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First Encounters: Statics as a Gateway to Engineering

Dr. Sinead C. MacNamara, Syracuse University
Prof. Joan V. Dannenhoffer P.E., Syracuse University

Joan Dannenhoffer is Associate Professor of Civil and Environmental Engineering at Syracuse University. She received her M.S. in Environmental Engineering from the University of Connecticut and M.B.A. and B.S. in Civil Engineering from Rensselaer Polytechnic Institute. She is a Professional Engineer in the State of Connecticut. Her research interests are in engineering education pedagogy, especially in implementing active learning strategies in large classes. She currently teaches Engineering Statics, Mechanics of Solids, and Civil Engineering Materials.

First Encounters: Statics as the Gateway to Engineering Culture

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.

At Syracuse University, as at many institutions, statics is typically taken in the fall of second year for civil, environmental, mechanical and aerospace engineering students. The only engineering course that the students have taken before statics is the first year cornerstone course, an experience that is dwarfed by the rest of the first year load of basic science and mathematics pre-requisite courses. The statics classroom can be one of the first true acculturation experiences for these future engineers. This is one of the first times these students are amongst only their departmental peers and are being taught by a professor from their home department. Thus, the statics course has a significant role to play in setting the tone for the years to come, and in introducing students to engineering culture.

This paper describes a pair of statics courses taught to civil and environmental engineering students at Syracuse University, both in the fall semester, for the past three years. These courses take a variety of approaches to inculcating engineering values and skills in the students. Issues such as the importance of understanding underlying assumptions, the value of conservative assumptions, the value of sketching and diagrams in engineering communication, the difference between precision and accuracy, and basic knowledge about the products of the profession and its role in society, are all addressed. These courses have been taught for three. An evaluation team from the School Education has designed an evaluation plan to identify what if any effect the courses have on students' perceptions of engineering. This paper presents the results of this evaluation, alongside student performance data, student response data and faculty observations.

1. Background

Studies into acculturation of engineering students are rare, but studies of retention offer a glimpse into the aspects of engineering education that most impact students' happiness with their choice of major, and into the student characteristics and skills that most influence persistence and success for students in engineering programs. It is generally acknowledged that high math and science barriers in the first two years of undergraduate study contribute to attrition, but it is also argued that more creative students become frustrated by a lack of "big picture" thinking or apparent social relevance, and that this effect is even more pronounced for women and minorities.[1]

Engineering education research also shows that engineering students have difficulty integrating their studies into real engineering situations because of lack of exposure.[2] It is this capacity to integrate knowledge and skills into the practice of engineering that defines engineering culture. 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.[3] 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.[4] 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.[5] 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.[6]

2. The Study

Group A were the students in a smaller class size (40) that, under the grant described above, undertook a series of experimental teaching methods aimed at fostering innovation and creativity and inculcate students into engineering culture including group work in class, small-scale experiments, real world examples, open ended problem solving, Group B were 65 students in a more traditional lecture format that utilized several methodologies to better inculcate engineering thinking including SAGE, ARCHIMEDES, OLI, look-ahead homework, and mapping inner space. Both courses are taught in the fall semester to the students of the civil and environmental engineering department. These students are friends and colleagues on the same campus, who take many of the same classes at the same time, and may share dorm rooms and study groups. The vast majority of those students will go on to take Mechanics of Solids together in the same course in the following Spring. As such, this experiment like many initiatives in education research, did not have perfectly isolated populations subject to entirely different experiences.

3. Group A

Several facets of the course taught to Group A in the Fall semester of 2012 were designed to inculcate engineering values and skills and improve students' knowledge of and enthusiasm for engineering. The goals of the course in this area are that after taking the course students would exhibit:

i. Better knowledge of what a civil or structural engineer does.
ii. An understanding of an engineer as one who "makes," "creates" or "designs."
iii. Increased enthusiasm for engineering as a discipline.
iv. More likelihood of describing engineering professionals as problem solvers, big picture thinkers, innovative, and creative.
v. More confidence in their own emerging engineering skills.
vi. Appreciation for the engineering principles of self-critique/validation and conservative assumptions.
vii. An understanding of the value and importance of drawing diagrams as a fundamental engineering skill

Specifically those teaching methodologies that aimed to meet the above goals were:

i. Emphasis on self-validation techniques. The instructor emphasized identifying the order of magnitude, direction and other aspects of believability of a mathematical answer. Students were required to estimate answers before attempting homework problems and reflect on confidence afterwards. Students were further encouraged to identify reasons when they DID NOT have confidence in answers on exam questions and some missed points were given back back when a student offered a rationale for why an answer was wrong that displayed good conceptual intuition.
ii. Design Competition. Students were required to build a small mobile, sculpture or device that displayed their understanding of 2 significant concepts: equilibrium in 3D and centroids of a complex shape. The model was required to look like it should fall over, but to be in perfect equilibrium. The building of the models also required students to investigate the nature of physical connections and pulleys in the real world and how they differ from the idealized conditions encountered in texts. The whole assignment was also intended to get the students thinking of engineers as those who MAKE objects – as opposed to the more scientific model of observation and analysis that many of their classes so far have emphasized.
iii. Real World Examples. Multiple lectures have focused on an analysis of real structures to learn a new concept. The George Washington Bridge, the Eiffel Tower, the Institute of Contemporary Art in Boston (which boasts an 80ft long cantilevered gallery thanks to the trusses embedded in the side walls), Shaq dunking a basketball, hanging planters in the instructors' garden, the mobiles of Alexander Calder, the bridges of Santiago Calatrava, the cranes in the shipyards where the Titanic was built, the rescue apparatus for the Chilean Miners, the Liberty Suspension bridge in North Carolina, and the "Flying House" of architect Rem Koolhass' Villa Bordeaux were all mathematically analyzed as part of the course. A real world application of all new concepts was discussed in lecture. The instructor demonstrated how to diagram real structures in a useful way and how multiple diagrams at multiple scales were necessary. Examples of engineering diagrams from an engineering colleague in practice were shown to the students to encourage them to work on their diagram drawing skills. A design build project that the instructor and one of the TAs are working on this semester (a tree-house currently under construction) was shown to the students multiple times as design and construction progressed. For one lecture on moments in 3D the students were asked to help figure out the reactions at the base of in the structure to help with a real time design decision that needed to be made that day.
iv. Identifying evidence of statics concepts in their everyday life. For each new concept in the course the students were required on a homework assignment to find an example of that concept in their dorm/home/campus and to photograph it then draw a diagram and list the things they would need to know to "solve" the problem. For some concepts they were allowed to search the web (or their vacation photos) for an example of a structure to do the same thing.
v. Small Scale Experiments. Five concepts were introduced using a small-scale experiment (sometimes done by all students, sometimes demonstrated to the

students in the interest of time). The aim of the experiments was to get the students to get used to physically manipulating objects to test how they work, and to get used to translating those observations into useable knowledge.

vi. Group Work in Class. Approximately one third of lecture time over the course of the semester was turned over to students working on problems in class in small groups. This presented an opportunity for the instructor and TAs to monitor student progress and to encourage students to draw bigger and more ambitious diagrams. This activity also required more active engagement in class and, because of the smaller class size, allowed the instructor to learn names/build rapport and notice absences (without any formal attendance taking).

4. Group B

In the Fall 2012 semester of Engineering Statics several teaching methodologies and programs were used to help students in Group B understand and embody the type of logical thinking, analysis, and self-learning that is required in the field of engineering. Student growth and confidence, during this course in particular, often is the factor that determines if a student will be successful in engineering and if they will continue in engineering. The goals of the course in this area are that after taking this course the students would develop:

i. Self-confidence in their ability to solve problems and more natural problem-solving skills,
ii. Life-long learning skills, the ability to teach yourself,
iii. Self-awareness and an understanding of themselves as a learner, and
iv. An understanding of the relationship between the concepts taught in the course.

The teaching methodologies being used and evaluated with Group B that aimed to meet the above goals this semester include ARCHIMEDES, OLI, SAGE, look-ahead homework, and Mapping Inner Space.

i. ARCHIMEDES is a web-based program that guides students through solving statics problems. The goal is to help students develop self-confidence in their ability to solve problems and to develop a systematic strategy for problem solving. Since Engineering Statics is often the first core engineering course that many students take, they haven't developed the natural problem-solving ability that experienced engineers possess. "Most students do not find statics to be conceptually difficult, but are often overwhelmed by the myriad of small decisions that they must get correct if they are going to successfully solve a problem. Too often, this causes a student to question if he/she should continue to study engineering. The key idea implemented in ARCHIMEDES is a just-in-time feedback process for enhanced learning of problem-solving strategies."[7]

   The system divides the problems into steps that would logically be taken. For example, the first step in many statics problems is drawing a free-body diagram(s). The system then assesses the student's work and gives immediate feedback on the correctness. The student cannot continue on to the next step until the free-body diagram is correct. Once correct, they write free-form equilibrium equation in the same way as they would with paper and pencil. Again, the system assesses the student's work and gives immediate feedback on the correctness, completeness, and consistency of the solution without giving the student the answer.

The instant feedback allows students to correct errors early and avoid the fruitless efforts that result from errors made during the early parts of a solution. Thus, the frustration that results from "not being able to get the answer in the back of the book" is eliminated. Additionally, students are guided by the system to develop appropriate problem solving strategies that they can then apply to problems they solve with paper and pencil.

ii. The Open Learning Initiative (OLI) is a grant-funded group at Carnegie Mellon University that offers "innovative online courses to anyone who wants to learn or teach."[8] The OLI Engineering Statics course is available without cost to any teaching institution. OLI was trialed in the beginning of the fall semester to see how students would respond to learning online in addition to activities and lectures in the classroom. Using OLI was meant to foster the students' ability to self-learn. The idea of self-learning and life-long learning is a foreign concept to most students, as they have not been challenged in this way before.

    OLI uses active learning to demonstrate and test concepts. The material is broken up into small segments where "students encounter activities, simulations, and virtual labs to help them apply and test their learning." The presentation of similar but different material in class gives students the opportunity to compare and contrast what they have learned. This is also a new experience for many students.

iii. SAGE (Self-Assess, Grow, & Educate) is a web-based system that students can use to assess themselves through self-reflection in a rich, contextualized environment. The objective is to increase the student's meta-cognitive skill of self-awareness so they can develop a culture of continuous improvement.[9.] Each week of the fall semester, beginning at the end of the first week, students answered a short series of multiple-choice questions and two open-ended questions focused on course-related behaviors that are essential for success. Students evaluate themselves by answering questions such as "I've worked with others (e.g., office hours, Academic Excellence Workshop, study group) this many times this week" or "I am this up to date on the reading". This weekly evaluation continually reminds students of what the important behaviors for success are in the course without lecturing about it and it allows students to reflect on these behaviors each week. Students receive an email that tells them the SAGE questionnaire for this week is open, they respond by the specified date and time and then they can view the pattern of their responses over the course of the semester and the pattern of the average of the other students in the class. The students evaluate their behavior in a dynamic context and see their growth during the semester. The questionnaire included two open ended questions about what the student could do to improve their success and what the instructor could do to help them. This often prompted the student to do something with the self-reflection. The instructor's prompt and thoughtful response to suggestions by students also modeled the behavior of self-reflection for students. The added benefit for the instructor was the immediacy of the suggestions.

iv. "Look-a-head Homework" was also used to help students learn to teach themselves. Students do homeowrk problems for which they have not had lecture. They are required to read the text, work with other students and learn some of the material on their own before it is presented in class. This allows for more clarification questions from students as the material is presented, since they now have some previous knowledge of the concepts being presented. The goal is to develop self-learning skills.

v. Mapping Inner Space was used to help students understand the relationship between the concepts taught in the class. The mapping of concepts in a non-linear fashion as two-dimensional, hierarchical diagrams is meant to help students see the big picture and create a long-lasting image. A colleague has described these concept maps as "bullets, but better."[10] "Conceptual understanding is considered lasting if the concept represents a "big idea" having lasting value beyond the classroom, resides at the heart of the discipline, requires discovery of misconceptions, and offers the potential to engage students."[11] In the class, the students were asked to brainstorm in small groups. This allowed them to connect ideas about concepts and the connection between concepts in a non-threatening way. They didn't have to have everything perfect and they were free to redraw their map as they realized they wanted to add something important. The mapping was done informally and made use of the diversity of knowledge and multiple intelligences within each group. Mapping especially makes use of Gardner's eighth naturalist intelligence, the ability to recognize patterns and notice the relationship to the whole. The goal is for the student to see "order within chaos"[12] and to help build confidence in the current state of their understanding.

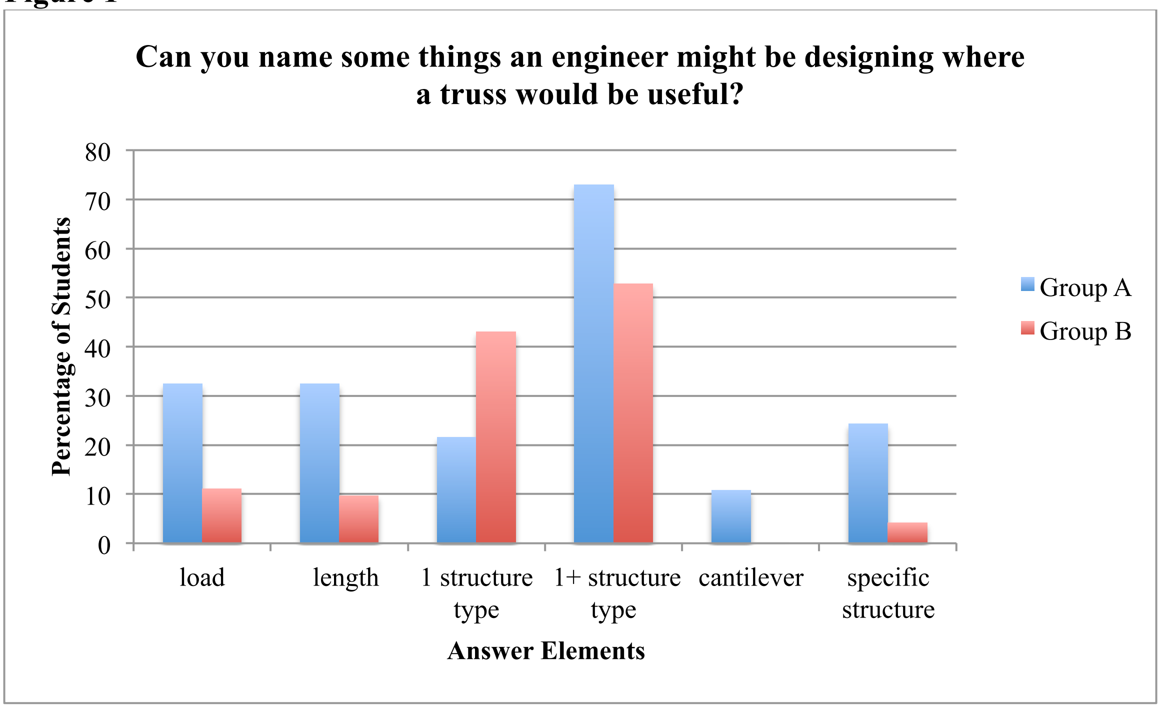
5. Student Performance

The students' took a common final exam that consisted mathematical questions similar to the typical textbook questions that both students had encountered over the course of the semester and of short answer "explanation" questions aimed at seeing if the students knew what are the engineering applications of the various mathematical solution strategies they had learned over the semester. These questions were given very little weight in the grading scheme and students were encouraged to try any answer and not to worry about them if they did not have an answer. The instructors for both courses developed these questions with guidance from the School of Education evaluation team who are working with the instructors to assess and improve student outcomes from both courses. To ensure uniformity of grading, the instructors and TAs graded the final exam jointly such that the same person graded each individual question for every student in both groups.

For the common final exam the average grade for students in Group A was 84%, the average grade for Group B was 77%. This result is not conclusive and requires closer study and an analysis of the GPAs of both groups along with results from subsequent courses to get a large enough sample size.

The two groups exhibited more difference in their answers to the short answer explanation questions than they did in their answers to the mathematical portions. In question 2 on the exam the students solved a truss, part b of the question asked them "Can you name some things an engineer might be designing where a truss would be useful?" For both groups the response rate was high and almost all students in both groups gave a correct answer (usually "a bridge"). However, when the answers were analyzed students from Group A were found to have more detailed answers to the question than the Students in Group B. Students in Group A were more likely than the students in Group B to correctly identify more than one type of structure where trusses are used, more likely to indicate that trusses were useful for longer spans and larger loads, and more likely to name a specific structure that they had seen in class, seen around campus, or knew from their hometown. These results can be seen in more detail in Figure 1. It should be noted that Group A were exposed to more real structures as part of their statics course and so this last observation is not surprising.

Figure 1



Similarly when asked "Can you name a couple of things an engineer might be designing where finding vectors in 3D would be necessary?" the students in Group A had slightly more detailed answers (see Figure 2) than those from Group B, although both groups answered the question correctly in similar numbers. Students in Group A were more likely to correctly identify multiple structural types and to name specific structures where 3D vectors were necessary.

Figure 3 breaks down both groups' answers to the question "What does calculating Moment of Inertia tell you about efficient shapes for beams?" Students in Group B scored an average of 0.55 out of 2 points for this question, while students in Group A scored an average of 1.5 out of 2. In Figure 3 it can be seen that students in Group B were more likely than the students in Group A to answer the question by saying that I measures resistance to rotation or that beams with higher I are "stronger" or can carry more load. Students in Group B were also much more likely than students in Group A to understand that the purpose of comparing I from shape to shape was to save material. However, students in Group A were far more likely than students in Group B to know that calculating I shows that efficient shapes are those that have material as far as possible from the centroid, and more likely to specifically cite I-beams and hollow shapes as efficient beam shapes.

Figure 2

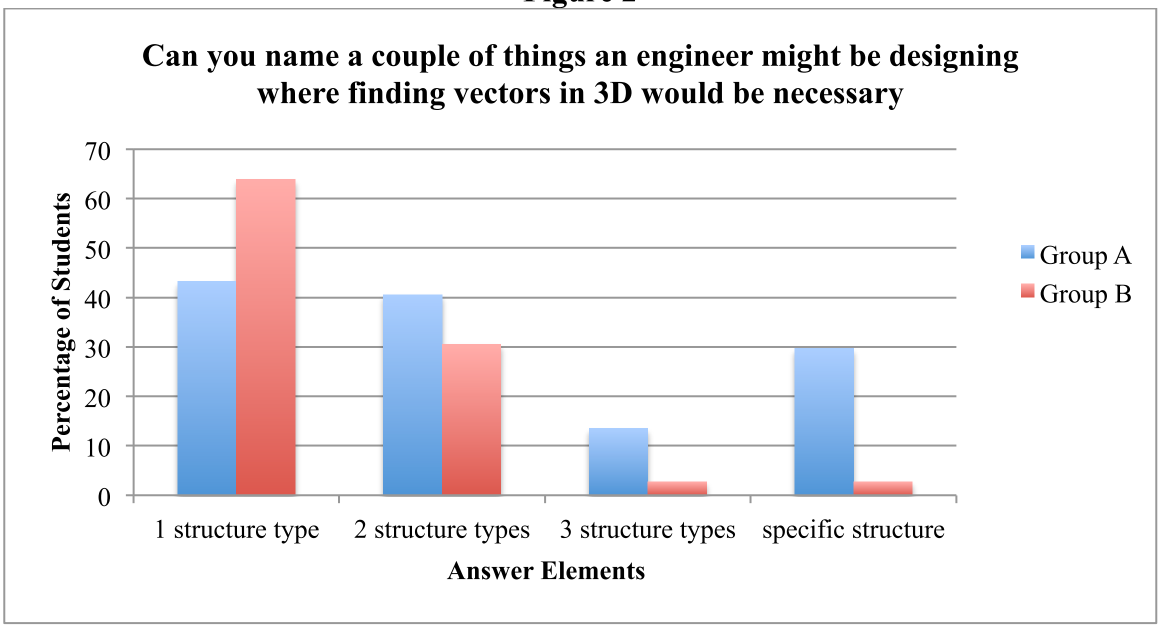
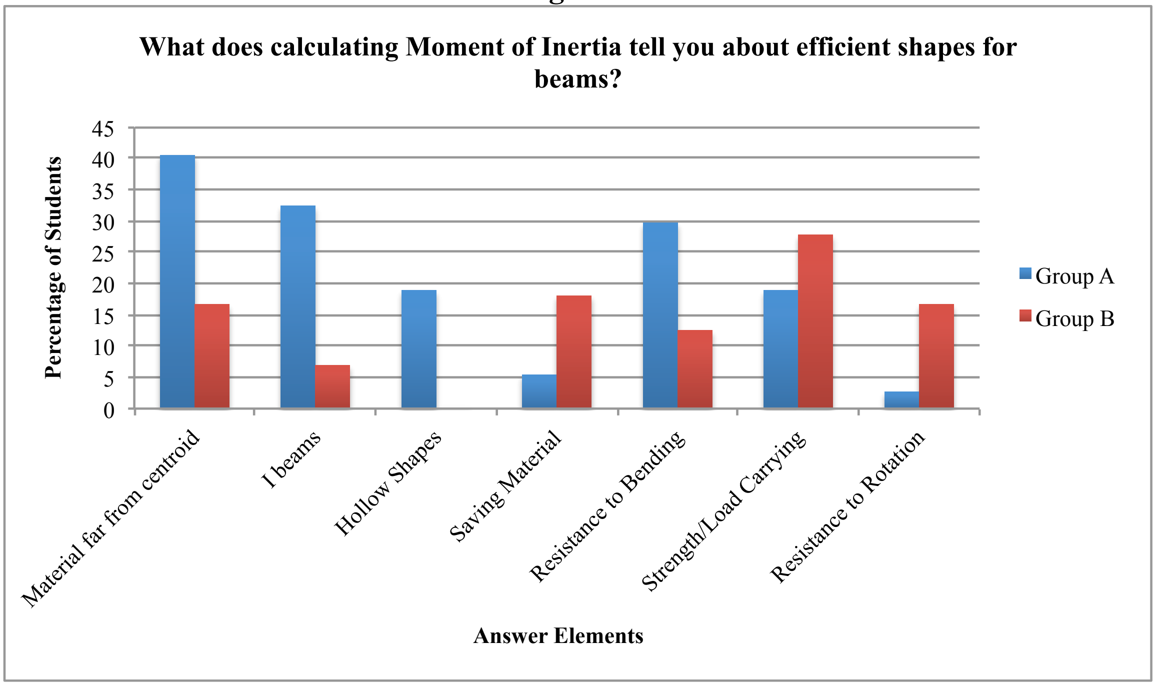


Figure 3



6. Student Response Data

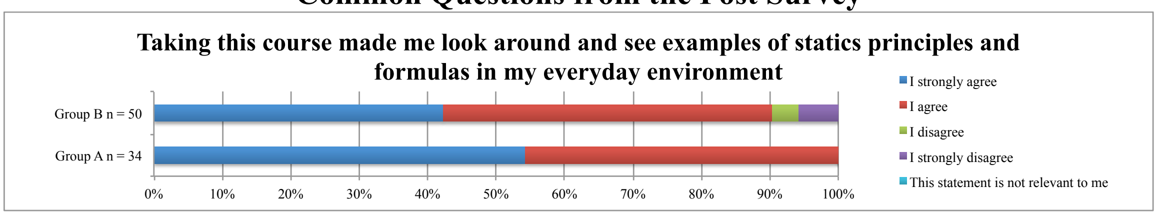
An evaluation plan for both courses was designed and administered by the Office of Professional Research and Development at the School of Education at Syracuse University. Students were surveyed before and after the course to determine their attitudes to engineering as a discipline, their evaluation of their own skills relative to their university peers and their disciplinary peers. In the post survey they were also asked questions regarding specific aspects of both courses and how useful they found them.

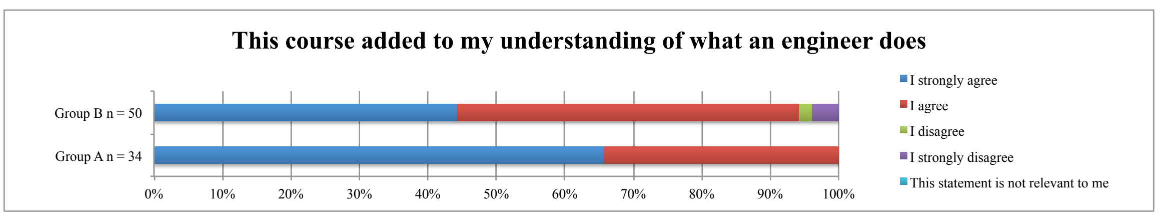
The pre and post survey yielded a large amount of data on students' perceptions of both the discipline and themselves with regard to a series of attributes: creativity, innovation, logic, intelligence big-picture thinking, etc. This data needs further analysis by the evaluation team to determine any statistically significant differences either between the groups or between between the pre and post surveys.

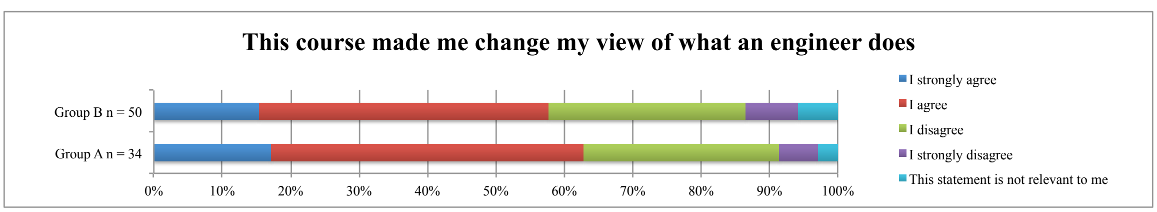
In the post survey students were asked a number of common questions about how the course in general influenced their perceptions of engineering and engineering learning. The results of these questions are presented in Figure 4. The results are interesting in that there are very few differences in the two groups' responses to many of the questions despite the different teaching approaches. For example when asked to rate their agreement with the statement "Taking this course made me look around and see examples of statics principles and formulas in my everyday environment," 100% of students from Group A agreed or strongly agreed with the statement, but so did 90% of the students from Group B. Group A had been explicitly required to find examples of statics principles in their everyday life on every homework assignment, while Group B had not. In fact it is encouraging that students in Group B, who were encouraged but not required to try to relate their statics lectures to real structures they encountered clearly began to do this of their own accord. Although it should be noted that when actually asked to demonstrate knowledge of statics principles from their everyday lives on the short answer questions on the exam, Group A had more detailed answers.

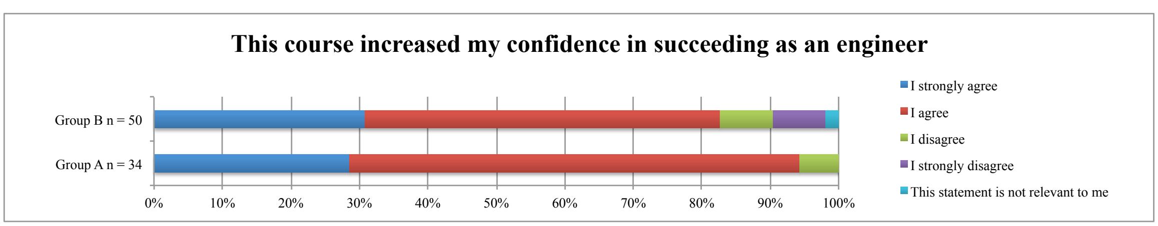
Similar results were seen when students were asked if the course improved their understanding of what professional engineers do and if the course had improved their confidence in their future success in engineering. One question where measureable difference could be seen concerned creativity. Approximately 35% more students in Group A (relative to Group B) agreed that the course had made them think of engineering as more creative than they had before. Since fostering greater appreciation for creativity in engineering was an explicit goal of the instructor for Group A, but not for Group B, this result is not so surprising. Also, a greater percentage of Group A students (73% vs 43% for Group B) felt that active participation in lecture was crucial for success in the course. This was also a stated goal for Group A.

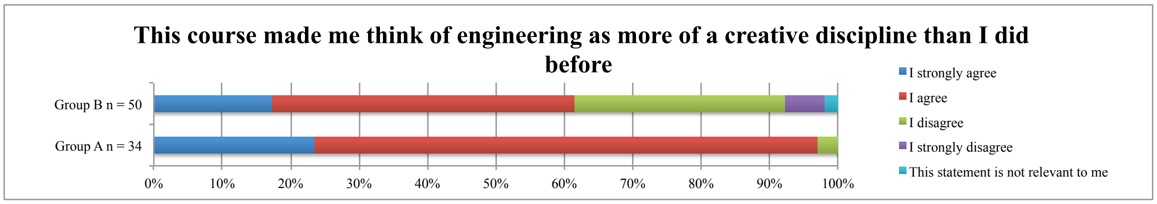
Figure 4
Common Questions from the Post Survey

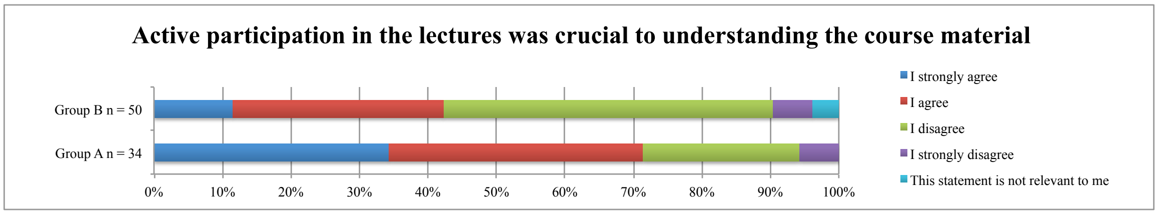


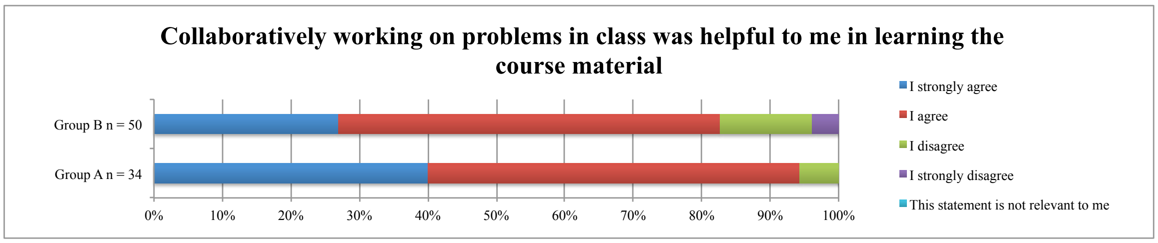












A series of course specific questions were also asked to each group. The results from the Group A specific questions are presented in Figure 5 and the results from the Group B specific questions are presented in Figure 6. Figure 5 shows that a large majority (approximately 90%) of students in Group A understood the instructors' goals and had responded positively to the methodologies aimed at meeting those goals.

Figure 5

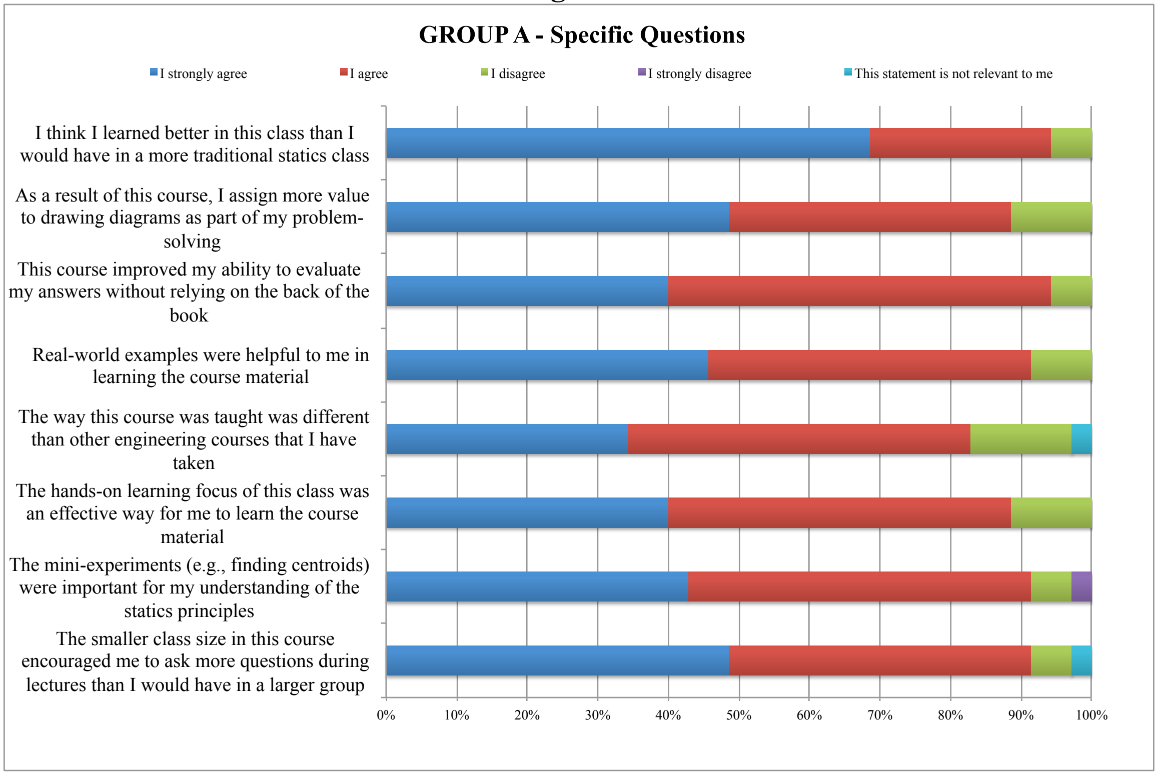
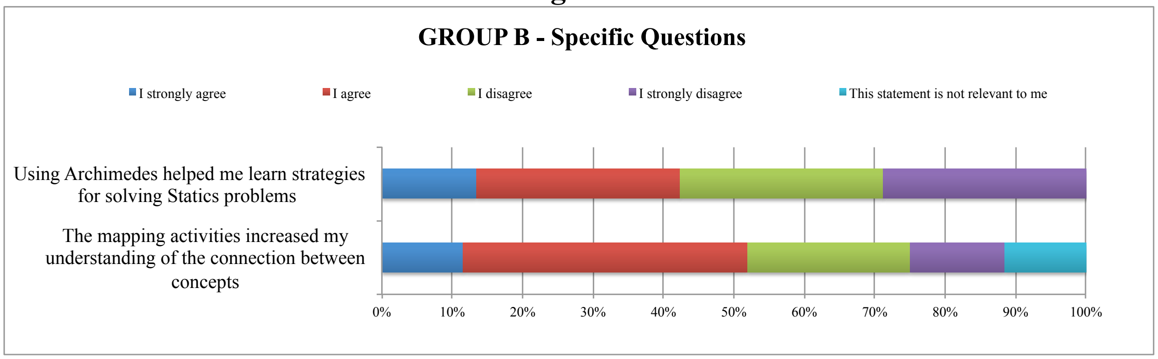


Figure 6 shows that students in Group B were somewhat less responsive to the specific methodologies used. Student reaction to ARCHIMEDES (gathered from Group B students independently from this survey) ranged from "it challenges me" to "I don't like it but it forces me to solve the problem correctly" to "I hate using ARCHIMEDES". It is not surprising that only 42% of the students in this survey responded that ARCHIMEDES helped me learn strategies for solving Statics problems. Students that understand the logical problem-solving process find ARCHIMEDES repetitive and unnecessary, while students with extremely poor algebra skills have difficulty writing the equations even when the equation that is not correct is identified. The instructor for Group B has found that students in the mid-range benefit most from ARCHIMEDES.

Some students liked OLI and asked the instructor to continue using it. Others felt there were too many on-line programs to deal with and were uncomfortable with the fact that the same terminology was not used in the text and within OLI.

Figure 6



7. Conclusions and Further Study

The results of this study are inconclusive. Control groups are very hard to establish in a teaching environment where one cannot deliberately give one group what one believes to be less effective teaching. In this case, there were two groups with two instructors testing methodologies that have proven effective in other contexts. Group A was testing a number of methodologies that are suited only to smaller groups, while Group B being the larger was looking at strategies that can be deployed in the traditional large lecture course.

There is some evidence that increased exposure to real world examples of statics principles yields students who are better able to interpret what they are learning and what that knowledge is used for. There is some evidence that students in a smaller class size will participate more and will cite that participation as crucial to their success in the course. It is also reasonable to conclude that focusing on real world engineers and engineering gives students a greater appreciation of engineering as a creative discipline.

Both groups in the post survey agreed strongly with the idea that statics contributed to their knowledge of what an engineer does, made them change their ideas about what an engineer does, and made them more confident about their future engineering learning. This is the single most significant result from the study and it strongly reinforces our proposition that statics is a very important course in the "engineering design of an engineer." Thus it is important that further study be undertaken on this topic. Further study is required to identify the most successful teaching strategies for increasing students' knowledge about and enthusiasm for engineering as a career, and the most successful strategies for ensuring future success as an engineer.

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