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Hands-On Beam Models and Matching Spreadsheets Enhance Perceptual Learning of Beam Bending

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Dr. Al-Hammoud is a Faculty lecturer (Graduate Attributes) in the department of civil and environmental engineering at the University of Waterloo. Dr. Al-Hammoud has a passion for teaching where she continuously seeks new technologies to involve students in their learning process. She is actively involved in the Ideas Clinic, a major experiential learning initiative at the University of Waterloo. She is also responsible for developing a process and assessing graduate attributes at the department to target areas for improvement in the curriculum. This resulted in several publications in this educational research areas. Dr. Al-Hammoud won the "Ameet and Meena Chakma award for exceptional teaching by a student" in 2014 from University of Waterloo. Her students regard her as an innovative teacher who introduced new ideas to the classroom. Such ideas include using "props" to increase students' understanding of the materials, as well as using new technology such as i-clickers and IF-AT cards. Dr. Al-Hammoud also organized a bridge-building contest in one of her courses where she worked with other professors in the department to integrate the project horizontally across the curriculum.

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Abstract

This evidence-based practice paper explores the use of a physical beam model and an accompanying spreadsheet that plots deflection, slope, shear, moment, and loading diagrams as teaching tools. These tools were used to reinforce engineering theory as part of a second year civil engineering statics and solid mechanics course.

The models consisted of three beams of known cross-section and stiffness, two supports which could be altered to provide clamped or simple support, and two dial gauges to measure beam deflection, all of which could be affixed to a base delineated with markings to quantify the distances between individual model components. Steel weights could be placed at any portion along the beam to apply vertical point loads to the beam. The physical model was accompanied by an electronic spreadsheet that back-calculated diagrams for slope, curvature, shear, moment, and loading. This was done based on the beam geometry, Young's modulus, and boundary conditions, as well as the measured deflections at the loaded points.

In the first of two exercises students examined clamped, simple, and free boundary conditions. They also observed linearity between loading and deflection, and used statics to calculate shear and moment diagrams. Students compared their calculations and plotted diagrams with a spreadsheet that plotted a full set of beam diagrams. The goal of this exercise was to encourage students to start thinking about the notion that deflection, slope, and curvature are related to loading and boundary conditions.

In a second session, after the students had been taught methods for calculating deflections in statically determinate beams, they examined model beams with various strategic boundary conditions and load patterns, looking for physical manifestations of deflection, slope, and curvature (moment) within those beams. As part of this exercise, students chose a particular beam design and loading, and used a version of the spreadsheet that could plot all of the beam diagrams based on geometric and boundary condition information and measured deflections at the loaded points. By comparing their model beam with the spreadsheet diagrams, students were able to make and strengthen their connections between mathematical, visual, and kinesthetic representations of beam bending.

After each exercise, students were asked to provide written feedback on the effectiveness of the exercise through questions such as: "What are three specific things you learned about beams today?", "Which observations were unexpected or in conflict with your intuition?", and "How did the physical model and spreadsheet enable you to better understand the operation of beams?" The students noted that the exercise helped them understand how the different support conditions, material properties, and applied loads affect the deflection of the beam. They also stated that the spreadsheet helped them understand the relationship between deflection, slope, and curvature. After changing the support conditions of the beam, the students mentioned that some of their observed beam deflections conflicted with their intuition, which made them question why the beam

behaved this way. This exercise helped the students think about how the theory relates to actual beam behavior and vice-versa.

Introduction

Traditionally, engineering lectures have been designed to deliver large amounts of theoretical content to students. The students have then been given written problems to solve using this content. While this method has had success in the past, it has been suggested that incorporating aspects of active learning into these lectures would help to increase understanding and knowledge retention, and to promote knowledge synthesis in students (1). The University of Waterloo's Centre for Teaching Excellence and the Engineering Ideas Clinic advocate the "intentional and reflective learning from experience" by students in lectures. This is commonly known as experiential learning (2; 3; 4).

This paper presents the findings of a pilot study into the use of bending beam models in a second-year engineering course. The activity was conceived with the intention of improving the understanding of the second-year engineering students in the area of beam bending. This included drawing connections between physical deflections and their corresponding internal bending moments and shear forces. The study used the models as a means to incorporate inductive and experiential learning into a typical undergraduate engineering course.

Overview of the Use of Models in Student Learning

The use of models to teach engineering concepts can be incorporated into a form of inductive education. In inductive education, an instructor will first introduce problems or case studies to students and then introduce and explain theories and tools which can be used to solve the problems. The goal of this education type is to provide meaningful context to students prior to delivering the related theory which can provide motivation. "You'll need this for the exam" or "you'll need this in your career" may not provide sufficient motivation to engage the students in learning the theories taught (5). The models can be used to illustrate real-world engineering problems in order to provide context to the students. Ambrose et al. suggest that providing students with tasks which authentically replicate or simulate real-world applications of the learning can increase the learning motivation of students (6).

The use of models could help in the development of deep conceptual understanding, which is a prerequisite for developing expertise in a subject. The models provide a means through which the students can interactively engage with the subject material being taught (7).

In addition to the inductive teaching opportunity that models provide, they also can serve as a differentiated style through which to teach engineering theory. There is often a mismatch between the learning styles of some engineering students and the traditional teaching styles of engineering professors (8). Also, instructors who provide accommodation for both extremities of learning styles (theoretical, fact based, abstract, intuitive and auditory versus practical, visual and engaging) often create an optimal environment for most, if not all, of the students to learn. It has been recommended that instructors should incorporate hands-on, practical models and examples to support and complement the traditional style of teaching facts and abstract engineering concepts and ideas to aid the learning process of the students (9).

The incorporation of models into engineering education can be described as a form of experiential learning which aims to improve the perceptual learning of engineering design concepts (10). Learning is defined as the process of transforming experience into its objective and subjective forms in order to create knowledge (11). In this circumstance, the beam models show the reactions of structural members to applied forces. The companion spreadsheet then interprets these observable physical reactions to provide insight into the internal loading within the beams. This can then reinforce the link between the students' observations and the related theory.

Learning can be considered a process in which concepts are explained and continually modified by experience rather than an expectation of results or an accumulated storehouse of facts (11). In addition, Kolb suggests that learning be considered an all-inclusive and well-rounded process of adjusting concepts so that they can be efficiently applied to real world situations. The use of models as a form of experience to teach ideas, whether theoretical or design, can serve as a conceptual bridge between life situations which aids creativity, problem solving, decision making, and scientific research (11).

The theory put forward by Kolb has been implemented in various ways, with varying degrees of success. Laboratory education has been found to benefit significantly from the application of Kolb's cycle, including hands-on activities and pre- and post-lab tests to prepare and consolidate the knowledge of the students (12). These theories were implemented within this activity by introducing the models, providing theory to reinforce the knowledge, and then using the models again with a greater knowledge base to consolidate the model and theoretical knowledge.

This process can also serve to maximize the students' knowledge gained by ensuring that each student has some level of preparation prior to the second instance of using the models and that the style of teaching is differentiated. Felder and Silverman (1988) contend that the amount of knowledge gained by any given student in a class is determined by "the student's native ability and prior preparation as well as the compatibility of the student's learning style with the teaching style of the instructor".

Abrahams and Millar (2008) questioned the effectiveness models alone to teach concepts based on observations of 25 science lectures which involved practical activities. According to this article, the primary purpose for the use of practical work is to provide links between concepts and real-life examples. From the observations, it was determined that the use of practical tasks for learning is more effective when it involves both the concepts and the practical models rather than focusing on the practical model alone. It has been generally found that

Also, the effectiveness of the use of models was influenced by the manner in which the activity was introduced and presented. It was observed that an inductive approach was not ineffective but rather using the models as a support system to establish and complement the abstract concepts was an effective method that aided learning. An objection to this theory is that all observations are theory-laden and often times a model or practical example is only considered to be successful if the students obtain results and conclusions which the teacher desires (1).

The previous studies helped to determine how the models might be best used in an engineering course so that they might serve as aids to experiential and inductive learning for the students.

The focus of this study is to implement an experiential learning-based activity in a second-year engineering course. Student feedback will be collected in an attempt to gauge the effectiveness of the activity and potential improvements for future iterations of the activity.

Description of Course

Mechanics 2 (CivE 204) is a second-year engineering course that focuses on statics and solid mechanics. The course begins by outlining systems of static forces in three dimensional statically-determinate systems and the methods which can be used to assess them, including the equilibrium equations. These concepts were then applied to the analysis of statically determinate beams which included the production of moment and shear force diagrams across the length of a given beam.

Following the statics portion of the course, solid mechanics is presented to the students. This portion of the course introduces and expands on the concepts of stress and strain, shear, torsion, and slopes and deflections of beams. The slopes and deflections of statically determinate beams are a specific focus in this section as this topic follows directly from the earlier topics of shear and bending moment diagrams of statically determinate beams.

The calculus behind calculating the deflections of beams is not trivial and can be difficult for students. Also, determining the direction of the deflections can be counterintuitive to the students. To determine the deflections, students must understand the relationships between loading, moment, beam curvature and deflection through calculus concepts. Students then need to understand and apply support, boundary and continuity conditions to the equations developed through the calculus concepts. Furthermore, they must know the material and physical properties of the beams to determine their stiffness “EI” which plays a major role in the beam deflection.

Some key assumptions need to be considered in the deflection calculations, including the fact that the square of the slope of the beam is negligible and that the value of EI remains constant throughout the beam’s length. While the theory behind this method can be followed by most students, it can become somewhat abstract and difficult to relate to the reality.

Objectives of Activity

The relationship between the loading, support conditions, cross-sectional beam characteristics, and deflection properties of structural members is important core knowledge in structural engineering. The section of the course presenting the deflection of statically determinate beams represents the first introduction of this relationship to civil engineering students at the University of Waterloo. For this reason, thorough understanding of this relationship is a key goal of Mechanics 2 and any further reinforcement of this understanding is highly valued.

To this end, an activity was designed to supplement the traditional dispensation method of theoretical knowledge. The aim activity was to allow the students to easily change beam characteristics such as support conditions (types and locations), beam stiffness, and loading pattern. As these characteristics were changed, the students could observe the physical deflections and the loading diagrams of the beam and how they were affected by the changes made to the beams.

The objective of the activity was to provide another means by which the students could make meaningful connections between beam layout, load cases, and beam deflections, with the intention of reinforcing the understanding.

Activity Tools

The activity was comprised of two main tools which the students used together to analyze the loading of statically determinate beams. These two tools were the bending beam kit, which included the physical beams, and the calculation spreadsheet, which took inputs from the students to produce summary plots of the beam.

The bending beam kit was developed and produced by one of the authors at the University of Waterloo. Details of the kit can be found at G. Wayne Brodland's website (13). The development involved several iterations. The cost of each kit was approximately $350 including material and production labour.

Bending Beam Kit

The beam model kits include the following components, which are illustrated in Figure 1 and Figure 2 as delivered to students and in a typical bending beam configuration, respectively:

- One aluminum channel base
- Two supports providing fixed or roller support
- Three beams of varying flexibility
- Two dial gauges for measuring beam displacement
- Six steel weights (nuts) to provide gravity loads on beam

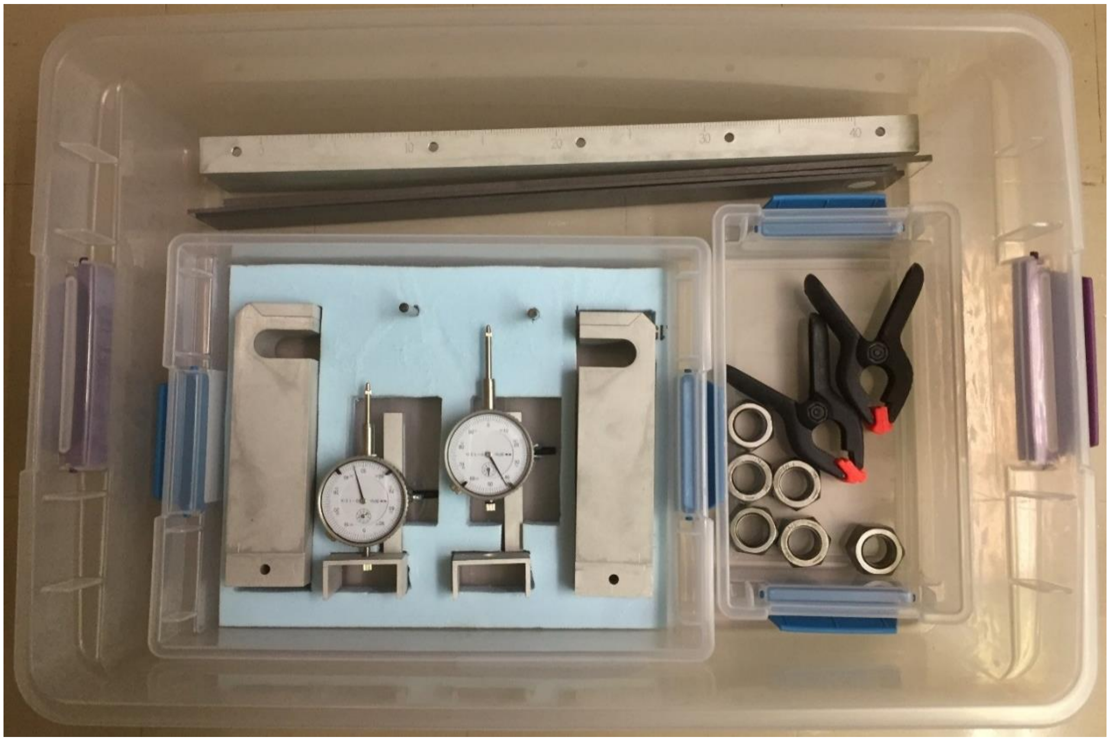

Figure 1: Bending beam kit as delivered to students

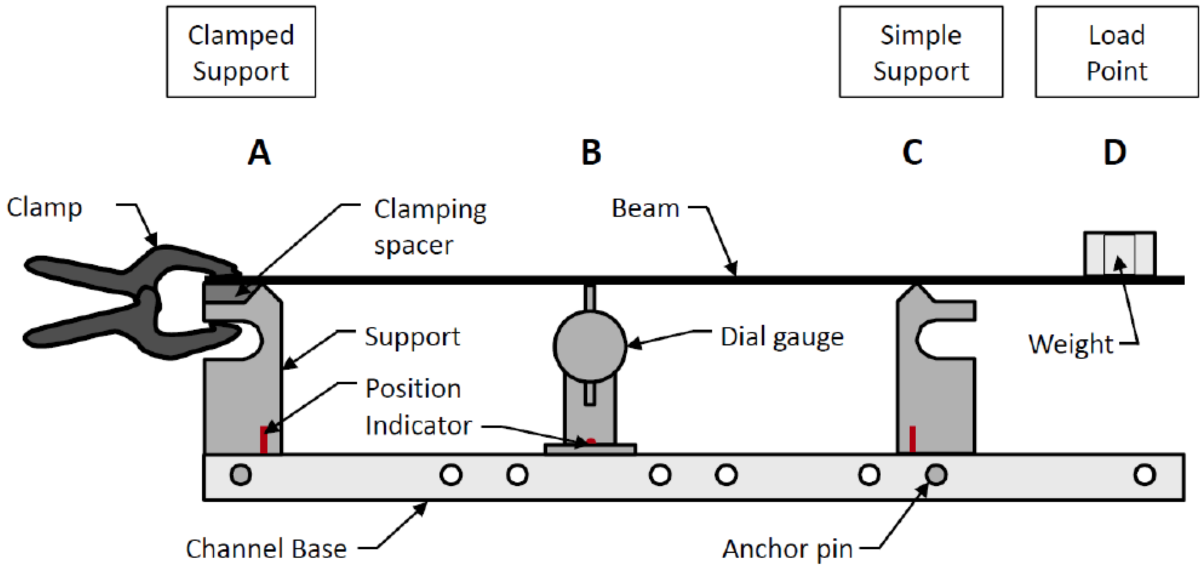

Figure 2: Example configuration of bending beam

The channel base serves to restrict differential movement of supports and deflection measurements through the use of pinned anchors. The supports and dial gauges fit within the base and can be moved longitudinally into place until they are anchored to the base itself. Each side of the base is delineated with markings spaced at 1 mm intervals which are used to determine the relative distance between individual components of the bending beam.

The two supports can provide either clamped support or simple support, which correspond to fixed and roller support, respectively. To provide the fixed condition, a magnetic clamping spacer is first attached to the support column and then a clamp is used to secure the beam to the support column, as shown. In the roller condition, the clamp and clamping spacer are removed and the beam is rested directly on the triangular portion of the support. In this condition the support provides no lateral or bending restriction, only providing an upwards vertical force.

Each of the three beams have similar dimensions of 5mm x 60mm x 400mm. The beams are each made of a polymer, however the mechanical properties of the polymer vary such that the beam stiffnesses are all different. The lower stiffness beams deflect more under a given load.

Two dial gauges were included as part of each bending beam kit and these were used to measure beam deflections. The gauges worked by extending the plunger upwards until it made slight contact with the underside of the beam. The plunger was extended manually by a member of the group. The gauges previously were spring loaded, however the springs were removed after it was found that they caused significant enough vertical force to change the deflection of the beam.

Six weights were also provided with each beam kit. These weights each weighed approximately 80 g and were used to induce local transverse loads on the beam.

Calculation Spreadsheet

Once a beam is chosen and constructed using the bending beam kit described previously, descriptions of its components are entered into a calculation spreadsheet which calculates and plots the deflection, slope, bending moment, shear, and applied load curves for the given configuration and loading case.

The descriptions of the components are entered using tabular inputs wherein the following information can be entered:

- The stiffness of the beam (A, B, or C)
- The support locations along the base channel (one end is specified as 0 m)
- The vertical position at each dial gauge prior to and following the application of load
- The support conditions at the key points (clamped, simply supported, loaded, or free)

Using these inputs, a sketch of the beam is created that can be used by the students to cross-check their inputs with the physical beam layout. An example of a typical layout produced by the spreadsheet is shown in Figure 3.

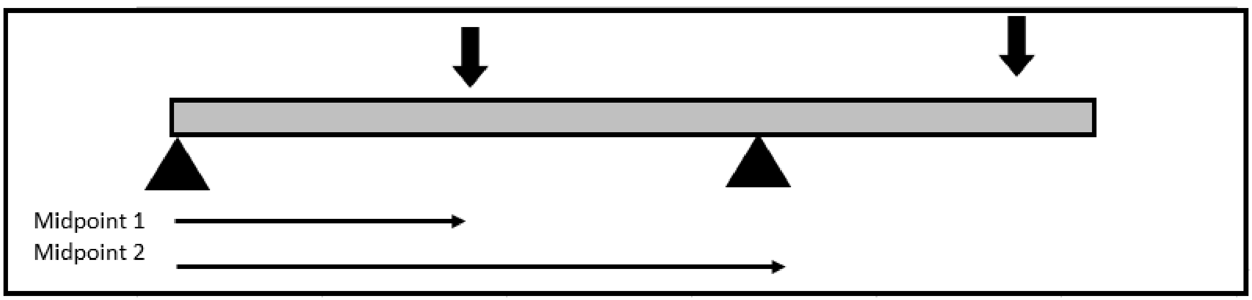

Figure 3: Example beam sketch produced by calculation spreadsheet

The deflection of the loaded beam is measured by taking dial gauge readings at beam locations under both loaded and unloaded conditions. The difference between the two readings provides the deflection of a point at a known location within the beam. Because of the dial gauges used, the deflection values which are input into the spreadsheet are in units of inches. The spreadsheet represents the beam deflection as a series of cubic functions (appropriate if only point loads are applied and the deflections are measured at all loading points) with appropriate continuity conditions and specified deflections. The linear equations used to determine the unknown coefficients in these polynomials contain just the right number of equations; two from typical endpoints, and 4 from typical internal key points.

When all inputs are entered into the spreadsheet, five plots are produced. These plots are deflection, slope, curvature (moment), shear, and load distribution across the beam. A sample of these plots for a simply supported beam with an overhang past the rightmost support is shown in Figure 4.

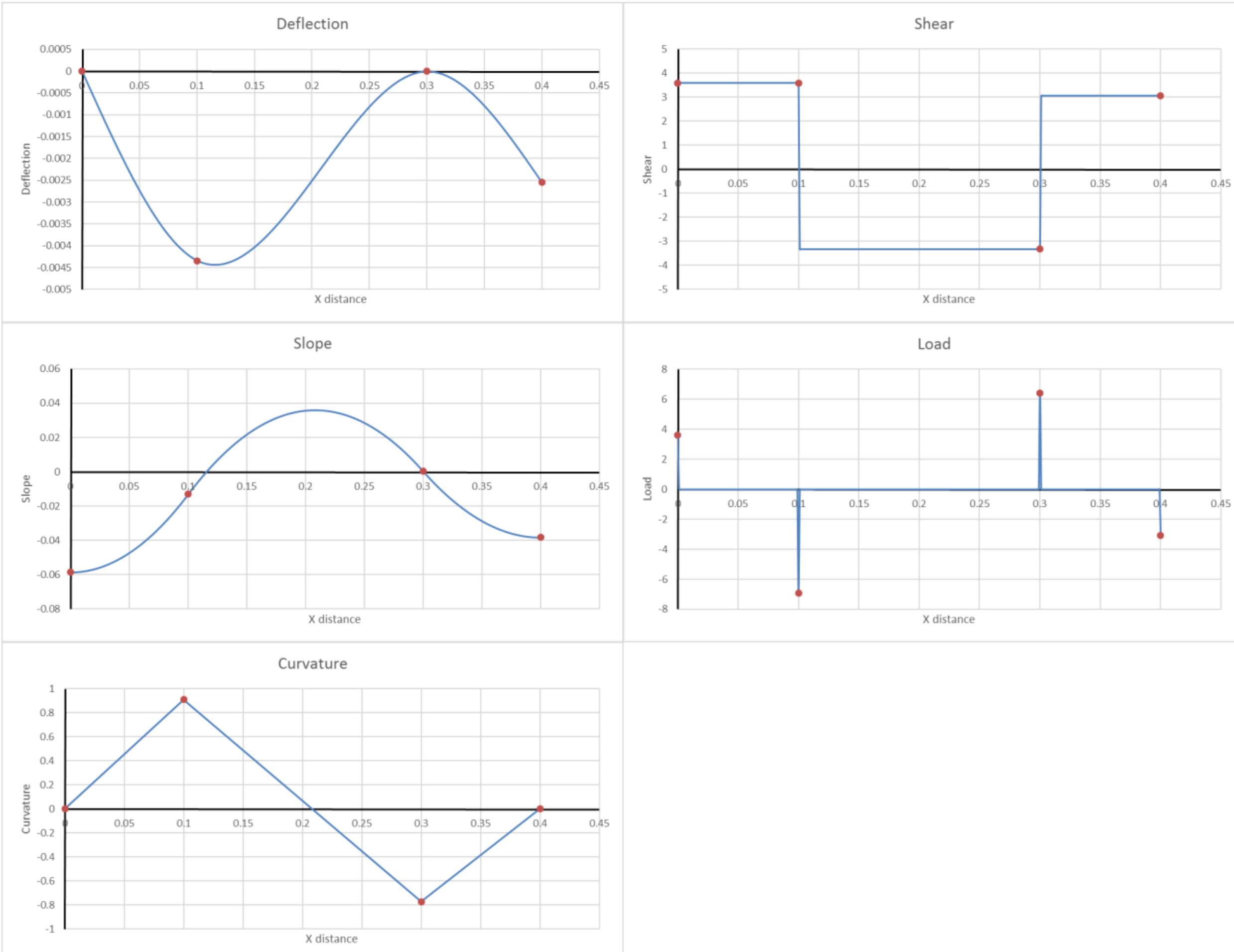

Figure 4: Sample output plots from Calculation Spreadsheet

The plots are based on information from four points (shown as large data points on the plots) for which loading information or support conditions are known. Because the spreadsheet was based on the assumption that all applied loads were point loads, the deflection between the input points can be represented by three separate cubic equations. The coefficients of these equations are determined using the known deflections and support conditions at each point and satisfying beam continuity. Once these equations are determined, they can be used to derive the slope, curvature, shear, and load plots.

The plots can be compared to the observable shape of the beam as well as to the plots which were produced by the students prior to the tutorial.

Activity Description

The bending beam activity was delivered to the students in two parts. Each part was comprised of a tutorial and an anonymous survey pertaining to the findings and effectiveness of the survey.

As part of an inductive, experiential learning design, the first tutorial was used to introduce the idea of relating bending and deflection of a structural member to the internal loading diagrams. This idea was then reinforced with theory during typical engineering lectures.

The goal of the second tutorial was to consolidate the knowledge gained during the first tutorial and subsequent lectures on theory. Any ties which had initially been made between the models, theory, and real world engineering, could be strengthened by using the models with and understanding of the underlying theory which the students did not have during the first tutorial.

First Tutorial

The first tutorial occurred during the portion of the course involving the production of moment and shear diagrams for statically determinate beams.

Prior to the tutorial, the students were provided with general cases and encouraged to assume values and produce shear and moment diagrams for these cases. The cases which were suggested for analysis were a cantilever and a simply supported beam with one overhang edge. The general diagrams which were provided to the students are shown in Figure 5.

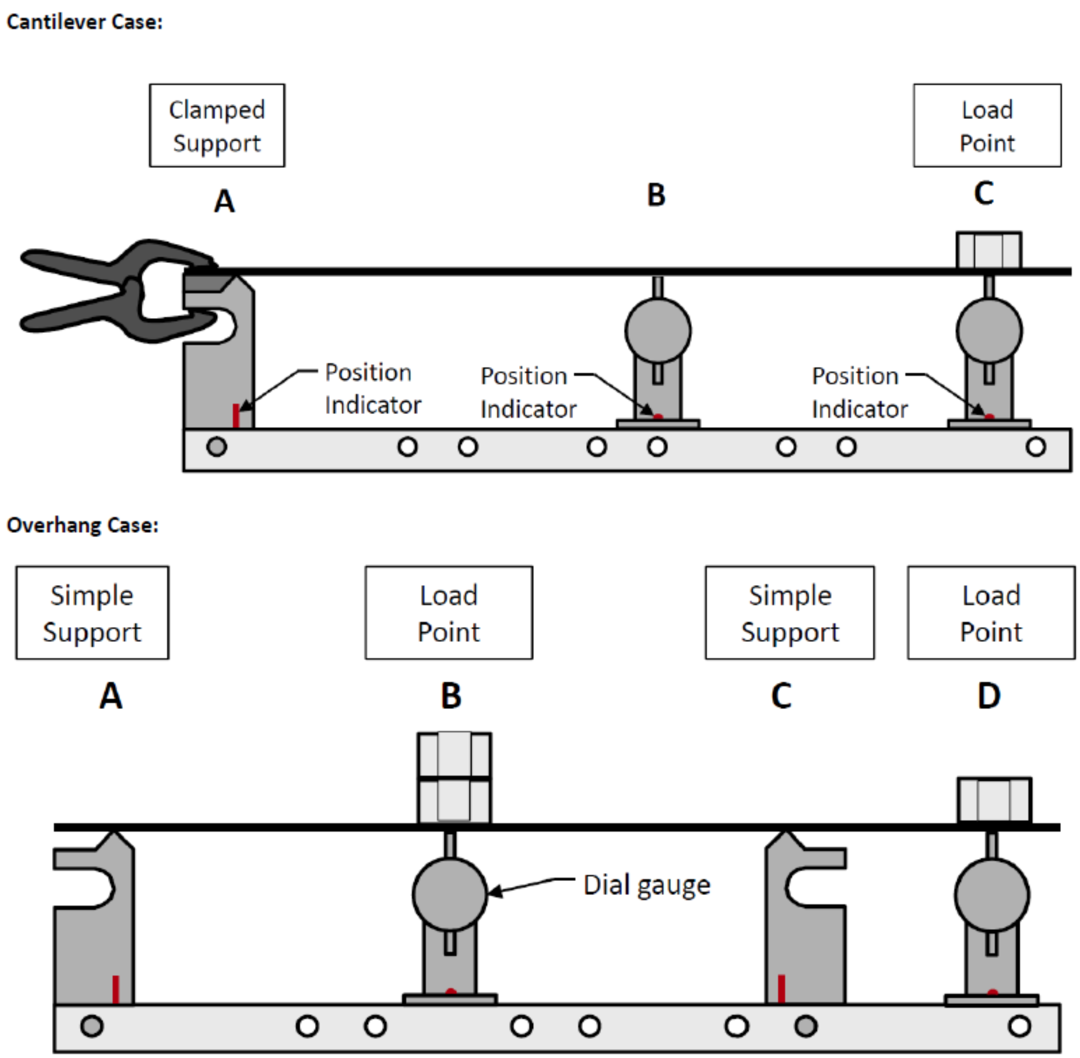

Figure 5: General cases for first beam tutorial

On the day of the tutorial, the class was split into four sections which were each given 30 minutes to work with the bending beams. This was done because there were only five bending beam kits for a class of 120 students. The students were asked to assemble groups of 6 students at the beginning of the tutorial, with at least one portable computer per group.

Once the groups were formed, the students were introduced to the components of the beam kit as well as the calculation spreadsheet. Following the introductory explanation, the students were encouraged to begin using the kit to build the suggested beams and then analyze them under loading conditions.

The students were encouraged to compare their own previously produced plots against the results which were produced by the spreadsheet in order to observe any similarities or differences.

The first goal of the first tutorial was to familiarize the students with the beam kits to better facilitate their subsequent uses. Secondly, the exercise was designed to initiate critical thought about the relationships between loading and boundary conditions and the beam's deflection, slope, and curvature.

First Student Feedback Survey

Following the completion of the first tutorial, the students were asked to complete a short online survey regarding the tutorial and its effects. The purpose of the survey was to gain insight into the effectiveness of the activity and any changes that should be made prior to undertaking the second tutorial. A total of 69 responses to the survey were collected.

The first portion of the survey provided statements for which the students were asked to indicate their level of agreement. The statements were relevant to the usefulness of the activity as a whole. The response ranged from "Strongly Agree" to "Strongly Disagree". The statements provided included the following:

1. I WOULD recommend this activity to future students in my program
2. The activity was NOT relevant to my discipline
3. I DEVELOPED an awareness of the importance of safety in engineering design
4. During the activity, I was NOT encouraged to think like an engineer
5. I have a BETTER understanding of beam behavior under loading
6. After the activity, I felt I was MORE engaged with the course

Figure 6 illustrates the responses to these questions. The figure shows that the responses to each question were varied, but that there was often a response which was clearly the most common.

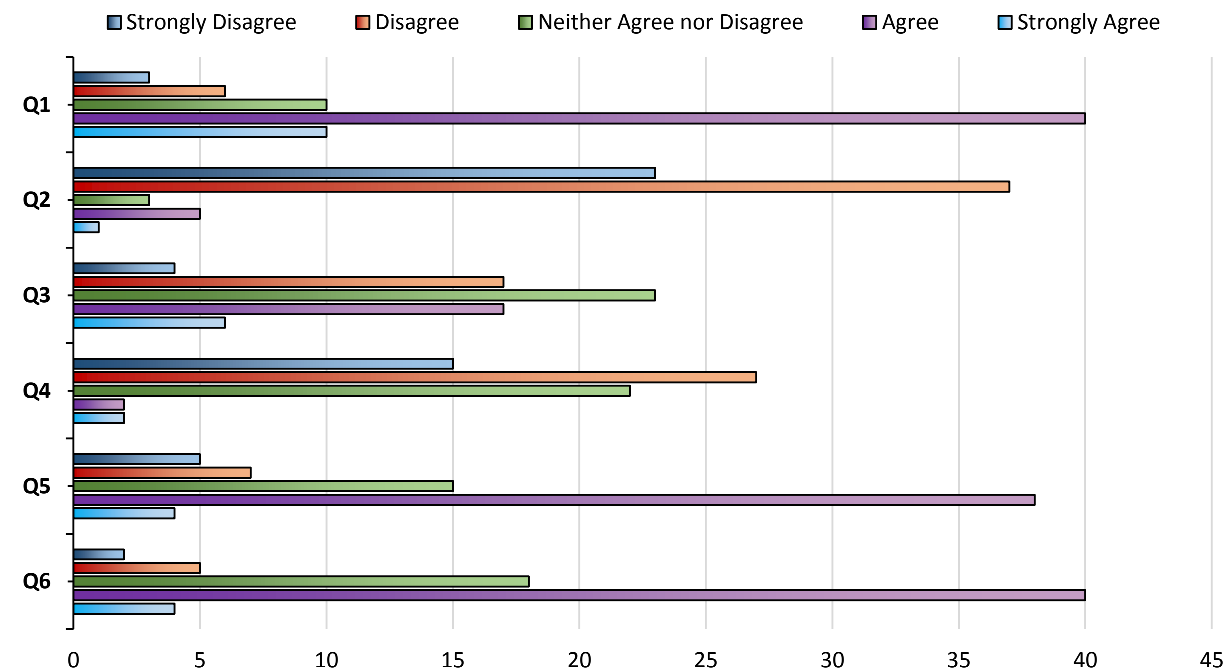

Figure 6: Responses to first portion of First Tutorial Feedback Survey

The responses were grouped according to positive, negative, and neutral response. As such, "Agree" incorporates responses indicating both "Agree" and "Strongly Agree". The responses to these statements were varied, however each had a response with a clear mode value. The mode value for each statement along with the percentage of total responses that corresponds to this value were as follows:

1. Agree (73%)
2. Disagree (84%)
3. Neither Agree nor Disagree (34%)
4. Disagree (67%)
5. Agree (57%)
6. Agree (65%)

While the responses to these statements are generic, they do seem to indicate that the students found value in the exercise. They generally responded that the activity enhanced their understanding of beam loading.

Engineering principles were not greatly associated with the activity by the students. Statements three and four which were related to this topic were responded to with no strong agreement or disagreement and the total percentage of the overall response was considerably lower than those of the other statements. This might indicate that no strong connections were made by the students between the beam models and real-world beams that they represent. If this is the case, then the models may not serve as a strong inductive education tool. The students must identify and associate the models with real-world problems in order to draw connections between the beams' associated theory and the real world. This indicates that parallels between the models and real beams should be drawn by the instructor as part of the preparation for the activity.

The second portion of the survey provided a second selection of statements for which the students could indicate their level of agreement or disagreement. These statements were related to how the activity was presented and run. These statements included the following:

7. The instruction provided prior to and during the activity WERE adequate
8. I felt that there were NOT enough teaching team members present to successfully run the activity
9. I felt that the space in which the activity was held WAS adequate
10. I felt that the tools I was provided to complete the activity were NOT adequate

For these statements, the responses were less unanimous than those in the first portion. This appears to indicate that the students felt that improvements were required to the delivery of the tutorial. This idea was further clarified in the specific feedback portion of the survey.

Figure 7 illustrates the results of the second portion of the survey.

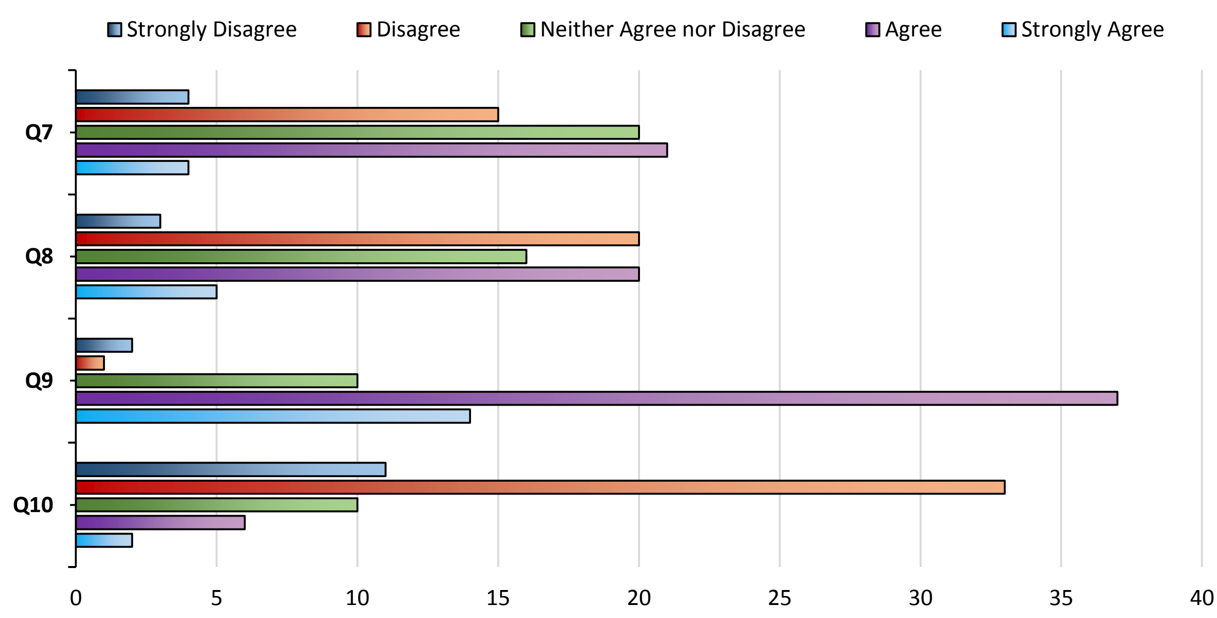

Figure 7: Responses to second portion of First Tutorial Feedback Survey

Generally, the students indicated that the room and tools were adequate, but that the instruction provided and the number of teaching team members were somewhat less so. Both of these complaints were related to the restricted time which was provided to the students for the tutorial. The instructions were attenuated in order to allow the students to begin trying the beams immediately. As a result of this, the number of questions was quite high and the two members of the teaching team were not able to quickly respond to all questions within the allotted time.

The final four questions on the survey allowed the students to provide specific feedback regarding the activity. The questions which were asked were:

11. Is there anything else you would like to add? Any additional/unexpected consequences (good or bad) after running this activity?
12. What would you like changed for future iterations of the activity?
13. What was the most enjoyable aspect of the activity?
14. What did you dislike about the activity?

The responses to question one generally mentioned either that not enough time was provided or that the explanation at the beginning of the tutorial was insufficient. These responses were expected by the teaching team even before the activity was run, and that expectation was confirmed by the students. Several students indicated that a short demonstration at the beginning of the tutorial would have expedited the process of learning about the models. Due to time constraints, this was not considered, however it may have been worth the time it required to better prepare the students for the activity.

The responses to the second and fourth question were similar to those of the first. Specifically, the students suggested that providing more time would greatly enhance the activity.

Most students responded to the third question that the hands-on aspect of the activity was enjoyable and that seeing the results in both graphical and actual representations was interesting.

Generally, the first goal of the activity appeared to have been met. The students were familiarized with the kits and each group produced at least one beam which they attempted to analyze. While the specific feedback did not clearly demonstrate that the students were led to critically think about the beam behavior, the general feedback seemed to indicate that this might be the case.

Second Tutorial

The second tutorial took place after the students had been taught methods to calculate the deflection of statically determinate beams under loading. It was intended that during this tutorial, the students could calculate the deflection under known loading and could compare this result to the outputs of the calculation spreadsheet. This comparison was presumed to have more meaning to the student than the previous tutorial in which the students could only compare the observed shape of the beam to the deflection curves which the spreadsheet produced.

Similar to the first tutorial, prior to the second tutorial the students were provided with two options for analysis. However, in this case the conditions which were suggested were much more specifically defined. Figure 8 illustrates the two options which were provided to the students for analysis. They included both a simply supported case and a cantilevered case. The locations of individual components within the arrangement were specified to ensure that the displacement curves which were calculated by individual group members were based on the same loading case. The dimensions shown in Figure 8 are in units of centimeters.

The values of the beam's "EI" product and the mass of one nut were provided to allow for calculation of deflections. These values were 0.39546 N m^2 and 83 g, respectively.

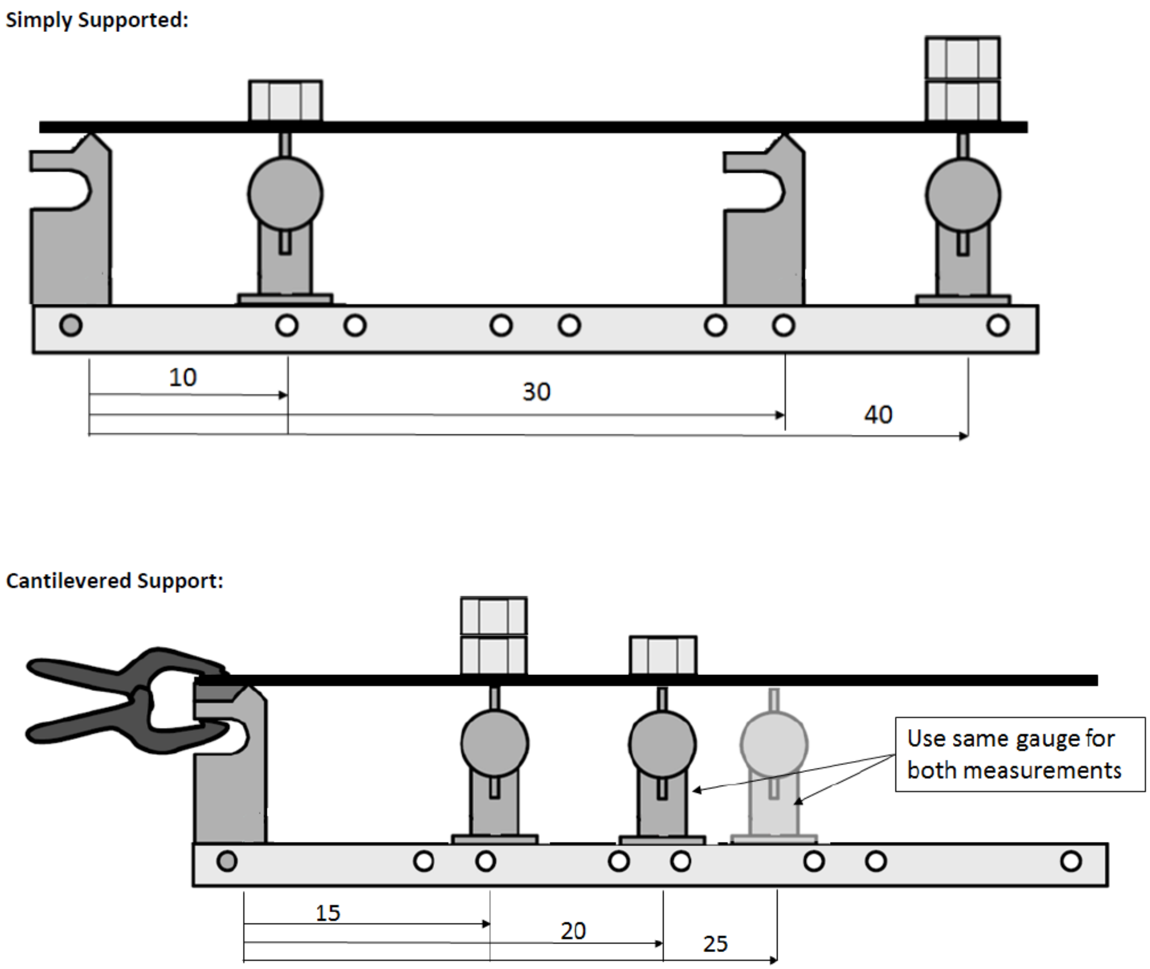

Figure 8: Beam cases for second beam tutorial

Based on the response to the initial tutorial, steps were taken to address the main issue which was identified, namely as not enough time. Therefore, seven more bending beam kits were constructed in addition to the original five kits. With 12 total kits, the two-hour tutorial was divided into two one-hour time slots with groups of 5 students as opposed to four 30-minute time slots with groups of six students.

The second tutorial began with the students forming groups of five students. A short re-introduction of the beam kit was undertaken first. Secondly, a more complete description and discussion of the calculation spreadsheet was undertaken. This was done in response to comments indicating that the students were somewhat confused about its use in the first tutorial. The groups were then asked to construct one or both of the provided beam cases and analyze them using the spreadsheet.

Three members of the teaching team were present during the second tutorials to address the stated concern that one or two members were not sufficient in the first tutorial.

Once the beam had been constructed and analyzed, the students were asked to compare the plots produced by the spreadsheet with the shear, moment, and deflection plots which they had previously produced. The students were asked to identify any differences that they observed between the plots and to provide critical reasoning regarding the source of these differences. For instance, were the differences due to an error in calculation? Or were they due to imprecise measurements? Did the plots exhibit similar shapes but different values? What could account for these differences?

Following the completion of the tutorial, the students were again asked to respond to an online survey regarding the activity, its effectiveness, and any findings which they made during the exercise.

Second Student Feedback Survey

Following the second tutorial, the students were asked to fill out an online survey regarding the activity. A total of twenty responses to the survey were collected.

Similar to the first survey, the second survey began with a series of statements to which the students were asked to state their level of agreement. The statements were again the same as the previous survey and included the following:

1. I WOULD recommend this activity to future students in my program
2. The activity was NOT relevant to my discipline
3. I DEVELOPED an awareness of the importance of safety in engineering design
4. During the activity, I was NOT encouraged to think like an engineer
5. I have a BETTER understanding of beam behavior under loading
6. After the activity, I felt I was MORE engaged with the course

The responses to the statements are summarized in Figure 9.

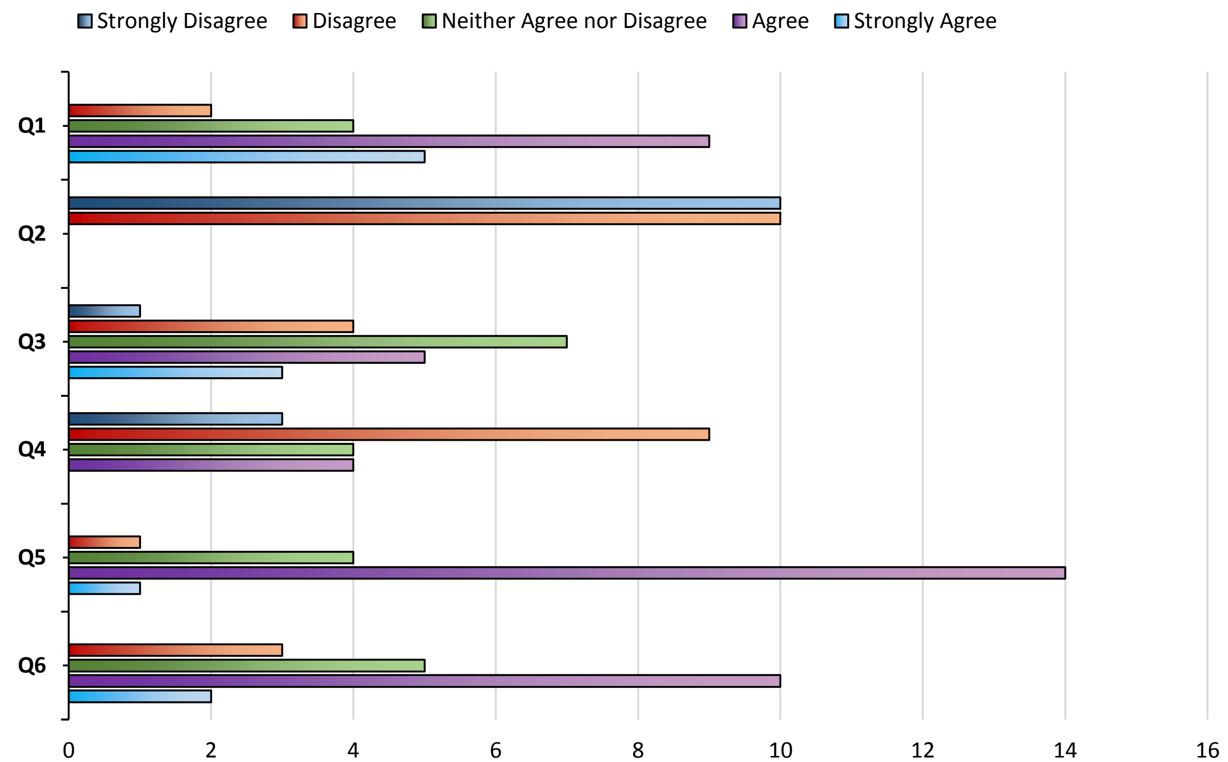

Figure 9: Responses to first portion of Second Tutorial Feedback Survey

In the second tutorial, the responses were similar to those of the first tutorial, with the responses being generally positive.

The second portion of the survey asked that the students respond to the same statements as that of the first survey. These statements were relevant to the delivery of the tutorial. The statements included the following:

7. The instruction provided prior to and during the activity WERE adequate
8. I felt that there were NOT enough teaching team members present to successfully run the activity
9. I felt that the space in which the activity was held WAS adequate
10. I felt that the tools I was provided to complete the activity were NOT adequate

The results of the students' responses are summarized in Figure 10.

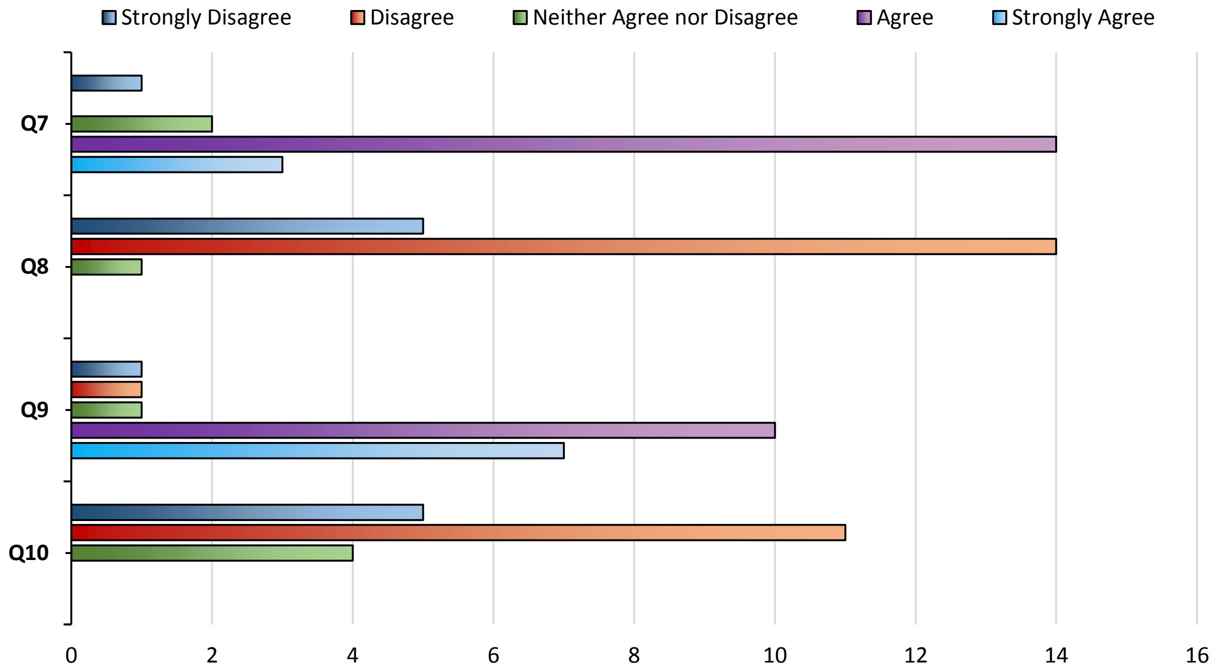

Figure 10: Responses to second portion of Second Tutorial Feedback Survey

The student responses in this section of the survey indicate that the changes made to the second tutorial were beneficial to the students. The instruction and number of teaching team members which was present were both found to generally be adequate. The space and the materials were both found to be generally adequate once again.

The specific feedback from the students indicated that more critical thinking about the beam activity was taking place in comparison to the first tutorial. Several students indicated that a beam model to which you could apply distributed loads would be an interesting next step, which showed that the activity was initiating critical thought.

Another observation which was made by several students was that they were surprised by vertical deformations under the given load scenarios. They indicated that they would typically assume that all downward external loads would cause only deflections in the downward direction. This is an example of a case wherein this activity may help bolster the knowledge of the students. Determining theoretical deflection curves for a given load scenario will give you the same result, but observing a beam deflecting upwards may serve to better reinforce this idea.

Similarly, students mentioned that the shape of the deflected beam was different than they had expected. One student indicated that this caused them to discuss this discrepancy with another group member. The conversation enlightened the student who then “found that it did make sense after all”. This is just one example of many conversations which the activity appears to have initiated.

Some students indicated that they would have preferred the tutorial time be spent on theoretical type problems that would be seen on the final exam.

The students were asked: “How did the physical model enable you to better understand the operation of beams?” The responses to this question seemed to indicate that the goal of reinforcing the theoretical knowledge relating to beam deflection was reached. Most responses were along the lines of “It was good to see the actual deflection rather than just a plot on paper”. One student indicated that the relative deflection of a cantilevered beam as compared to a simply supported one would give them pause when designing future instances of each.

Finally, the students were asked: “How did the spreadsheet enable you to better understand the operation of beams?” The responses indicated that the students found this spreadsheet to be one of the most important parts of the exercise. It was identified as a link between a tangible example and theoretical calculations.

Several of the students liked the fact that the spreadsheet could be used to provide a quick check for other problems assigned in the course when a simple loading situation was applied. While the equations and specific values of these other problems could not be gained, the general shape of the deflection curve could be easily identified. This indicated that the students were using the results of the tutorial to synthesize new uses for the spreadsheet, indicating that they thought it could be a useful tool.

Conclusions

The surveys indicate that the beam bending model provided benefit to a class of second year civil engineering students. The goal of the activity was to reinforce the students’ understanding of the interactions between applied load, support conditions, stiffness, and beam deflection. This was attempted by first allowing the students to experiment with the models during a half hour tutorial and then directing them to attempt to analyze a beam using theory learned in class as well as the beam and spreadsheet during an hour long tutorial. Both specific and general feedback was collected after each tutorial.

The feedback from the initial tutorial indicated that the students required more clear instructions and more time in which to use the beam models. These were both expected, and the production of more beam model kits was undertaken such that in the second tutorial, more time could be allotted to each student.

General feedback from the second tutorial seemed to indicate that the increase in time to one hour for a 5-person group was sufficient to make the activity more effective.

The specific feedback indicated that the students drew more connections between their theoretical knowledge and the physical models in the second tutorial. Students commented that the models helped them to identify misconceptions that they had previously held about determinate beam deflections. Several conversations were initiated during the second tutorial in which the students discussed the beams’ deflections in order to arrive at a deeper understanding of the roles of applied load, support conditions, stiffness, and beam deflection.

This activity was considered to be a useful addition to the Civil Engineering curriculum, and improved versions of this year's activities will be implemented in future offerings of this course. The activity will be slightly revised based on the findings of this initial study. These revisions will include the following:

- Some class time will be spent prior to each tutorial to explain its content and goal
- More time will be devoted to the first tutorial to improve student familiarity with the bending kit
- An example will be run before the activity that demonstrates the use of the models with theory which had been previously taught in class

A survey will be conducted to gauge the effectiveness of the revised activity.

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