Achieving coherent and interactive instruction in engineering mechanics

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Abstract

A new interactive learning environment was implemented in the Engineering Statics course at Boston University, where the students now work in peer groups. The new structure provides real-time feedback on the steps taken by the groups to solve the problem. Each group is supplied with a wireless-enabled tablet, allowing the Free Body Diagrams and equilibrium analysis to be drawn. The instructor is able to lead a discussion on common misconceptions about the material based on the shared work. The same instructor in the Spring 2012 semester taught two sections of the course. One section followed the traditional lecture format, while the other section piloted the new format. Both sections received the same assignments, and covered the same example problems and course material. A comparison of student performance and course feedback assessment indicates that the new format improves the students' comprehension of the course material, motivation, and interest in the course.

Introduction

Internal funding was recently received to restructure the introductory course on Static Mechanics and Strength of Materials ('Statics'). Taking advantage of a modern pedagogical approach, the course format was restructured with the purpose of achieving a more interactive learning environment and uniform experience for the students. The standard passive lecture format of a single instructor describing the material to the students has been replaced by a sequence of topic introduction, active learning examples based on peer instruction, and an active discussion on the lessons learned from the examples. The lesson incorporates two-way discussion (student to instructor and vice versa) by leveraging wireless-enabled tablet technology that allows the students to graphically describe and transmit their work to the instructor. This study describes the new method and compares student outcomes based on instruction with either the historical or new teaching model. While the general method of implementing peer learning in an engineering course is not novel, the combination of tablet technology use for enabling discussion on free body diagrams and comparison of student outcomes based on similar assignments in a control and test group is a novel method for validating the approach.

Historical Course Structure and Motivation for Change

Engineering Mechanics I (EK301) is one of the large introductory courses offered in the undergraduate engineering program at Boston University. As a core engineering course taught primarily to sophomore-level students, it is a requisite course for students in all undergraduate engineering majors, and has a total enrollment of approximately 350-400 students per year. It introduces students to static analysis of forces applied to and acting in basic structures. Until recently, approximately five sections were offered each fall, with a single section in the spring and summer semesters. The course meets twice a week for a 110-minute lecture. Typically 5-7 instructors are involved with the course throughout the academic year. Student assessment includes weekly problem sets and quizzes, a semester-long truss design project, two midterm exams, and a common final exam. Weekly tutoring assistance is provided by graduate teaching fellows (GTFs) across multiple sections.

The vision for restructuring the course arose from several key deficiencies. As a service course that introduces all students in the College of Engineering to the basics of engineering analysis, it is vital that the material taught to the students be delivered in a coherent fashion and on a uniform level. Section-to-section disparity was a common concern raised by the students throughout the semester, since several faculty members are required to handle the high enrollment. A course coordinator was tasked to organize and oversee the multiple sections, but inconsistencies in pace and depth of the material presentation were inevitable and common. Some instructors chose to introduce some form of active learning problems during lecture where the students worked on their own or in informal groups on an example problem, while others lectured the entire period and worked example problems directly. Increased exposure to example problems was another common student request considered in the course revision.

Course Revision

The plan to improve the course involved arranging the lecture structure into a new format. The student enrollment across the fall and spring semesters was more evenly distributed, so that 60% of the students took the course in the fall. The individual sections now share common lecture presentation material, so that all students receive uniform instruction. In addition, each section is team-taught by 2 faculty instructors and a GTF. One of the instructors assumes a dedicated Lecturer role in teaching the course and the other instructor acts as an Active Learning Facilitator and assists during the Learning component of the lecture. The lecture period is organized into a structured *Presentation-Learning-Discussion (PLD) Cell* that is presented twice per lecture:

(1) Presentation: The Lecturer presents a 15-20 minute lecture on the new material to the entire class section.
(2) Learning: An active learning example is presented, and students work in four-person groups to collectively solve the problem over 15-minute period. The instructional team circulates throughout the hall to assist in understanding the problem.
(3) Discussion: The section re-convenes and the Lecturer leads a discussion on the correct and incorrect steps that were exposed from the group work.

The lecture opens with an overview and closes with a summary of the key concepts.

Improving Active Learning

Active learning and peer instruction have been shown to be valuable tools in achieving material comprehension, particularly with regards to Mechanics-based problems[1-4]. Providing real-time feedback on the steps the students follow to solve a problem was identified as an important aspect to improving comprehension of the course concepts. The bulk of the course material requires extensive graphical analysis through the drawing of a Free Body Diagram (FBD), and one drawback to the previous course format was that the students were not equipped with a method to graphically describe and question the concepts during lecture. An additional issue with understanding the course material was the long delay time for receiving feedback that most students face when submitting assignments for grading.

These issues were addressed by having the students work in prescribed groups during lecture on example problems that incorporated a new concept. Each group was equipped with a wireless-enabled tablet (Apple iPad) and stylus that had the problem graphic preloaded as a template document in a drawing application (PaperDesk). During the Learning component, the group illustrated the steps followed to solve the problem on their tablet. The tablet was an integral part of documenting the FBD analysis, since the students could easily communicate their graphical analysis to the instructor for the first time in this course setting. The final document was uploaded to a central server, which allowed the instructors to review the work. The Lecturer would display the work documented by one or two of the groups and facilitate a discussion of the correct problem steps. This discussion principally involved having the chosen group explain their work and inviting the rest of the class to critique and discuss the solution. Often the work was selected based on documentation of common mistakes that were then used as teaching examples.

Implementation

Two sections were offered in sequential time slots in the Spring 2012 semester, and the same instructor taught both sections. Unannounced to the students prior to the semester, the first section (‘A’) followed the historical ‘lecture-only’ format, while the second section (‘B’) introduced the new group-learning lecture format. The second section also included the second instructor and GTF as part of the instructional team help during the group work. Section A had an enrollment of 65 students and section B had 56 students. Both sections featured the same assignments, in the form of weekly homework sets and in-class quizzes, two midterm exams, a group final exam, and a design project that featured written reports and design testing outcomes. Administering identical assignments and sharing the same lecturer provided a basis for direct comparison of averages and distribution for the quizzes and exams. Concerns about sharing information regarding in-class test content were diminished by the short (10-minute) interval that separated the two section timeslots; appreciable transfer of question content and subsequent study of that material in such a short time period is likely to be negligible. Further, the students in section A were made aware of the negative impact on their grade if test questions were discussed with students in section B since a theoretical grading curve would be dependent on the combined performance of both sections. Both sections covered the same in-class example problems in varying forms of student effort and collaboration. Therefore, the main difference between sections was the manner in which the example problems were presented and discussed.

In Section A, the students were free to choose their seats in the lecture hall. The instructor presented a typical chalk-style lecture, where a new concept would be introduced, followed by a short instructor-led example, and finally by an example problem for the students to work on their own. The students were encouraged to work on and discuss the problem with their peers, and the instructor would travel around the room to provide assistance. After approximately 15 minutes the instructor would then review the problem on the board in front of the entire section and field questions. This general format would often feature two iterations per lecture.

In Section B, the instructors assigned the students to a four-person group and instructed the students to sit next to their group members during the lecture. The lecture followed the PLD format and the students were encouraged to move as necessary to better engage their group members in discussion about the example problem. The faculty instructors and GTF circulated throughout the hall to provide feedback. During the Discussion segment, the group members whose work was chosen were prompted to describe the steps that they followed, and the rest of the students were encouraged to comment and ask questions throughout the process. The students' group work was subsequently posted to an open-access website following lecture for future access and review. The group rosters were modified twice throughout the semester, for a total of three different group iterations. No grade was attached to the students' involvement with the group work, as it was intended to be a non-stressful environment to practice the material for the first time.

Results

Due to the close proximity of lecture times, and shared assignments and instructor, the quizzes and exams were used as a basis of quantitative comparison for whether the new instructional format had a direct impact on student comprehension of the course concepts. The institutional end-of-semester course and teaching evaluations provided a qualitative insight on the students' perception of the course format. The quizzes were administered weekly over a 20-minute period and consisted of a single problem that was based on the homework set concepts due the previous lecture period. Comprehensive homework solutions were available in the interim period. Midterm exams were administered in lecture during the lecture period. All tests were closed book.

Two student populations were considered in the analysis, where the mean and standard deviation per assignment was compared between the two sections. The first population set involved the entire group of students in each section. The second set involved only the undergraduate students. A small percentage of students in the course (8 students in section A, 1 student in section B) were enrolled in the Late Entry Accelerated Program (LEAP), an institutional Master's-level program that builds on an undergraduate degree outside of the engineering disciplines. The program involves taking a set of requisite engineering courses that includes the Statics course. These students are more experienced and typically perform at the highest level in this course. The hypothesis in this comparison study was that the top-level students likely would excel in either course format, so the influence of this cohort was removed by examining the performance of only the undergraduate students. The four groups (by population per section) outcomes on the test assignments are compared in Fig. 1. The performance in section B was higher in all test categories. With the exception of the second midterm exam, where the relative performance was only slightly higher in section B, the difference between sections was found to be statistically significant based on a paired sample Student's t-test in all other categories. A p-value below 0.05 was considered significant. In all assignments the difference between sections was more pronounced when the undergraduate-only group was considered.

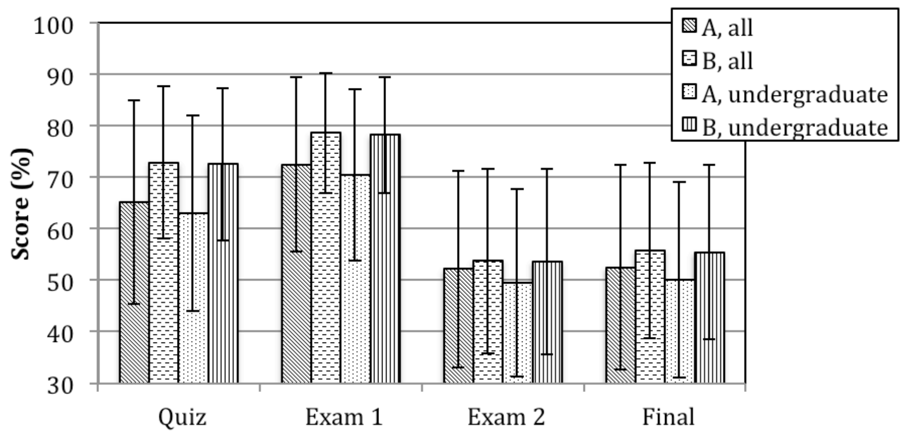

Figure 1: Comparison of mean scores per assignment based on section, where the error bars represent the standard deviation. The quiz scores were the mean of the nine quizzes given throughout the semester.

As part of the continuous improvement initiative in place in the College of Engineering, the students were asked to rate several aspects about the instructor and course at the end of the semester. The questions were evaluated out of a five-point range, where 1 corresponds to 'poor' and 5 corresponds to 'excellent' and are reported here by the section average and standard deviation. Of particular interest was the impression of the students on the new course format. While several of the evaluation questions exhibited little difference between the sections, Table 1 shows four key points that indicated a discernible response based on section. The difference in these particular categories was found to be statistically significant ($p < 0.04$). Due to the anonymous nature of the evaluation, the results are inclusive of all the students in each section.

Section	A	B
Explanation of basic concepts & principles	3.98±0.9	4.17±0.8
Ability to motivate and create interest	3.05±1.0	3.79±0.9
Course level of difficulty (low: easy; high: difficult)	3.80±0.7	3.36±0.7
Overall course rating	3.07±0.9	3.98±0.7

Table 1: Lead instructor teaching evaluation averages and standard deviation.

Discussion and Conclusions

As a pilot effort, the new course format was found to be an improvement, both from the basis of a measurable increase in student test scores, and on a basis of perception of course difficulty and understanding. The new teaching style is a major departure for a course that has a large annual enrollment and requires communication between multiple instructors. Anecdotally, the course instructors observed a higher level of involvement and discussion amongst the students than was originally expected. While actively working with other students may not be a suitable environment for every student, the general format allows students to participate and engage at a level that they are comfortable with. The students were informed of the many studies[5,6] that describe the benefit of peer learning, and this new approach will hopefully become more comfortable over time as it becomes institutionalized.

Since tests for baseline concept comprehension were not run in advance of this course change, the administered tests were used as the main points for comparison between the two sections. The section that featured the facilitated group work demonstrated a higher level of understanding in each test category. In drawing clear differences between the two sections, both sections featured some level of group work. Whereas section B featured prescribed group rosters, a focus point around which to organize their work, section A allowed the students to work with other students at their discretion. The difference in audible discussion between the two sections was substantial. Some students in section A discussed the problem with their peers, but nearly all the students remained in their seats and focused on their own work. A large percentage of the students in section B stood up and actively engaged their group members and argued about the benefits or drawbacks on different methods for solving a problem.

The other main difference between the section formats was the technology involvement. Working out the mathematical steps with the stylus on the tablet was not always smooth, but it allowed the students to document their FBD analysis. This in turn allowed the instructor and class peers to comment on the correct and/or incorrect steps that were used, in a manner that was not feasible to arrange in the non-tablet section. Based on direct visualization of student work, the Discussion component provided an open forum that showed not just the correct solution but more importantly, common mistakes, so that the students could correct their thought process while the problem and related concepts were still fresh. This format recognizes that every student learns differently, that multiple paths may lead to the same problem solution, and that most mistakes are indeed common and can be learned from. In the Active-Constructive-Interactive taxonomy proposed by Chi[7] the course transitioned from a passive experience to an interactive experience for the students. Working on problems introduces an active experience, while working in groups with instructor feedback and discussion ultimately provides an interactive setting.

The benefits of peer learning are not new, and this study did not directly test for the efficacy of using a tablet to improve concept comprehension based on immediate feedback on FBD analysis. However, the combination of these two new aspects did result in a discernible impact on the students' grades, and the ability to compare a control and test group in such a manner gives validation to the outcomes. The course evaluations also clearly show that the students in section B found the course material more motivating, easier to understand, and more enjoyable overall. Implementation of tablet technology is not necessary to implement in every course, but it is particularly helpful in a setting where graphical analysis is the first step for the majority of the problems. The success of this new format has now been implemented in all sections of the course and will serve as the basis for the course in the near future.

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