2006-1283: MAKING STATICS A FRIEND FOR LIFE

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Kevin Dong, S.E. is an Associate Professor of Architectural Engineering (ARCE) at Cal Poly – San Luis Obispo. For the past five years he has been teaching classes that emphasize structural systems and structural design to various majors (Architecture, Architectural Engineering, and Construction Management) within the College of Environmental Design and Architecture. His class work utilizes his 13 years of experience with Ove Arup & Partners (ARUP), where he worked in both the San Francisco and London offices. As an Associate with ARUP he worked on a wide variety of projects within the United States and abroad. A trademark of all the projects was the concept of integrated design where the building solution incorporates the design efficiencies and aesthetics from each building discipline. This approach to design is stressed in all of his courses for engineers, architects, and construction managers alike.

Additionally, he is interested in promoting “hands-on” learning using interactive activities. Most of his courses include activities that involve model building, construction simulation, and sketching to reinforce engineering principles or emulate engineering practice.

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Making Statics a Friend for Life

Overview

This paper presents an alternative way to teach entry-level engineering principles, in this case statics and strength of materials. The material presented focuses on engaging students through the use of hands-on model building activities, the re-packaging of engineering topics, and the impact student contact time has on the success of a program. An emeritus faculty member coined the phrase noted above and this paper outlines how this new course sequence has given new life to both students and faculty at our institution in hopes of making statics a friend for life.

Historical

Five years ago a charge was made by the Cal Poly Architectural Engineering Department to revamp the 2nd year engineering series. The task was to invigorate the students in the College of Architecture and Environmental Design (CAED) - all of whom are required to take engineering courses – with the goal of increasing pass rates and increasing interest in the subject. In the college, Architectural Engineering, Architecture, and Construction Management majors are required to take traditional statics and strength of materials courses so this was no small task.

During the conceptual stages of course development, six key issues (the 6 I's) were identified to make the new series a success:

1. Increase effective contact time
2. Incorporate tactile (kinesthetic) learning[1] versus aural (passive) learning in order to provide another avenue for reaching the students
3. Introduce conceptual ideas with physical modeling exercises then reinforce with calculations
4. Infuse statics topics with related strength of materials topics "simultaneously" in the same course
5. Integrate 3-dimensional stability into the curriculum from the start
6. Insist on the same rigor of a traditional engineering course

The critical change was increasing contact time with the students. The previous engineering series consisted of three (3) one-hour lectures with 32 students per section. The new series consists of two courses, Structures I and Structures II. Each course consists of two (2) one-hour lectures plus a 2-hour activity session and a decrease in the classroom size from 32 students to 24 students. The key component to this change has been the activity. During the activity sessions short lessons are discussed followed by a hands-on model building exercise that targets the topic discussed. In this manner, students immediately apply topics discussed in the lecture to physical models, which help reinforce abstract engineering concepts. An ancillary benefit has been the additional contact time instructors have to mill around the classroom engaging with students and identifying problem areas immediately.

The Activity

A major concern within the college was to address the teaching approach. As instructors we all learned statics and strength of materials the same – lecture and chalkboard examples led by an instructor or graduate assistant then homework problems from a textbook. The task was to implement a teaching style that would involve students in an active and engaging manner. It was a universal concern that the CAED primarily uses tactile learning activities while the engineering course implemented passive learning techniques. So the question became "how could active learning be incorporated into the engineering curriculum?" The one-hour lecture period was identified as the problem. It did not afford the instructor enough time to teach a lesson and lead a group of students into a model building exercise. So the solution was to increase the meeting time, in this case from one hour to two hours for one of the three weekly class periods. The plan was to lead the class in a short discussion on a specific topic and then introduce an activity or demonstration that reinforced that topic. It was perceived that a two-hour activity session could meet the goals for increased contact time, increased tactile learning by using physical models and demonstrations to introduce engineering concepts, and allowing opportunities to introduce 3-dimensional stability.

This was a major departure from the department's previous way of teaching - introduce concepts using textbook type problems and then follow-up with modeling second and typically the follow-up was in another course. The premise was to instill a visual image of the engineering principal being "discovered" then relate that "discovery" to an equation or concept in hopes of establishing a better understanding in the minds of the students. As an example, the concept of stability and equilibrium are introduced using "the point", "the line", and "the plane" models[2]. First, a conceptual discussion about translations and rotations is presented. Then a more specific discussion ensues where the degrees of freedom are established (3, 5, or 6 degrees of freedom depending on which model is being examined) and whether those degrees of freedom are translational or rotational. And that's the extent of the discussion, no "x", "y", or "z", just movement in this direction or rotation about an axis. The next step is for the students to build a stable model that can restrain motion or an applied force in any direction, (see Figures 1 and 2). Once this activity is complete then the "number crunching" begins. Students are introduced to action and reaction, summing forces to zero, stability principles, and configuration issues – topics typically discussed in a lecture format.

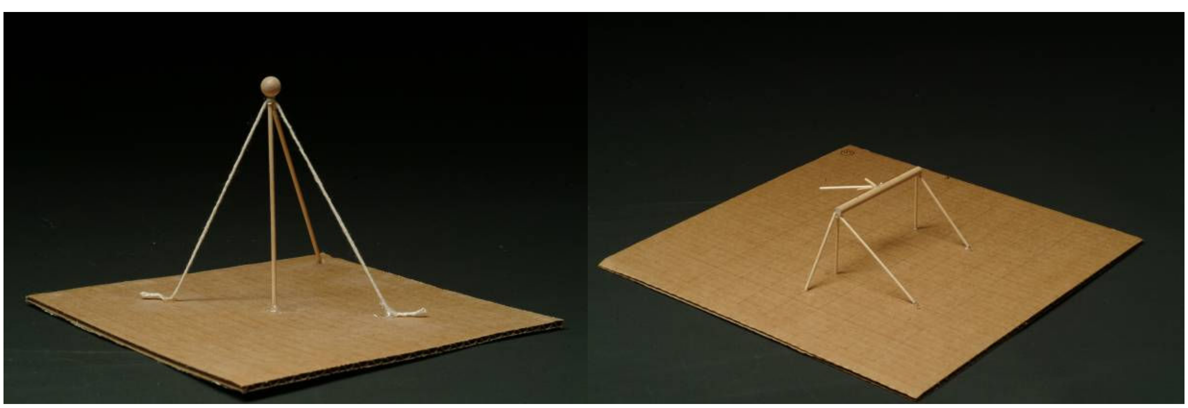

Figure 1 and Figure 2: Point and Line Models

Assessment surveys indicate that the introduction of the activity and model building has made each class more interesting and the students credit the activity for increasing their learning and overall success in the class – a summary of comments and confidence rates are shown on Table 1 and Table 2 at the end of the paper. The activities also allow for individualized student-teacher contact time, which may increase student success rates. The goal was to create a friendly environment in the activities where students would find the instructors "more approachable" and potentially lead to more informal drop-ins during faculty office hours. The intent was to reach out to those students who typically don't use office hours or tutoring for additional instruction because they're intimidated or uncomfortable coming to an instructor's office. This has not been monitored in any scientific manner, but the author has noticed a slightly higher number of students visiting during office hours when these courses were offered.

The Models

The models are a key component for the activity sessions and one of the successes for the new series. It was crucial that instructors not use the activities as an opportunity to lecture for an additional hour since this would defeat the changes being implemented. The models were constructed either individually or in pairs, were typically completed in about an hour, and were part of subsequent homework assignments where the engineering principles could be reinforced numerically.

The models are typically constructed with hot glue, applicator sticks (small dowels), string, and cardboard. All of the model building exercises have been developed to incorporate engineering topics such as; stability, center of mass, shear and moment diagrams, moment of inertia, and horizontal shear, etc... The models also provide a natural means for incorporating three-dimensional equilibrium into the curriculum. There were two goals in mind when using model making as a learning tool: integrate three-dimensional activities from the start since building problems are naturally three-dimensional and show how most three-dimensional problems can be simplified into two-dimensional problems. This meant that most examples were rectilinear, but this conceptual way of teaching allows for students to relate building forms to structural behavior and also allows students to apply abstract concepts to problems that model the built environment.

As an example, a "12-node" model is used as an outgrowth of the point, line, and plane models discussed previously. With this model, as shown in Figure 3, students develop a very simple structure that consists of 12 points (nodes) in space and each node is restrained using columns, beams, and diagonal braces. The next step is for the students to find the imaginary force in each member if a horizontal load is applied to one of the "roof" nodes. In order to find the force in each stick, students solve for the roof plane members using the "x-y" plane, and then find the forces in the vertical and brace elements by using free body diagrams in the "x-z" and "y-z" planes. The result is the students see how the figures in traditional textbooks relate to a simplified three-dimensional building and also begin to understand how buildings behave in three dimensions, i.e. is this diagonal brace going to be in tension or compression? As we progress further in the curriculum, this same model can be used to demonstrate load path concepts (developing the beam and column loading diagrams), demonstrate deformation due to compression and tensile forces by replacing sticks with strings or rubber bands, and axial deformation by adding additional levels. This model is helpful for demonstrating the use of statics in the built environment as well as providing a transition into strength of material topics since students can determine the stress on an element.

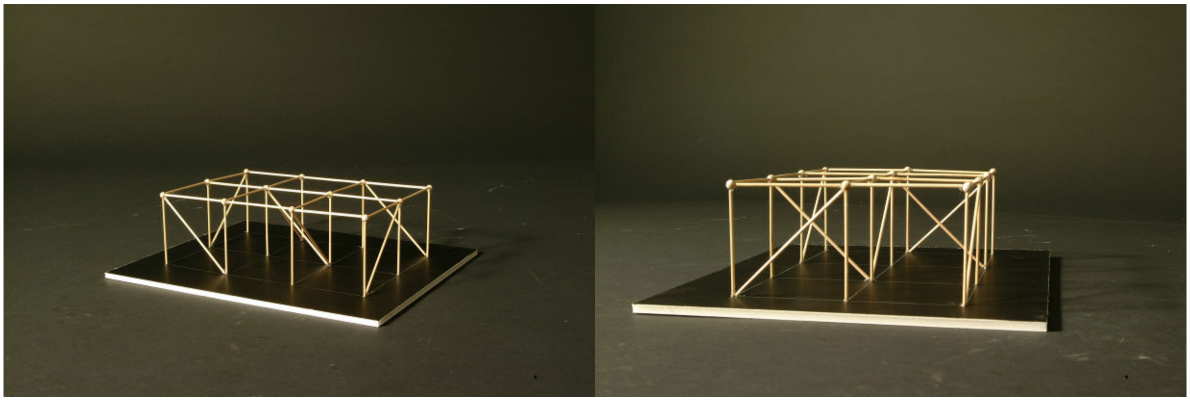

Figure 3 and Figure 4: 12-node model, iteration one

Break from traditional teaching models

Another change that breaks with traditional engineering teaching methods is the material packaging. Previously, students were taught traditional statics in the first course and then strength of materials in the second course. In the new course sequence, statics and strength of materials topics are covered in both courses. The two courses can best be termed “the axial course” and “the shear and bending course”. The first course, Structures I, covers basic statics (reactions and loads), stability and equilibrium in 3 dimensions, truss analysis, axial stress and axial deformation. The second course, Structures II, covers shear and moment diagrams, bending stress, horizontal shear stress plus combined axial and bending elements. The plan was to group similar topics together so students could make a connection between the statics topic and a related strength of materials topic: or more simply put, relate what happens externally to what happens internally.

As an example, in the new sequence students analyze beams using shear and moment diagrams and then evaluate the stresses by calculating moments of inertia using the parallel axis theorem and bending theory in the same class. The intent is for students to draw a direct correlation between why we develop shear and moment diagrams and what it’s used for, rather than learning how to draw the diagrams in statics and then in the next term learn how to calculate bending stress. As instructors, we separate statics and mechanics materials because they deal with different concepts, but in the working world, statics and mechanics problems are solved simultaneously every day, so this procedure is copied in the classroom to give the students immediate exposure to simplified member design. Students see how shear and moment diagrams can be used to determine bending stresses, average shear stresses, and horizontal shear stresses in one process.

The development of activities and homework problems that deal with buildings was another requisite of the course. Since our students – CM, ARCH, ARCE - all deal with the built environment, the topics and the related homework were geared to match problems seen in the “industry”. In order to fulfill this goal, load path problems were added into the curriculum.

Students were taught how to draw and "read" a framing plan and then how to trace a load to the ground. This gave the students something tangible – why are we doing this - and a direct application to real world situations. Our "hands on approach" philosophy is epitomized by the Structures II capstone project; students build a simple two-story model, draw a floor framing plan, develop the beam and column loading diagrams, compute the shear and moment diagrams for the beams and the axial load diagrams for the columns, calculate the internal stresses for the beams and the columns, and then finish by calculating the vertical displacement for the columns. This capstone exercise pulls all of the concepts traditionally covered in two separate courses into one exercise with the addition of load path concepts. Ultimately, students should be better prepared for their upper division design courses where load path and simple analysis problems are assigned routinely. A simple one-story structure is shown below in Figure 5 and Figure 6.

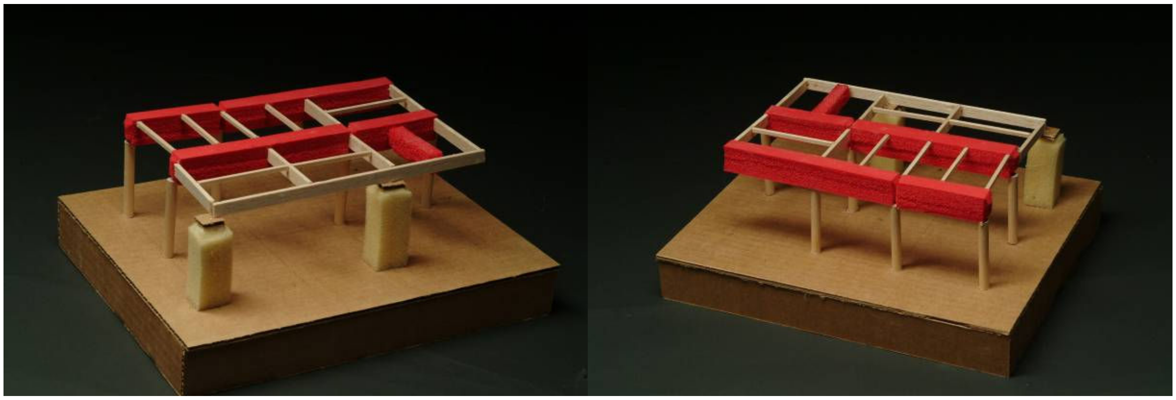

Figure 5 and Figure 6: One-Story Load Path Example Problem

Progress Report

One of the unexpected learning outcomes of the course sequencing is that students come into the shear and bending course with a solid grasp of statics which enables them to draw shear and moment diagrams that "close" from the start. In our old sequence students were taught basic statics and shear and moment diagrams together. Repetition has been one of the keys to our success, so now that students have one complete term to grasp the concepts of centroids, reactions, and internal pins, they are better prepared and have a better chance at drawing correct shear and moment diagrams.

The program is in its second year of implementation. So far, the results have been positive based on student assessment/questionnaires and student passing rates. The students have identified the activity sessions and model making exercises as key points in understanding the material presented in class. Student performance reflects this sentiment - failure rates have decreased dramatically when compared to the failure rate for our old engineering sequence. In the first year when ARCE 211, Structures I, and ARCE 212, Structures II, were offered about fifteen percent failed to progress to the next course. Since the new sequence was introduced in Fall 2005 a definite trend towards higher success has been achieved, previously one-fourth to one-third of a class failed the older sequence where statics and strength of materials were taught primarily in a lecture format. This heightened level of success has given the students and faculty alike a new perspective towards engineering.

In the first year weekly meetings were scheduled to discuss what did and did not work and most importantly plans for the activity session. Normally an idea for the session was planned, but with collaborative effort of the group, activities were tweaked in hopes of developing something successful. The initial activities were like faculty design projects, the final "solution" was iterative not direct, and even today, we revisit the activities developed last year in hopes of ferreting out all the bugs. An example is the center of mass activity. This initially started as a two dimensional problem – cutting a cardboard shape and hanging it from its center of gravity. After group review, the activity developed into a three-dimensional problem where "the plane" model was further developed to include "cut-outs" (negative space) and "add-ons" so that multiple shapes could be integrated into the problem and a bit of design is incorporated as well. (See Figures 7 and 8) The whole process of developing new and intriguing hands-on activities has re-charged the faculty and given each a sense of ownership to the class which in turn has helped with the student success.

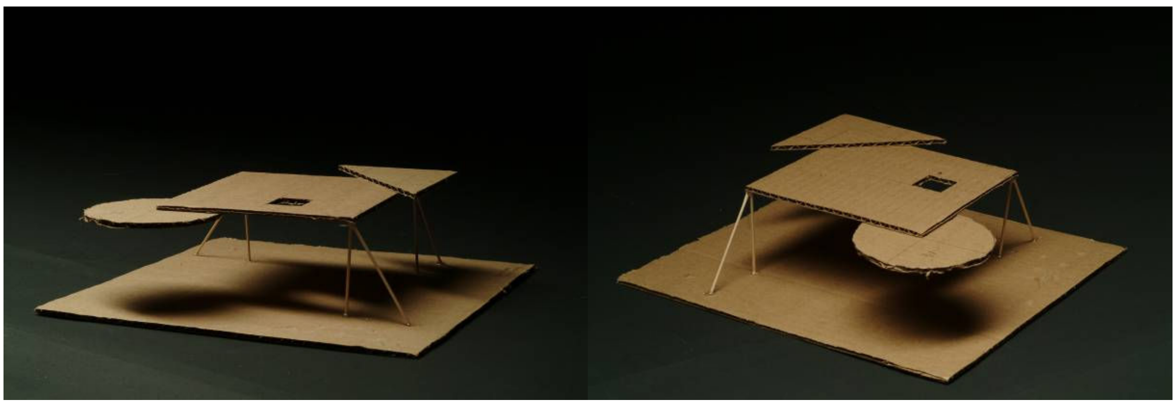

Figure 7 and Figure 8: Center of Mass Model

The model building aspect incorporated in the activity session has addressed most of our goals at once. The models have increased the students' kinetic learning, provided a mechanism to increase contact time and introduce engineering principles on a conceptual level first and follow-up with rigorous calculations second, and integrate stability. Based on student feedback, this is the most popular portion of the class and the students credit the activities with their success in the class. Even if the department were to revert back to the "old way" of teaching the classes, faculty would find a way to incorporate some of the new activities into the old sequence. The activities have proved to be vital to the success of our teaching and the students enjoy participating in this manner.

The process of developing and implementing this new series has brought new life into the department. It's common to find faculty members discussing the next "big model" or how "I'm going to do it next time". The faculty has been re-invigorated in finding new and improved techniques for teaching the "old" topics. As an instructor, it's gratifying to know we are contributing positively to society and on a smaller "ARCE" scale it's nice to know we're one step closer to making "statics a friend for life" for our students.

Tables

ARCE 211: Structures I
Exit Assessment

How confident are you with the following topics? Do you think you could explain either verbally or numerically or a combination of both the following topics to one of your classmates? Please answer the following questions dealing with the following engineering topics.

What is your confidence level with …

1) Summing moments and forces & equilibrium in 2-dimensions

(15) Very (I rock, bring it on)	Not Very (let me check with someone first)
(7) Somewhat (I'm better than 50-50)	Not at all (I'm drawing a blank here)

2) Summing moments and forces & equilibrium in 3-dimensions

(6) Very (I rock, bring it on)	**(6)** Not Very (let me check with someone first)
(10) Somewhat (I'm better than 50-50)	Not at all (I'm drawing a blank here)

3) Creating stable 3-dimensional arrangements with compression and tension members

(6) Very (I rock, bring it on)	**(5)** Not Very (let me check with someone first)
(11) Somewhat (I'm better than 50-50)	Not at all (I'm drawing a blank here)

4) Determining the internal stresses for axial loaded elements

(7) Very (I rock, bring it on)	**(1)** Not Very (let me check with someone first)
(14) Somewhat (I'm better than 50-50)	Not at all (I'm drawing a blank here)

5) Determining the deformation for an axial loaded element

(3) Very (I rock, bring it on)	**(3)** Not Very (let me check with someone first)
(16) Somewhat (I'm better than 50-50)	Not at all (I'm drawing a blank here)

6) Modeling/analyzing a truss or braced frame in a simple building

(7) Very (I rock, bring it on)	**(1)** Not Very (let me check with someone first)
(14) Somewhat (I'm better than 50-50)	Not at all (I'm drawing a blank here)

- ARCE 211 is the first course in the new 2nd year architectural engineering series. What do you feel are the strengths and weaknesses of the new course? What could be provided or was provided to aide in successful completion of this course? Your input is greatly appreciated.

  1. Activity sessions were very helpful; hands-on activities to lecture material
  2. Assignments in activity are helpful
  3. Spend more time solving problems in the activity session (tutorial sessions)
  4. More homework examples, otherwise a great course
  5. Activity session made class run smoother than ARCE 221.
  6. ARCE 211 is a better class than ARCE 221
  7. Cover 2-D material prior to 3-D material, more 3D coverage.
  8. 2-D material was harder to understand than 3-D material
  9. Add an extra hour of class

Table 1: Exit Assessment and Comment Sheet for ARCE 211: Structures I

How confident are you with the following topics? Do you think you could explain either verbally or numerically or a combination of both the following topics to one of your classmates? Please answer the following questions dealing with the following engineering topics.

What is your confidence level with …

1) Summing moments and forces & equilibrium in 2-dimensions

   [35] Very (I rock, bring it on) — Not Very (let me check with someone first)
   [2] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

2) Summing moments and forces & equilibrium in 3-dimensions

   [19] Very (I rock, bring it on) — **[1]** Not Very (let me check with someone first)
   [17] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

3) Determining the internal stresses for axial loaded elements

   [12] Very (I rock, bring it on) — **[4]** Not Very (let me check with someone first)
   [21] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

4) Determining the deformation for axial loaded elements

   [14] Very (I rock, bring it on) — **[3]** Not Very (let me check with someone first)
   [20] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

5) Determining member reactions and forces for pinned frame systems

   [23] Very (I rock, bring it on) — **[1]** Not Very (let me check with someone first)
   [13] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

6) Drawing the free body diagram and determining reactions for systems with pulleys

   [16] Very (I rock, bring it on) — **[3]** Not Very (let me check with someone first)
   [17] Somewhat (I'm better than 50-50) — **[1]** Not at all (I'm drawing a blank here)

7) Drawing shear and moment diagrams for beams with point loads

   [35] Very (I rock, bring it on) — **[1]** Not Very (let me check with someone first)
   [1] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

8) Drawing shear and moment diagrams for beams with uniformly distributed loads

   [33] Very (I rock, bring it on) — Not Very (let me check with someone first)
   [4] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

9) Drawing shear and moment diagrams for beams with linear distributed loads

   [17] Very (I rock, bring it on) — **[3]** Not Very (let me check with someone first)
   [17] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

10) Determining the neutral axis location for an asymmetrical cross sectional shape

   [25] Very (I rock, bring it on) — **[1]** Not Very (let me check with someone first)
   [11] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

11) Determining the moment of inertia for a beam with an asymmetrical cross section

   [18] Very (I rock, bring it on) — **[3]** Not Very (let me check with someone first)
   [16] Somewhat (I'm better than 50-50) — Not at all (I'm drawing a blank here)

12) Determining the bending stresses in a beam

[11] Very (I rock, bring it on) | **[3]** Not Very (let me check with someone first)
[23] Somewhat (I'm better than 50-50) | Not at all (I'm drawing a blank here)

13) Determining horizontal shear stresses in a beam

[7] Very (I rock, bring it on) | **[9]** Not Very (let me check with someone first)
[21] Somewhat (I'm better than 50-50) | Not at all (I'm drawing a blank here)

14) Determining the combined axial and bending stresses along a cross section

[3] Very (I rock, bring it on) | **[11]** Not Very (let me check with someone first)
[23] Somewhat (I'm better than 50-50) | Not at all (I'm drawing a blank here)

- ARCE 212 is the second course in the new 2nd year architectural engineering series. What do you feel are the strengths and weaknesses of the new course? What could be provided or was provided to aide in successful completion of this course? Your input is greatly appreciated.

1) I like the practical application, ie. looking up the beam moments etc…
2) Good course
3) The activity session definitely helped since most of the exercises brought clarity to the topics covered.
4) This class had a good flow and mixed well with ARCE 211
5) Pace was okay, might help to introduce stresses earlier in the quarter allowing students time to learn better.
6) I think the course was a success. The activities are a good idea, especially the one regarding tracing loads throughout a girder-joist-column.
7) Often dreaded lab, but it helped clarify the topics
8) I think this is a good class and it was taught very well
9) I wish there was a little more model building
10) I'm not sure I would change anything about the class, I love the activity
11) The class was very well run … I really enjoyed the teaching style … example problems and notes were very helpful.
12) I thought it was a good course, perhaps spending more time on stress and load flow would help
13) This class was well organized, well prepared, grading was "fair game". Lab portion takes away from lecture time, but it is good to get the hands on experience.
14) The tutoring center was a great idea this quarter, it allows students to work with other students when sometimes the teacher is not around.
15) I appreciate spending an extended period of time on the shear & moment diagrams as that topic was completely new and tricky in the beginning. Tutoring a plus!
16) I felt I learned a lot more efficiently in this second course, especially cuz the teacher was more understandable. The concepts this quarter were easier to understand, but it seemed to be crammed into the quarter. But besides the point, I thought this class was successful.

Table 2: Exit Assessment and Comment Sheet for ARCE 212: Structures II

Acknowledgements

These courses wouldn't be a success without the imagination and thoughtfulness of emeritus Professor Jake Feldman. Jake helped develop the base models used in the Structures I course and has been a strong and vocal advocate of learning with models. Additionally, I would like to thank the entire Architectural Engineering faculty. Without their dedication and willingness to try something new, we would be missing out on a new adventure in teaching.

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