
AC 2011-645: TRUSS PROJECTS AS AIDS IN VISUALIZING INTERNAL FORCES: STUDENT PERCEPTIONS VERSUS ACHIEVEMENT

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Truss Projects as Aids in Visualizing Internal Forces: Student Perceptions versus Achievement

Introduction

In the 2004 - 2005 academic year, Texas A&M University was awarded a grant from the National Science Foundation entitled “STEPS: Retention Through Applied Physics, Engineering, and Mathematics”, with the purpose of increasing freshmen retention in the College of Engineering¹. Many incoming freshmen who fail to continue with their engineering studies report that difficulties with mathematics and physics are the cause for their withdrawal². In order to remediate this problem, the College of Engineering partnered with the College of Science to put in place project-based curriculum so students could more easily see the interconnectedness between engineering, mathematics, and physics². Institution of this curriculum change required a restructuring of the entire Freshmen Program.

Structure of the Freshman Program

Originally, the Freshman Engineering Program (ENGR 111 and 112) was comprised of common curricula and these classes were taken by all entering freshmen, regardless of major. In response to dissatisfaction among individual departments who desired more discipline-specific curriculum, the entire program was reorganized into three basic categories. The departments of Mechanical Engineering, Civil Engineering, Aerospace Engineering, Industrial Engineering, Engineering Technology, Nuclear Engineering, and Biological and Agricultural Engineering desired a freshman sequence focusing on mechanics and basic engineering graphics and were thus labeled the Mechanics track. Electrical and Computer Engineering and Computer Science and Engineering removed engineering graphics and desired an intensive focus on programming and were labeled the Programming track. Petroleum Engineering and Chemical Engineering focused on engineering and physical processes and graphics and were labeled the Process track. The Process track was designed to be almost identical to the freshmen sequence before reorganization. Each of these tracks, called tracks A, B, and C respectively, agreed to follow the basic guidelines of implementing a project based curriculum.

Track A had the students construct a truss from magnetic members, program a robotic vehicle, and demonstrate the power of parametric solid modeling. Track B focused on various programming tasks for their projects, normally using some type of robotic vehicle to follow a line or navigate a maze. Track C focused its projects on fluid flow. The two semester projects used are fluid flow through microtubes to estimate viscosity and pressure release of a gas through a nozzle to propel a vehicle.

Mechanics Track Project

To complete the Truss project, the students were grouped into four member teams in random fashion, taking care to not isolate women or minorities. The majority of students were true first-semester freshmen (students without any previous college level coursework). Each class averaged 76 students with 19 teams. Class periods were two hours in duration and met twice each week for 14 weeks. This project spanned approximately eight class periods during an eight-week period.

Initially, the teams were provided the Magnastix, a bag containing magnetic rods and steel spheres and were instructed to create a structure or bridge to span a 4.25 inch gap across two textbooks. No further instruction was given. The student designs were diverse as can be seen in Figure 1. Designs varied from trusses, to walkways, to fairly random arrangements.

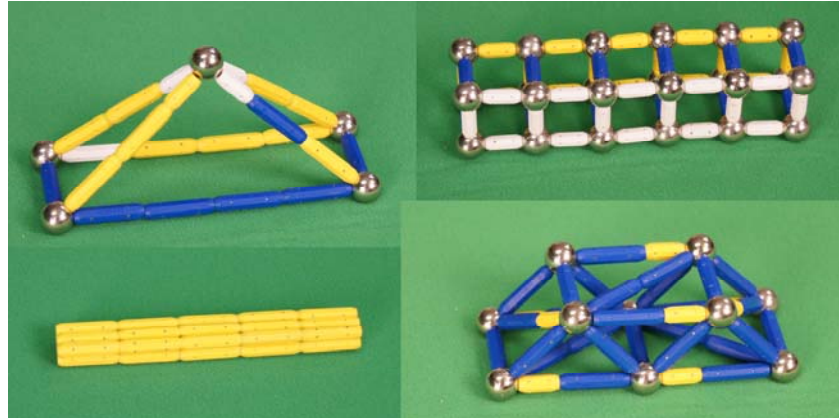


Figure 1. Examples of structures without previous instruction.

Once the teams built their original bridges, they were directed to prepare a sketch of the bridge and submit it in order to document their specific design. These sketches were collected and held until the next class period, when they were distributed, at random, to other teams who were told to recreate, without improvement, the bridge depicted by the sketch. The teams were then tasked to evaluate the sketches and designs and to make notes on the sketch to record their findings. The sketches were then returned to the original teams for their edification. A team's ability or inability to recreate a design strictly from a sketch affirmed the importance of good graphical communication skills. It also allowed the topic of constructive feedback to be discussed.

In the next stage of the project, the teams were given specific performance criteria for their bridge and were instructed on the technical definition of trusses. The project requirements stated that the teams build a statically determinate truss structure that would span at least 4.3 inches, but no more than 5.2 inches. With these requirements, the teams collaborated in order to construct their bridges. Figure 2 shows some examples of the trusses similar to those built by the students. Note that not all qualify under the given guidelines.

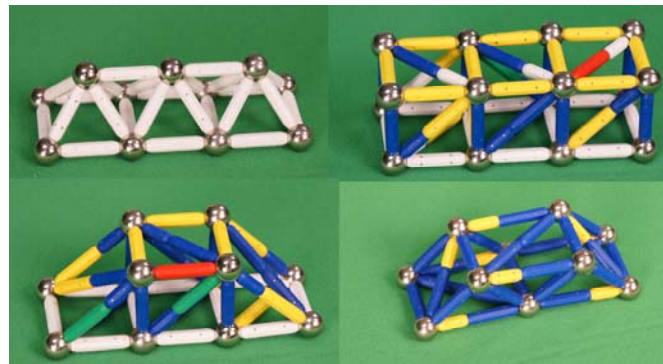


Figure 2. Examples of student trusses.

The major area left unexplored was the load-bearing capacity of each truss. In addressing this topic, the students were queried as to the method they would use to determine how much load their truss would support. Most students proposed experimental determination by loading the truss until failure. When they were posed the question, “Is that how the load capacity of a bridge across a river is determined?” many students were stuck for an answer. The students realized that there was a better alternative, but they were not yet analytically capable of determining the answer. This illustration hopefully piqued their curiosity and motivated them to learn Statics.

Statics has long been recognized as one of the foundational concepts in engineering education and a backbone for engineering design³. With the trusses designed, the students were placed in a position that they would need to understand some basic concepts of Statics to complete the project. If this project motivates the students to grasp the basic statics concepts needed to perform actual truss analysis, hopefully they should be better prepared for the following engineering mechanics courses (Statics, Mechanics of Materials, Dynamics, and Fluid Mechanics).

This motivation was the main purpose behind the mechanics track project: to motivate students to learn the mathematical and physical concepts necessary to analyze their truss. To many students, the concepts of mathematics and physics exist isolated from each other and even isolated from engineering. When they attend math class, they exist in “math world” and then in physics, they are in “physics world” and the students do not understand the interconnection between them.

To perform the analysis on the truss, students were shown the Method of Joints, where each joint (represented by the steel spheres) must be in static equilibrium. Even a cursory introduction to the Method of Joints requires vector concepts used in physics along with simultaneous equation solving methods from mathematics. Once the students understand the basic concepts of the Method of Joints they are asked to reconsider their bridge design. The only acceptable design from a team must have a complete analysis using the Method of Joints. If a team cannot analyze their current design, it must be simplified until it can be analyzed. The more capable teams (those capable of analyzing a 3D truss) had access to more solution options.

The final technique a team needs in order to fully analyze a truss is the strength of a member in tension. The compressive strength of the magnets is so much greater than the tensile strength that compression failure is not even considered. This tensile strength is determined experimentally by using more concepts from physics and mathematics. Each team built a test apparatus from Lego parts. Figure 3 shows an example of one such apparatus. By setting the sum of the moments to zero about the pivot point, the failure load for a magnet/sphere can be found.

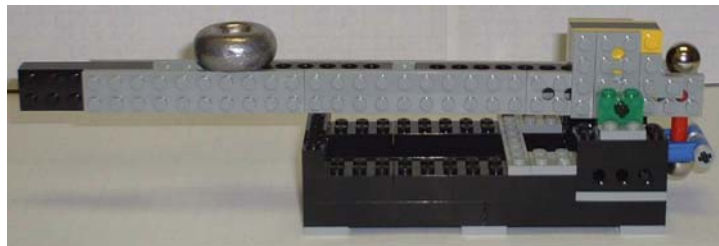


Figure 3. Example of a testing rig.

With this failure strength known, each team was given the final requirement for the project and a metric by which “the bid” would be awarded. This bid was not part of the grade, but was a competition among the teams for bragging rights. For a bridge to be considered viable, it had to support a minimum two-pound load applied uniformly to the central spheres of the bridge. There are several possible loading patterns, depending on the design. It could be a one- point concentrated load or might be distributed over four nodes. The bid criterion was based on a load capacity to cost ratio. However, the maximum load capacity in which a bridge could be given credit for is four times the minimum. This ratio was then modified based on how close to the actual failure load the predicted failure load was when the design was actually loaded to failure. The capacity/cost ratio was reduced by the percent error on the prediction.

The cost was calculated by assigning a price of \$1.00 to each long Magnastick and a cost of \$0.60 for each short Magnastick. The cost of the spheres was factored in by using a construction cost based on the number of Magnastix attached to each sphere. Each member connected to each sphere was assigned a cost of \$0.20.

Example

Figure 4 shows an example of a simple truss which meets the above stated guidelines. When this truss is tested until failure, the failure load was 3.71 pounds. The long magnets are dark and the short magnets are light colored for clarity. Using the Method of Joints and the tensile strength for the magnets, the calculated failure load should have been 4.07 pounds.

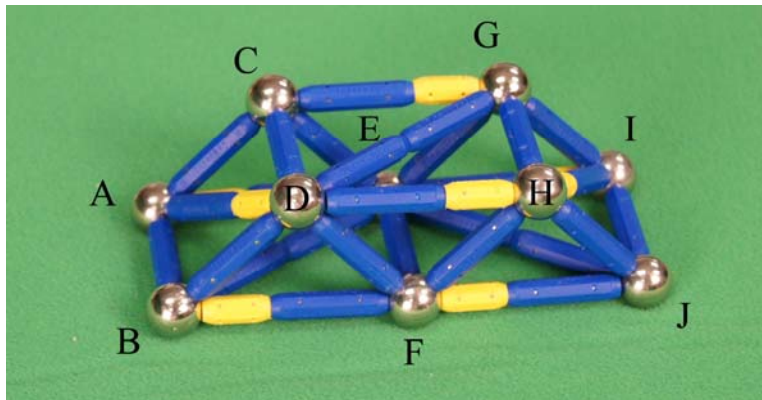


Figure 4. Simple truss that satisfies project guidelines.

The calculation for the final bid score follows:

Cost:

26 long magnets at \$1.00 = \$26.00

8 short magnets at \$0.60 = \$4.80

Construction cost by joint: A: 4 members=\$0.80; B: 4 members=\$0.80; C: 4 members=\$0.80; D: 6 members=\$1.20; E: 7 members=\$1.40; F: 5 members=\$1.00; G: 5 members=\$1.00; H:5

members=\$1.00; I: 4 members=\$0.80; J: 4 members=\$0.80. Grand Total Construction cost = \$9.60

Total Cost=\$26.00+\$4.80+\$9.60=\$40.40

Prediction accuracy $|3.71-4.07|/4.07=8.85\%$

Final Bid Score= $3.71 \text{ pounds}/\$40.40*(1-8.85\%)=0.0837$

Student Opinions

At the conclusion of the project, students were given a survey to gather their opinions about the project and the benefits they felt it had. Five statements were posed, and the students were asked to respond on a Likert scale of 1 (not at all) to 10 (very much so):

1. I understood statics before starting the truss project.
2. I enjoyed the truss project.
3. The truss project helped me to visualize internal forces better.
4. The truss project helped me perform better in my physics class.
5. I feel more confident in my ability to pass my engineering mechanics courses.
6. I enjoyed the truss project.

These data were collected for 4 of the classes during the Spring 2009 semester. Items 1 and 3 showed a mostly flat response with averages very near 5. Item 2 was slightly positive with an average response of 6.33. The remaining two items, numbers 4 and 5, showed a definite bias toward the positive. The data for questions 4 and 5 are presented in Figures 5 and 6.

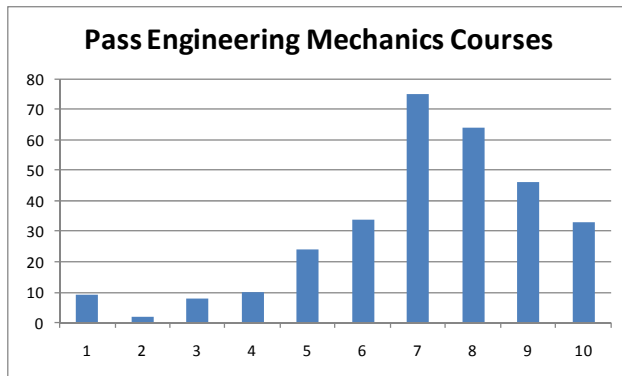


Figure 5. Confidence in passing engineering mechanics courses.

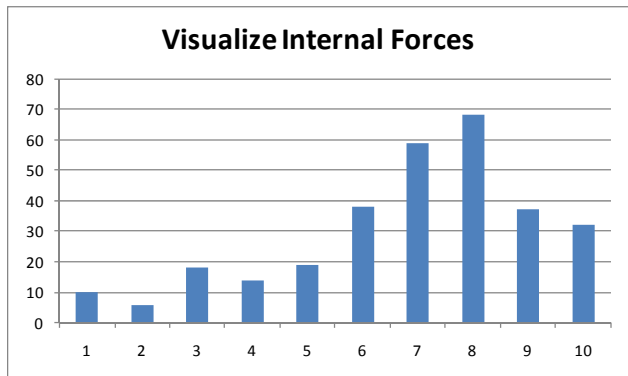


Figure 6. Ability to visualize internal forces.

Actual Outcomes in Mechanics classes

In order to measure the impact of the Truss project on future performance in engineering mechanics classes, two different measures were examined. Student achievement in the

subsequent Statics course (MEEN 221) was examined between students who took ENGR 111 before the Truss project was instituted and those who took ENGR 111 after the Truss project was instituted. The letter grades for 3560 students from Summer 2006 through Fall 2010 were considered. Also, the course grades for students who completed the Truss project in ENGR 111 were compared against students taking Statics who did not enroll in ENGR 111, and thus did not have exposure to the Truss project. MEEN 221 is taken primarily by Mechanical Engineering students, but also has substantial numbers of Industrial Engineering, Petroleum Engineering, and Nuclear Engineering, as well as a few students from virtually every major in the college as well as quite a few who are not even part of the College of Engineering. Table 1 shows the distribution of majors of the students in this study.

Table 1. Distribution of engineering majors.

Major	Number	Percent
Aerospace	3	0.1%
Agricultural	24	0.7%
Biomedical	118	3.3%
Computer	30	0.8%
Chemical	35	1.0%
Civil	7	0.2%
Electrical	144	4.0%
Engineeing Technology	9	0.3%
Industrial	641	18.0%
Mechanical	1101	30.9%
Nuclear	266	7.5%
Ocean	8	0.2%
Petroleum	626	17.6%
Radiological Health	58	1.6%
Industrial Distribution	2	0.1%

Students enrolling in ENGR 111 before the Truss project was instituted (Fall 2007) consisted of 1315 students, whose average GPR (Grade Point Ratio) in Statics was 2.386, with a standard deviation of 1.117. For students who took ENGR 111 after Fall 2008 (2245 students), the average GPR in Statics was 2.506 with a standard deviation of 1.073. Using Welsh's t-test to compare these two means, it was found that the difference is statistically significant at the 99.99% level (d.f.=2664, t=3.151, p=0.0001).

Next, the GPR in Statics of students since Fall 2007 who have been exposed to the Truss project versus students who took Statics without prior enrollment in ENGR 111 (who were not exposed to the Truss project) was then examined. Students not enrolled in ENGR 111 prior to taking Statics earned a GPR of 2.342 with a standard deviation of 1.091 (365 students). Students who had completed the Truss project in ENGR 111 prior to their Statics class earned an average GPR of 2.538 with a standard deviation of 1.067 (1880 students). Using Welsh's t-test to compare the means, it was found that the difference is also significant at the 99.9% level (d.f.=508, t=3.141, p=0.001).

In order to examine whether the Statics curriculum increased or decreased in difficulty over time, an additional test was performed. The average mean of Statics GPR, before and after exposure to the Truss project was compared. In comparing the means of 2.386 and 2.342, there is no statistical evidence that the two means are unequal. This finding reinforces the belief that the Statics course did not change in difficulty and that there was a significant improvement in the grades earned by those students who participated in the Truss project.

Conclusion

The data clearly show an increase in performance in the subsequent Statics course and the fact that it correlates with the introduction of the Truss project. Since the student performance for those not exposed to the truss project has not changed during the study period, there is a strong indication of causation. In addition to the obvious reasoning that more exposure to statics concepts is better than less, other factors may well be present. Litzinger et al. studied cognitive development in the context of statics problems and one of the major findings from that work was that students did not fully grasp the concept of free-body diagrams, including the differences between internal and external forces⁴. Using Magnastix to construct trusses gives students a tactile feel for internal forces and allows them to visualize the truss by actually holding it in their hand. The differences between an internal force (those acting on the Magnastix) and an external force (the loads applied to the truss) is physically visible.

A secondary finding of Litzinger et al. was the difficulty students had with basic trigonometry. This problem has been observed in students involved in the mechanics track as they worked on the Truss project. By motivating them that better understanding of mathematics provides for more design options, it is hoped that students will be increasingly self-motivated to improve their mathematical abilities.

Future Plans

This paper concerns only students enrolled in MEEN 221 as their introductory Statics course. This course is primarily taken by mechanical engineering students. Further examination of other commonly taken Statics courses could yield important insights. Of particular interest is student achievement in Aero 211, ENTC 275, and CVEN 221. These results will be presented in a future paper.

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