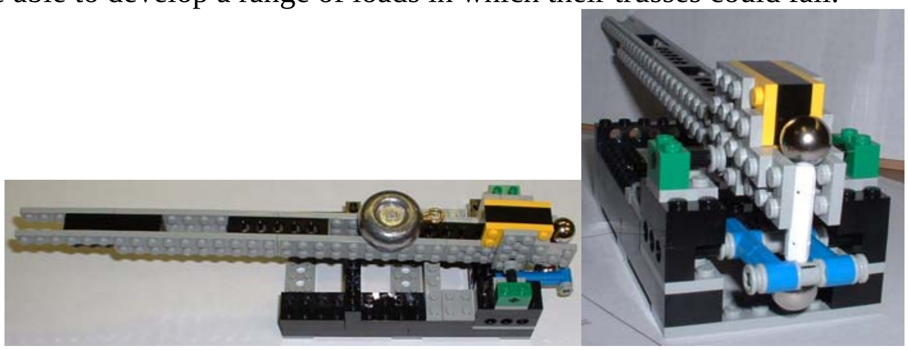

Figure 3 Tensile Load Rig for Stick and Ball Separation Capacity

Table 3 Summary of Tensile Strength Capacity Testing

	Load Lbf (N)	% Difference to Mean
Mean Failure Load	1.34 (5.96)	0
Maximum Failure Load	1.72 (7.65)	28%
Minimum Failure Load	1.04 (4.62)	22%

Verification

Truss loading rigs, shown in Figure 4, were provided to the students so that they would be able to test the response of their truss to a load. Analysis of the loading apparatus again required the students to apply free-body diagrams and equilibrium of moments. The use of Supermag® kits allowed the students to make multiple tests so that they could fully observe how the truss failed, if it consistently failed at the same joint, and if that joint matched their analysis results.

The combined results of 49 teams from two sections showed that 47% of the teams had results that fell within the range of possible failure as dictated by the tensile results shown in Table 3. These teams had percent differences that ranged from less than 1% to high as 30%. This is expected, as the teams really did not know what tensile load the ball-stick joint that did fail could support. And, most of the predications calculated by the students were based on the mean value of the tensile load that was provided to them. The remaining teams had results that were greater than 50%. These results could be explained by four reasons: a) not applying the assumed load to their truss correctly, b) truss did not meet the required dimensions and wedged in the tester, c) unit conversion (pounds vs. Newtons) errors, and d) trigonometric issues. The trusses were to be loaded on four points and their analysis was to account for this by using a *P/4*, where *P* is the applied load, on each loaded joint. However, some teams used *P/2* instead. This explained some of the results that were greater than 50%. Teams that had trusses that were too long or too short and wedged in the tester did not allow for one end of the truss (which was to be a roller support) to move and a much greater load was required to initiate failure. Some teams that did encounter this problem were able to modify their design, perform an analysis, and retest their new truss during the class time. This would not have been possible if their truss was made out of glue and wood.

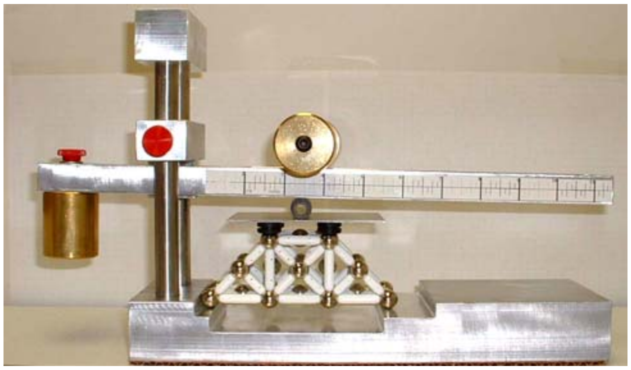

Figure 4 Truss Loading Apparatus with 2lb (8.9 N) Weight

Reporting

The students are required to submit technical reports at different stages so that when they get ready to write a final project report they have most of the material that is required. By having a project that has manageable parts the students generally will have a better feel for what they are writing about and apply the engineering, physics, and mathematics terms that were presented to them through the semester.

Conclusion

Keeping the knowledge level required to analyze a project within what the students know or are concurrently learning gives them an opportunity to see how science and mathematics are used in the engineering process. As students grow in their knowledge levels, they can start to identify what they need for analysis and pursue the required concepts. At the freshmen level, it is critical to keep the knowledge needed for analysis simple. This allows for deeper discussion on how, why, and what science and mathematics are required in engineering. In addition, the time in the class then allows for a concept to be presented to the students at least four times. Once when a concept is introduced, once when the students apply it, once when the students' results are discussed, and once when reviewing for exams. The interactive atmosphere of the freshmen engineering class at Texas A&M University requires that the students play an active role in discussing issues that they encountered when applying a particular concept.

The flexible timeline that was adapted was critical. The initial schedule planned was for a seven-week period. Monitoring feedback from instructors, teaching assistants, peer teachers, and the students, the schedule was modified so that more time could be spent on instructor-identified issues. Balancing time to spend on a project is tricky. It is possible to drag a simplistic-appearing study out too long and lose the interest of the students. On the other hand, you can have a project that is too involved and the students are overwhelmed.

The Supermag® truss project demonstrated here was done for the first time in the fall 2004 semester. During this time a number of lessons were learned that would make future implementation more streamlined. Elements that were found to need more attention were:

1) Developing greater algebra, trigonometry, and plane geometry skills to obtain equilibrium equations
2) Free-body diagrams and equilibrium of moment problems
3) Better discussion on relating analysis results with failure load results
4) Training the TA's and instructors on what issues to be monitored to insure that the students are approaching and understanding requirements correctly.

One area that was crucial in making the implementation feasible were weekly meetings held to discuss what was covered during the week, perceived students response, feedback from TA's regarding what they had graded, and what is to be covered in the upcoming week. These issues help define what material may be incorporated in the upcoming week, and what material is posted on the course web site as follow up material.

The project factors stated here and the emphasis on planning what is needed may seem to limit the open-ended solution of the engineering design. However, the key is that by selecting a suitable need with appropriate constraints, the concepts needed for analysis can be universal for all teams and multiple solutions can be obtained.

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