# AC 2012-4322: THE DESIGN COMPETITION AS A TOOL FOR TEACHING STATICS

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# The Design Competition as a Tool for Teaching Statics.

## *1. Introduction*

This paper describes ongoing efforts at Syracuse University to re-engineer the traditional statics course. This course forms part of a larger NSF funded project aimed at increasing innovation and creativity in engineering curricula. The principal aim of the overall project is to find strategies to foster and reward creativity in engineering students.

This study examines a design competition project assigned to sophomore statics students aimed at introducing: more open ended problem solving; design as a core component of engineering education; and the importance of innovation and creativity in engineering. The evaluation of the overall project includes both student performance data and student perception data. This study presents the results of the competition and the evaluation of the intervention and the value of such an assignment in learning statics concepts.

## *2. Background*

There is no doubt that both academic and practicing engineers are creative everyday in their labs, their jobsites, their workshops and offices, but engineering education does not consistently address this vital skill. Nor does it address creativity's relationship to research and design, or explicitly integrate creativity or innovation into an undergraduate student's training. Leading engineering education experts have described "creative experiential, problem based learning" as the model for future engineering curricula if the US is to maintain a technologically and economically competitive workforce.[1] Teaching engineering design as a vehicle to incorporate creativity into engineering curricula is widely acknowledged by engineering education researchers.[2,3] Engineering students have difficulty integrating their studies into real engineering situations because of lack of exposure.[4] It is this capacity to integrate knowledge and skills into the practice of engineering that signifies the creative engineer.

Engineering education researchers and practitioners have acknowledged the problem of design education in engineering programs. In the 1990s first-year design courses were widely introduced in engineering programs in an attempt to introduce students to the nature of their chosen profession earlier in their college careers.[5,6] Capstone design courses at the end of engineering programs likewise represent an opportunity for students to take on both design work and a holistic real world project. However, design is not generally included as part of the curriculum in core courses in the second and third years of study. There is a critique that this bookending approach (with cornerstone courses in the first year and capstone in the final year) can create a "valley of despair" in the second and third years and that the benefits of project-based learning are limited when they are not spread throughout the curriculum.[7] The project described in this paper represents an attempt to fill in the valley of despair by adding a design assignment to the required statics course for civil and mechanical engineers.

Previous studies in the area of teaching statics lament the difficulty that students often have translating the knowledge encountered in early mechanics courses to the analyses required in later courses.[8] Steif and Dollár argue for introducing new material by grounding it in existing knowledge, being open to multiple modes of learning, and having students begin to learn about forces, couples etc by working with those examples that they can perceive either by manipulating with their own hands or by viewing resulting deformation or motion.[9] They also argue for significant interaction and discussion in the classroom. Williams and Howard discuss the value of a laboratory experience or classroom demonstration in helping students learn the elementary statics concepts and further advise that students estimate and evaluate expected outcomes in advance.[10] O'Neill et al report on a successful lab lecture hybrid interdisciplinary mechanics course that uses longer meeting times and inexpensive models and equipment get students to "discover" engineering concepts.[11] The project described here forms part of an experimental statics course that uses classroom demos, small-scale experiments, real life examples, smaller class sizes, and group work in class. The aim of the experimental course is to improve creativity and innovation in problem solving and increase students' enthusiasm for engineering and perception of engineering as creative and innovative. There were 40 civil engineering students in the course. The design competition project specifically, was designed to provide a hands on experience, and a design experience.

## *3. The Design Competition*

The Design Competition was assigned at the mid-point of the semester, after the subjects of vectors, moments, and equilibrium in both 2D and 3D had all been covered. The students were shown a series of sculptures designed using static equilibrium (see Figures 1-2), they had also previously undertaken an analysis of the mobiles of Alexander Calder as an in class assignment and as a homework (Figure 3). They were asked to form teams of two and brainstorm ideas for their entry into the design competition for the duration of the class period. The design aim they were given was to create a sculpture/mobile/device /assembly that was statically determinate and in static equilibrium, but one that looked like it should fall over.

**Figure 1:** Examples of sculpture and static equilibrium used by architect/engineer Santiago Calatrava

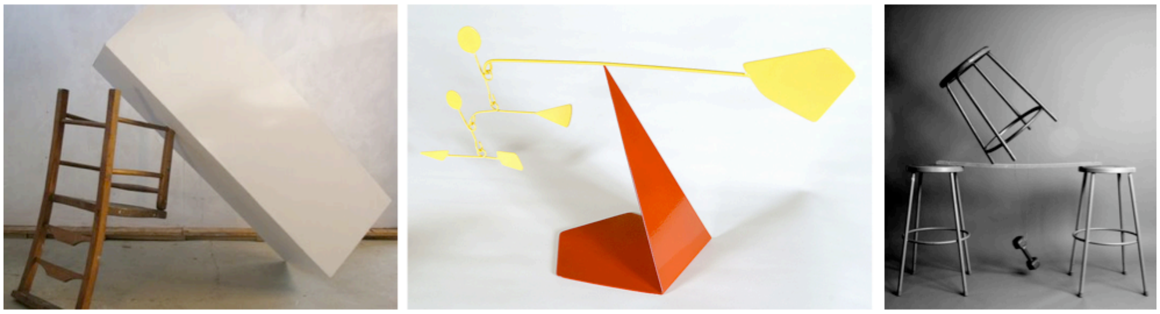

**Figure 2:** L-R Equilibrium by Theo Turpin, Table Top Mobile by Bruce Gray, Sculpture by Architecture Students at the GSD (Permissions Pending)

**Figure 3:** Mobiles by American Artist Alexander Calder (trained as an engineer at Stevens Institute for Technology!)

The competition was entitled “Asymmetric Equilibrium”. The two teaching assistants and the instructor provided feedback and help to each team during the class period. At the end of the class period the students were asked if there were things they did not know that they would need to understand in order to complete the project. It emerged that the primary missing piece was a method (or methods) to find the centroid of complex shapes or the center of gravity of a complex object. So the next two lectures focused on centroids and center of gravity (topics that were at least somewhat familiar from previous physics courses). Definitions of these properties of shape, mathematical methods for finding the center of a complex shape made up of shapes of known centroid, and experimental methods for finding the (approximate) center of gravity of an object were all covered. In the next 10 days each group was offered the chance to meet with the instructor for a one on one design consultation. In the meantime they were required as part of their homework assignment to sketch up the centroid/center of gravity problem they had chosen for their design and submit their proposed solution to the TAs for feedback.

Most groups took advantage of the offered design consultation meeting. One of the principal issues for most groups was how to construct the types of connections they needed (pins, rollers etc). This prompted some interesting discussions of what connections really are, how most real connections only approximate the behavior of the idealized conditions assumed in their text, or how some connections might be assumed to be pins while there was enough friction to resist a the applied horizontal forces, and that if those horizontal forces got bigger then the connection would really act like a roller. Another group set out to build a perfect pin complete with the appropriate fixings from the hardware store, only to discover when they tightened the bolt that they had a moment connection (under the small loads on their sculpture) and had to start again. Other issues that came up in those meetings were: where and how to source materials, what if any tools they might need, and where on campus they could find help. There was one architecture student in the class who volunteered to assist some other groups who needed to use the architecture shop to cut shapes from wood or Plexiglas. Some students took the initiative to get help from the staff at the engineering shop (not normally used by undergraduates). Other students borrowed tools and scrap materials from the instructor. This aspect of the project was time consuming for both the TAs and the instructor, but was central to the success of the project. The only other building experience that most of the students reported was in the first year design course where model bridge designs were made from a predetermined subset of provided materials. The only other hands on experiences reported by most students were in lab courses. As such, these meetings were a good opportunity to allay any concerns that students had about the assignment, offer practical assistance, and push some students to more complex designs. The students were encouraged to spend as little as possible and were reimbursed for $20 worth of materials.

The designs were presented to the whole class and a panel of judges including the instructor, a senior colleague in Civil Engineering and the TAs for the course. Each of the judges got two votes each for the most technically interesting design and two votes each for the most aesthetically interesting design. Each group also submitted their votes for the same categories (they were not allowed to vote for themselves).

### *4. Student Work*

Examples of the students' work are shown in Figures 4-10. There were a mix of mobile-like devices in the vein of Calder and assemblies that borrowed from Calatrava's sculptures. Extensive use was made of fishing wire as a tie back or tie down in order to add to the asymmetric illusion. In addition to the design project, students were required to turn in a report detailing their design process and including a full set of calculations showing how they estimated the centroids of their elements, the reactions at their connections, and the tensions in any wires.

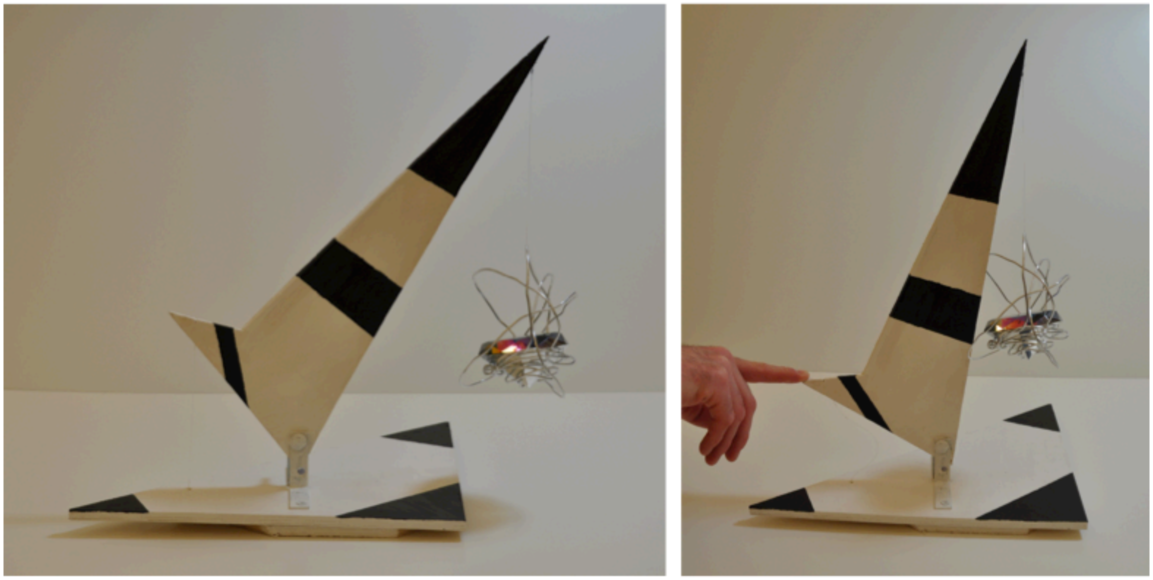

**Figure 4:** Asymmetric shape with hanging weight. Working hinge and counterbalancing tension cable.

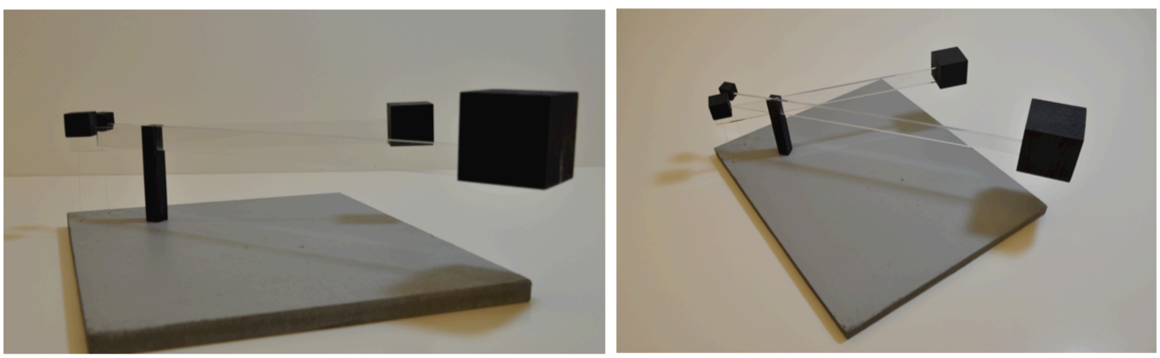

**Figure 5:** Equilibrium in 3D. Larger weights and longer levers counterbalanced with a tension cable. The hinge on this model had too much friction.

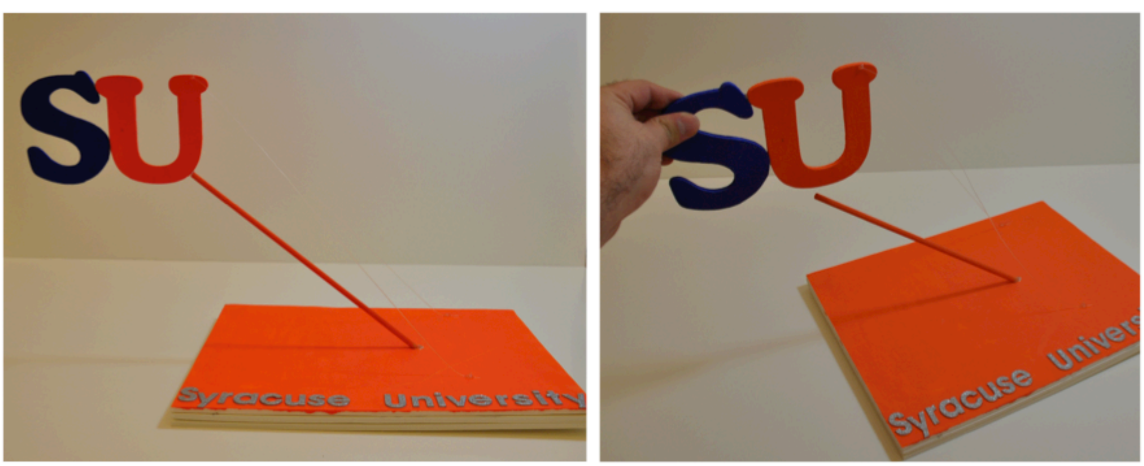


**Figure 6:** School Pride. Moment connection at base, cantilever structure made with two pin connections and a tension and compression member.

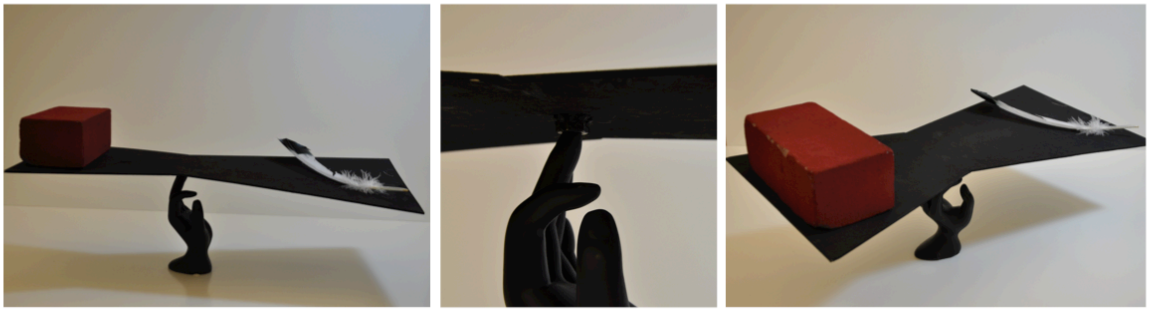

**Figure 7:** Which weighs more, a pound of bricks or a pound of feathers? Pin connection made with a hexagonal bolt and an artist's model.

**Figure 8:** Device with multiple states of equilibrium. Plastic piping and fishing line used to approximate a frictionless pulley

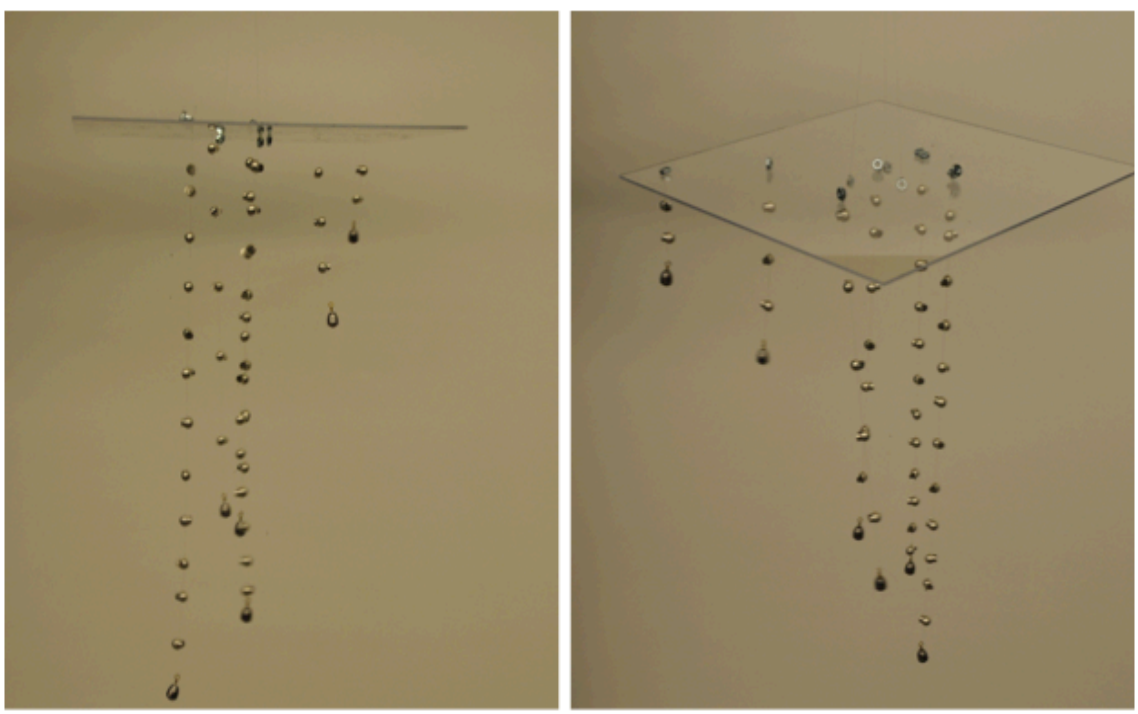

**Figure 9:** Equilibrium in 3D. Asymmetric mobile with horizontal support.

**Figure 10:** Smashing Smurf.

## *5. Student Response*

In order to investigate student response to the assignment a short survey was sent to the 40 students in the course. The response rate was 50%. The responses to the survey were very encouraging. 100% of respondents agreed that the design competition was useful in learning the course material. Further, approximately 85% of students agreed that the design competition made them more enthusiastic about engineering, and that in doing the project they learned something over and above the course material. Very few students felt that the project took too much time from their other work, or that they were unprepared for the assignment by their training so far. Finally, and most encouragingly, 100% of respondents indicated that they would like to undertake similar assignments in future courses. The full results are shown in Figure 8.

In addition to the questions on the chart in Figure 8 the students were given an opportunity to expand on how the design competition helped them learn the course material (if in fact they agreed that it had). Interestingly a number of the comments addressed the "reality" of the project.

> *"It helped me see the actual application of it rather than a problem that was taken out of the book, which may not make sense to me at the moment but this just allows me to see that everything we did in the class was relevant."*
>
> *"It was cool to see that what we learned in class really could apply to something that we could make."*
>
> *"it helped realize how the concepts in the course applied to real life situations"*
>
> *"understanding the fundamental concepts, what we learned is real."*
>
> *"Helped understand how something, that would normally look like it was falling over, actually was in static equilibrium rather than just believing it because we were told to in class. Provides practical engineering skills to the real world."*

The project required students to build a model sculpture or mobile-like assembly (as opposed to a model bridge, or crane, or machine). These were not hugely different from the kinds of things they might find in a textbook problem. It would appear that it was the physical and hands on nature of the assignment that made the students feel it was more "real" as opposed to the subject matter.

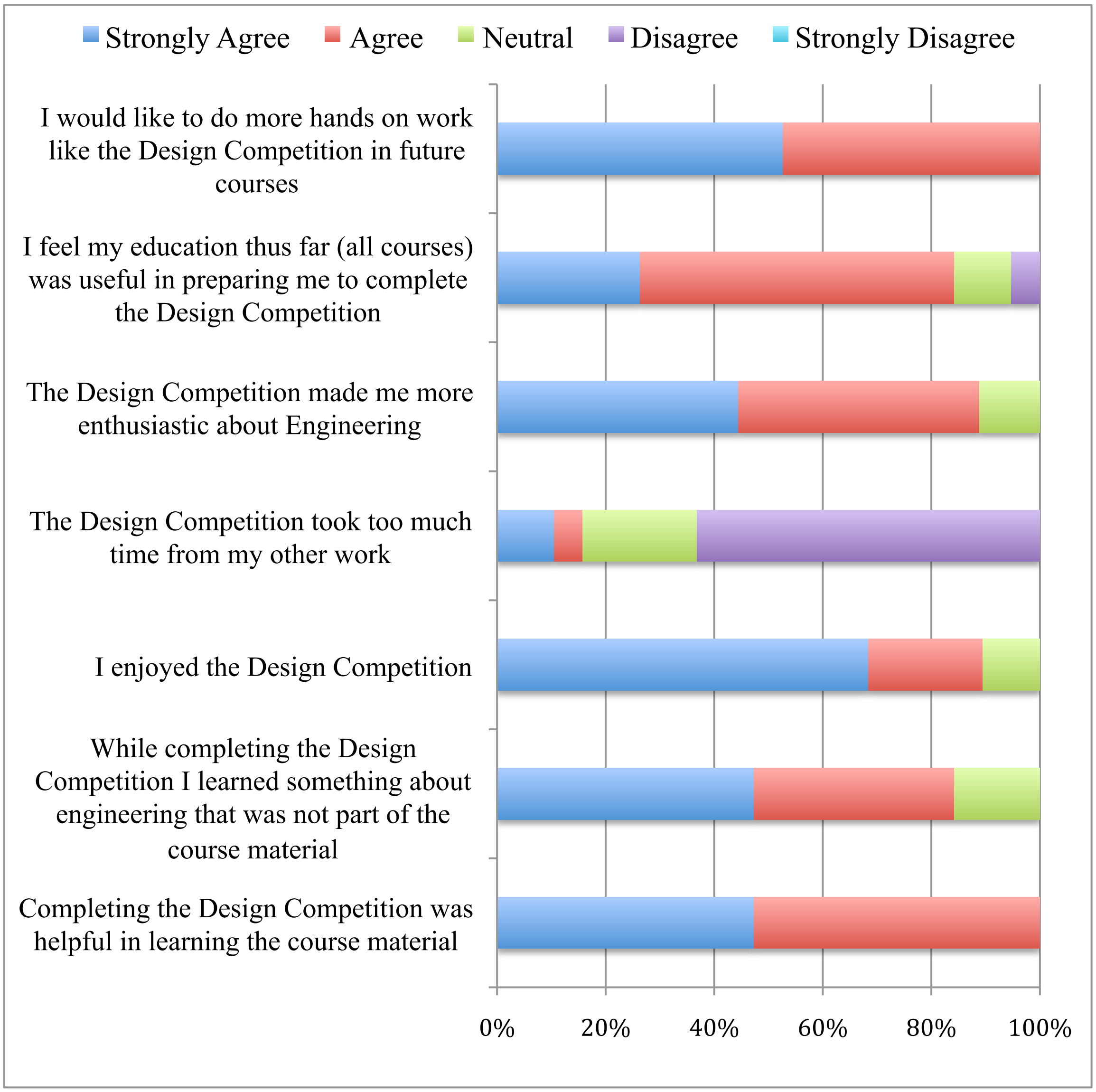


**Figure 8:** Student responses regarding the design competition assignment

Other students commented that visual and physical learning are useful but are not the normal mode of learning that they encounter in their other engineering classes.

*"Practical application of principles is good learning reinforcement that we usually don't get."*

*"It allowed me to visually and physically see what I am learning instead of just writing down formulas and drawing diagrams."*

Surprisingly, a number of students cited the lack of an "answer in the back of the book" as a positive aspect of the project.

*"The competition had me take material learned in the classroom and implement it into a real life scenario that I created like real engineer and had to solve all the unknowns and had no answers in the back the textbook to go off of it really had me think and work hard to arrive at my conclusions and had me feel confident in my own answers were correct and prove it."*

This is encouraging as in previous iterations of teaching this course, students proved to be very uncomfortable working without a net. When homework problems were assigned that were among the small group in the textbook that did not have an answer provided, anxious emails asking for confirmation of their answers (often from some of the strongest students in the class) would ensue. In this iteration of the course validation techniques were discussed in class and demonstrations of how to self evaluate an answer to a new problem were presented. Additionally, the students had at least one question on every homework assignment that either was non-numerical and open ended, or required some kind of reflective statement on the numerical answer.

A few of the responses indicated that the project helped engender increased enthusiasm for the course material and engineering more generally.

*"It was cool to see that what we learned in class really could apply to something that we could make."*

There was a small minority of students who did not feel the project was useful in learning the course material but interestingly their comments implied that the project was not difficult enough.

*"I think it more or less reinforced it rather than helped me learn it."*

This result will be investigated more closely in a focus group setting (which is scheduled for later in the semester as part of a larger evaluation of the whole course). There could perhaps be multiple options for a future assignment that might allow more ambitious students to take on a more complex project. Some of the stronger students in the course did try to do this by attempting to design a device with multiple states of equilibrium and testing various materials to see how close to a frictionless pulley they could get with cheap hardware store materials.

The respondents were also offered an opportunity to comment on the experience of hands on work more generally as a method of exploring and learning engineering course material.

> *"the physical world is rarely as well behaved as the calculations and adjusting to and accounting for unforeseen problems is a good engineering lesson"*
>
> *"I realized that even though we had the same task in mind we all went about it differently by using different materials to add an illusion to our work."*

### *6. School of Education Evaluation Results*

The assignment described here forms part of a course for which the primary aim is to improve innovation and creativity in engineering student problem solving. Specifically it was hoped that the students would become: more comfortable taking on unfamiliar problems and working on open-ended problems; more confident in their ability to take on unfamiliar problems; and more knowledgeable and enthusiastic about the role of innovation and creativity in engineering design. There were forty students in this experimental course, and the remaining sixty students in the cohort experienced a traditional lecture format with another instructor.

An evaluation plan for the course has been prepared and implemented by a team led by Dr. Scott Shablak who directs the Office of Professional Research and Development at the Syracuse University School of Education. As part of the evaluation of this course two researchers conducted classroom observations for a number of sessions for both the experimental course and the traditional course. These classroom observers did not read the experimental course proposal and were merely instructed to observe both courses and comment on the differences found. One of the course topics for which the observers attended both courses was properties of shape.

The most encouraging result from the observers report was that they readily identified the experimental course as engaged in creative problem solving (recall they had not been informed of the experimental course aims in advance). They also observed that the design competition assignment had clearly been created to elicit a diversity of solutions (as opposed to the problems assigned in the traditional course in which all students should arrive at the same solution). That these facets of the course were immediately obvious to observers who were unaware of the course aims is very encouraging. Other observations in their report for included:

a) considerably higher attention paid by the students in the experimental course (no sleeping, considerably less cell phone checking),
b) students in the traditional lecture were very passive (taking notes from the board) while students in the experimental course were actively engaged (working on problems, discussing their designs with other groups, presenting their work to each other),
c) students were much more responsive to the instructor in the experimental course (responding to questions from the instructor, initiating questions, verbal

and non verbal affirmations as the instructor explained new ideas).

d) students in the experimental course displayed confidence and enthusiasm for engineering problem solving while presenting their design competition entries (note there was no analogous activity in the traditional course for camparison).

These observations suggest that the teaching methods deployed in this course, including the design competition, have resulted in increased engagement on the part of the students, confidence in taking on unfamiliar problems, and comfort with open-ended problem solving.

Additional work is underway processing pre and post survey data to understand what if any impact the experimental statics course and the traditional course had on students perceptions of both themselves and the discipline of engineering, particularly in the area of creativity and innovation. There were multiple common exam questions given to the two groups over the course of the semester and initial results show that at a minimum the time spent on in class experiments, demonstrations and the design competition did not result in any decrease in ability to tackle normative exam questions on the part of the students in the experimental section. A more fine-grained analysis of the exam questions on properties of area is underway to establish if the experimental students displayed more diversity of problem solving or increased understanding of the topic, which could be attributed to the design competition. Additionally an analysis is planned of the grades of the students from both courses in mechanics of solids, which most of them are taking this semester.

## *7. Conclusions*

There is considerable support in the relevant literature for the importance of design in the middle years of engineering education. There is strong evidence that hands on work, where students can see and manipulate the forces they are calculating, is of value in teaching statics concepts. The project described here combines both of these concerns. An external faculty member adjudicated the quality of the student work as very high. The evaluation team from the school of education concluded that the methods deployed in the experimental course were appropriate to the aims of the overall project, and that the design competition in particular showcased increased student engagement in learning relative to those in the traditional course. The student response was overwhelmingly positive. Further work is necessary to see if this approach can be used in other required engineering courses.

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