Slow and Steady: The Effects of Teaching a One-Semester Introductory Mechanics Class over a Year

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Abstract

From the time of the earliest work in educational psychology, there has been evidence that expanding the time for study leads to enhanced retention of knowledge. Yet, the current format of tertiary education in the US tends to package material into compressed units. The goal of this study was to explore whether increasing the time over which students are exposed to material results in a deeper knowledge of the material, with better problem-solving skills. An introductory mechanics class usually taught over one semester was taught over two semesters, with no change in total content, work-load, delivery, or assessment. A control was established with the usual form of the class being taught by the same instructor in the second semester. At the end of the two classes, a common final exam was given to both sections and graded together. The performance on the homeworks and the first mid-term appeared to reflect the academic performance of each section prior to enrollment in the class. The performance of the experimental section in the second midterm improved slightly relative to the control section. However, the performance of the experimental section in the final exam was significantly better than the performance of the control section. Extending the time over which students are exposed to new material may lead to a deeper understanding and better problem solving skills.

Keywords: Mechanics education, Distributed practice, Problem solving

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1. Introduction

One of the defining features of the US system of higher education is the packaging of information into discrete classes, each lasting a single quarter, semester, or half-semester. Although a sequence of such classes can be prescribed for a curriculum, each class is seen as a unified whole, with mastery being assessed over the short period of each class. An alternative approach is the traditional UK system, where information is packaged into more classes taught in parallel, at a lower intensity over the entire year. Mastery in each class is assessed after the passage of an entire year. A similar approach is used in some high schools within the US; the choice of whether to follow the standard tertiary-level academic calendar seems to be a local one.

The US system of accumulating credits on a quarter-by-quarter or semester-by-semester basis creates a powerful administrative flexibility, whereby students can transfer credits between institutions, can change majors, and can accommodate part-time education to fit personal needs. This flexibility is one of the most striking strengths of the US system, and it is much harder to replicate in a system where classes are taught over a year. However, the short-term nature of instruction in the US system creates a very fast-paced mode of instruction, and limits the time scale over which the learning process can take place.

Many basic engineering-science classes, such as mechanics, have two goals: (i) transmittal of fundamental concepts, and (ii) training students to use these concepts to solve engineering problems. An important question that does not appear to have been addressed within the engineering-education literature is whether the duration (or, equivalently, intensity) of instruction affects the ability of students to develop the deep understanding required for solving complex problems and for long-term retention. Were the answer to this question known, it might have an impact on the design of engineering curricula. Although the question has not been addressed within the engineering-education literature, related questions on the relationship between intensity of leaning and memorization have been addressed within the educational-psychology literature. This work is summarized below.

A commonly accepted model of the cognitive process is that "working memory" provides an interface between the environment and information stored in "long-term memory" [1, 2]. Although not expressed in these modern terms, the first experimental studies into the psychology of learning [3] showed that the limits of working memory mean that no more than about seven items can be processed at the same time (the limit was examined as the number of syllables that could be learnt in a single exposure). It was shown that processing additional complexity required repeated interaction with the material, and that knowledge acquired by this process decayed with time, but could be boosted to original levels by distributed additional exposures that became more efficient with increased repetitions. Of importance to motivate the present study was an observation made in this early work on educational psychology (chapter 8 of Ref. [3]) that the same level of learning could be achieved for less total effort, when the learning was distributed over time, rather than concentrated in a single burst of activity.

From a general engineering-education perspective, learning can be thought of as the process of getting the facts, concepts, and tools that working memory requires to solve a problem into long-term memory [4]. Recall of data from long-term memory is much faster than processing by short-term memory, and part of the education process is to embed chunks of information and automatic responses into long-term memory [5]. For example, students need to learn strategies that will augment the limitations of their working memory. From the perspective of teaching an introductory mechanics class, this includes the use of neat figures and free-body diagrams, clearly defined co-ordinate systems, subscripts for stress and strain components, and sketches of Mohr's circle. Students also need to be able to assess solution strategies, and to decide which equations need to be used for different situations.

The format of a single-semester class dictates that the time available to transfer information from working memory to long-term memory is necessarily short. This means that any mechanism used to learn the material (such as problem solving) is, essentially, concentrated. Following on from the earliest work of Ebinghaus [3], there have been a number of studies suggesting that expanding the time over which practice occurs is beneficial to long-term retention [6, 7]. While this concept appears to be very robust [8], the associated experiments in the psychology literature illustrate potentially intriguing implications for the design of classes and assessments [9, 10, 11]. For example, single, massed exposure to material may benefit immediate recall, but distributed practice may benefit longer-term retention (with a possible optimum relationship between the study interval and time before retention is tested).

The reasons why distributed practice might be beneficial have not been unambiguously identified in the literature. One possible reason is the obvious effect of fatigue decreasing efficiency [12]. However, Oakley [13] provides another perspective by describing the roles of two modes of thinking on learning: the focused mode and the diffuse mode. The focused mode allows a concentrated engagement with material or skills being learnt. The diffuse mode allows ideas to percolate in the background, allows connections to be made to other skills, and generally cements the concepts in long-term memory. This diffuse mode is associated with nominally restful states and day-dreaming [14, 15].

The intent of the present study was to investigate an hypothesis that the simple fact of providing additional time for students to interact with the material of a reasonably complex class allows them to develop a deeper level of conceptual understanding, and a stronger ability to solve problems, as measured by their responses to multi-step problems set in a comprehensive final exam. No attempt was made to shape the way the students engaged with the material; they were left to use the extra time in the manner of their own choosing.

2. The experiment

The experiment was conducted under the auspices of the Center for Research on Learning and Teaching at the University of Michigan, under their program, "Investigating Student Learning." As such, it received Institutional-Review-Board (IRB) approval.

ME211, "Introduction to solid mechanics," is a sophomore-level, 1-semester, 4-credit class. It is a required class for mechanical-engineering majors at the University of Michigan. The class is also a required class for two other engineering majors, and serves as an optional technical elective for several more. The class combines an introduction to statics with an introduction to strength of materials. A typical syllabus for the class, as taught to the control section in the Winter semester of 2016, is shown in Figure 1. In this syllabus, the references to Hibbeler [16] were provided for students who wanted to see how a standard text-book presents the material. However, although the class followed a standard outline, text-books were not required, used or, even, recommended, since experience has taught the instructor that conventional textbooks in the field share similar pedagogical faults that tend to mislead students when they move on to more complicated topics. The references to "suppl" in the syllabus refer to a second set of notes written by a colleague. Students were also provided with access to the instructor's detailed lecture notes. The homeworks for the class came from a data-base of questions created by the faculty that are intended to develop the type of problem-solving skills desired for ME majors at the university.

As shown in Fig. 1, the regular form of ME211 consists of three fifty-minute lectures each week on Monday, Wednesday and Friday, taught by a faculty member. There is also one fifty-minute discussion section taught every Wednesday by a graduate-student instructor. Typically, there are two or three parallel lecture sections of ME211 every semester, each consisting of between 50 and 120 students, and five to eight discussion sections that are not tied to any particular lecture section. Grading is based on homework problems that are typically due every Friday (20%), two in-class mid-term examinations (2 x 20%), and one comprehensive two-hour final examination taken in finals week (40%). Historically, the mean GPA earned by students in ME211 in large sections tends to be about 2.8 (out of 4.0 scale). At the time of the experiment, departmental rules required a "C-" to be earned in ME211 before continuing in any class that it was a pre-requisite for.

The experiment consisted of taking the regular version of ME211 (Fig. 1), teaching it at half speed over two semesters (Fig. 2), and comparing the performance of the students taking the class with the performance of students in a regular section of ME211 taught by the same instructor as a control in the second semester. A common final exam given at the same time was used for both sections. The experimental section consisted of three lectures and a discussion every fortnight (each Monday and Wednesday). Instead of one set of homework problems being due every Friday, the same amount of homework was due every other Friday. For bureaucratic purposes, the experimental class was offered as two separate, two-credit, special-topics classes (ME499), and the departmental undergraduate committee officially waived the ME211 curriculum requirement for all students who got passing grades in both semesters.

The experimental sections in the two semesters were treated and graded as a unified and coherent whole. This meant that there was one mid-term about two-thirds of the way through the first semester, a second mid-term about one-third the way through the second semester, and a final at the end of the second semester. A temporary incomplete grade was assigned at the end of the first semester, and a final grade was assigned to both classes after the completion of the second semester. For the most part, the same grade was assigned for both semesters, although the possibility of assigning two different grades did resolve a difficulty of what to do in borderline cases.

3. Selection of students

The original hope had been to teach a large section of the experimental class. However, recruiting students was more problematic than expected. First, the experimental course number was ME499, rather than the more familiar ME211. Second, the university course catalogue did not allow the title of the class to be listed as anything other than, "Special topics in mechanical engineering." Third, students often enroll in

ME211 before they have declared mechanical engineering. Although the undergraduate advisors in the department heavily advertised the experimental section to students who sought advice from them, and helped interested students plan schedules for future semesters around the two-semester class, many of the students relied on advising from outside the department, where such detailed help was not available.

Just before the beginning of the Fall semester, less than ten students had signed up for the experimental class. Therefore, at the beginning of the semester, all students in the regular sections of ME211 were sent information about the experiment, and asked if they wanted to switch classes. Furthermore, the instructor went to the first class period of each regular ME211 section, and presented the students with the schedule for the class they had enrolled in, and compared it with the schedule for the experimental class. The instructor also informed the students about the intent of the experiment, and the motivation behind it. This active recruitment resulted in a class size of nineteen students. Additional students moved into the experimental section during the first few weeks of the semester, yielding a total of 25 students.[1] Forty-four percent of the students had declared mechanical engineering before taking the class, four percent had declared another major for which ME211 was a required class, and thirty-six percent were undeclared. The diversity of this experimental group was striking: forty percent were female, and only thirty-two percent were male of apparently European descent.

[1] One student didn't continue in the second semester, because of a decision to transfer to a program that did not require mechanics.

The control section of ME211 in the Winter semester was created by the usual enrollment process. It ended up with 50 students,[2] and a level of diversity much more typical for such a class. Twenty-two percent of the students had declared mechanical engineering before the beginning of the class, twenty-eight percent had declared another major for which ME211 was a required class, and forty-two percent were undeclared. Given the different methods by which the students become enrolled, it was thought to be useful to characterize the two sections by the GPA of each student at the beginning of the class (*i.e.*, at the beginning of Fall 2015 for the experimental section, and at the beginning of Winter 2016 for the control section). These data were made available to the instructor only at the end of the experiment. The frequency distributions of GPAs for the control (ME211) and the experimental (ME499) sections are shown in Fig. 3. It will be observed that the distribution of GPAs for the experimental section seems to be somewhat tighter than that for the control section, but with a slightly lower median. A summary comparison between the demographics of the students in each section is provided in Table 1.

4. Results

4.1 Homeworks

As can be seen from Fig. 2, students in the experimental section had two weeks to complete each homework of approximately ten questions. The material related to the homeworks was covered in class ten days before the homework was due, with a corresponding discussion session being generally held on the Monday before the homework was due. The students in the control section (Fig. 1) had only one week for a

[2] One student didn't take the second mid-term or final.

similar amount of material. Often the material in the control section was not completely covered in lecture until the Monday before the homework was due, and the corresponding discussion session was not held until the Wednesday. These are standard features of the way ME211 is regularly taught to fit within a single semester.

For both sections, the homework questions consisted of some relatively straight-forward questions based on simple applications of techniques and equations taught in class, and a few questions identified by an asterisk as being at a higher intellectual level. Rounded numerical answers were given for every question, so students would know if they had done a question correctly. Students in both sections were told that the homeworks were not intended as assessment tools, but as learning tools. The students were encouraged to get whatever help they required in office hours to do the problems correctly. They were also told they could collaborate with each other, provided each student eventually worked through the problems on their own when the homeworks were submitted. Extensive, common office hours for the regular section were provided by graduate-student instructors and the professors for both of the regular ME211 sections taught in Winter 2016. (There was a second section of ME211, taught by another faculty member, that was run in parallel with the control section.) Office hours for the experimental section were provided by the author and an undergraduate instructional aide.

As shown in Fig. 4, the homeworks scores were relatively high for both sections, as one would expect when answers are given. A comparison between Figs. 3 and 4 suggests that the distributions of the homework scores for each section are similar to the corresponding distributions of GPAs, in that there is less of a tail for the experimental section. However, there was no correlation between GPA and homework score for individual students; individual students across the whole GPA spectrum got close to 100% on the homework, and some of the lowest homework scores were associated with students who had a relatively high GPA.

4.2 Mid-term exams

Two mid-term exams were given in this class. Each section got given an essentially identical exam, with very minor numerical changes between them. The experimental section took each mid-term before the control section, but solutions to their exams were not made available. There were no obvious indications that any knowledge of the exams was transmitted between the sections.

4.2.1 First mid-term

The purpose of the first mid-term was to check whether students had a sufficient command of the basic concepts of statics to be able to move on to the rest of the class. Therefore, the questions were designed to be quite straightforward, and each focused on a single concept. Students were asked to calculate an effective force and couple, to draw correct free-body diagrams, to solve equations of equilibrium and a simple truss problem, and to draw shear-force and bending-moment diagrams.

Figure 5 shows a comparison between the scores of the two sections. As with the homeworks, the overall distribution of marks for each section appears to mirror the corresponding distribution of GPAs. However, despite this overall mirroring, there was no correlation between GPA and mid-term score for individual students. This lack of individual correlation is seen in the plot of Fig. 6.

4.2.2 Second mid-term

Most of the questions in the second mid-term were designed to be readily identified with a concept taught in the second part of the course. However, slightly more problem-solving ability was required than in the first exam, since the initial steps in the solutions generally required the use of techniques covered in the first part of the class. The first question involved calculating the extension of a bar with an axial load (however, it also required applying 3-D Hooke's law, and integrating a non-uniform strain). The second question involved calculating the location of a centroid of a section and the corresponding second moments of area. The third question was essentially a reprise of the bending-moment question from the first mid-term, but with the added requirement of calculating the maximum compressive and tensile stress for a non-symmetrical section. The fourth question was, perhaps, more challenging, asking students to calculate the maximum shear stress resulting from torsion in a statically-determinate problem of two shafts interlocked by two different sets of gears.

A comparison between the scores of the two sections is given in Fig. 7. Although the general forms for the distribution of marks are similar to those for the first mid-term, there are two observations to make. The first is that the median score of the experimental section was now slightly higher than the median score of the control section. The other is that the experimental section was being tested in February on material that they had first encountered in November, and Winter Break had occurred during the intervening period. It did not appear that students had used the break as an opportunity to think about the material, and this may have been responsible for a surprisingly weak performance by a subset of students. On the other hand, the alarm that this performance caused prompted some very useful engagement with both the material and instructor that continued over the remaining two months of the class. The format of the class provided plenty of time for the students in that subset to get back on-track.

4.3 Final exam

A common, two-hour final exam was given at the same time to both sections. While all the questions in the final exam related to topics covered in the last third of the class, it was a cumulative test in the sense that much of the material covered in this last segment of the class built on what went before. The exams for each section were graded together as a unified whole. As can be seen in Fig. 8, the frequency distribution for the scores in the experimental section was uniformly shifted above that for the control section. This is a significantly different result from those of the earlier two exams. The effect in the final was so large, that when all the marks from the different assessments were assembled and compared between the two sections, the final average grade for the experimental section ended up being 3.1, as opposed to 2.8 (the historical average for large sections of ME211).

5. Discussion

The major difference in performance between the two sections occurred in the final exam, where the students in the experimental section did much better overall than their counterparts in the control section. There appeared to be two questions (out of five) that the students in the experimental section performed much better on than the students in the control section did, one question that they performed slightly worse on, and two questions that they performed comparably on. Frequency distributions of the marks for all five questions are provided in Fig. 9. Summaries of the results, in the form of mean scores and standard deviations for each question, are provided in Table 2.

The question (Q3) that students in the control section did slightly better on was a question that included three single-step parts: one on beam deflection, one on redundant supports, and one on shear-force and bending-moment diagrams. Each part of this question could be answered independently of the others. The two questions (Q2 and Q4) on which both groups of students performed comparably were beam-bending questions. Question 2 required a multi-step solution, in which knowledge of internal pressure, shear-force and bending-moment diagrams, and stress transformations had to be combined to find the maximum shear stress. Question 4 was a straightforward question asking students to set up the discontinuity function that could be used to compute the displacements along a beam.

The students in the experimental section did significantly better on Question 1. This was a reprise of the interlocked-gears problem from the second mid-term. However, the students were now asked to consider the bending of the shafts, in addition to the torsion that had been the focus of the question in the second mid-term, and to combine this with their knowledge of stress transformations to calculate a maximum shear stress. Interestingly, a significant group of students in the control section got this question completely correct. However, this was balanced by the fact that about 40% of the students in the control section did not seem to recognize how to tackle the problem in a meaningful fashion; whereas only just over 20% of the students in the experimental section had similar difficulties.

The performance of the two groups of students on Question 5 was so remarkably different that it is worth quoting the full text of the question:

> "A 0º-45º-90º strain-gauge rosette is placed on the free surface of a steel component. The steel has a modulus of 210 GPa, Poisson's ratio of 0.320, and a coefficient of thermal expansion of 16 x 10^{-6} /ºC. The component is locally heated by 30 ºC, and the strain gauges record strains of 850 x 10^{-6}, 1250 x 10^{-6} and 1050 x 10^{-6} in the 0º, 45º and 90º gauges, respectively. Calculate the maximum shear stress associated with this increase in temperature."

To solve this problem, students needed to combine their knowledge of strain transformations (to obtain the local strain state from the strain gauges), 3-D Hooke's law with a temperature change (to obtain the local stress state), and stress transformations (to calculate the final answer). As can be seen from Fig. 9, about 80% of the students in the experimental section essentially knew which equations to use, and how to use them, whereas only about 20% of the students in the control section had a similar level of understanding.

It should be noted that students were first taught 3-D Hooke's law in Lecture 17, when initially introduced to the concept of the relationship between the stress and strain tensors. They were then taught it a second time in Lectures 35 and 36. So, this is a topic to which both sections were exposed twice. The difference being, the length of time between exposures, and the fact that the second exposure for the experimental section came at a time slightly more removed from the increased pressure levels associated with the last portion of any semester.

The performance on the final exam seems to confirm the hypothesis that students in the experimental section would be more comfortable with higher-order problem solving as a result of the extra time they had to absorb the material. For at least one student, the increased confidence with which the material was known going into an exam was a new experience:

> "When I was thinking about the exam later, I realized that I knew the material well enough to know the next step in any problem, or at least have a general idea of what to do, so if I forgot how to actually execute a certain part, I at least knew what I should have done. This was the first time in my academic career that I knew the material well enough to identify every mistake I made on exam."

Unfortunately, a formal assessment of the students' progress in subsequent classes wasn't done in a rigorous fashion, because it was not clear whether the IRB covered continued experimentation in subsequent semesters. However, several of the students who had been in the experimental section made a point of informing the author how well prepared they had felt, compared to their colleagues, when meeting the ME211 material in the subsequent class, and their appreciation of having taken the slower format of the class.

6. Limitations and implications for future studies

The major limitations of this study were imposed by the nature of the project: taking a group of students out of a required degree path to participate in an experiment. This meant that students had to self-select into the experimental section. Although administrative protocols were established to eliminate any negative consequences for the students concerned, such as establishing pathways to degree completion that resulted in no time penalties, a truly equivalent cohort of students could not be established in the control. This resulted in an imbalance between the sizes of the experimental and control sections. However, this discrepancy probably did not have a significant impact on the class dynamics, since the control section fortuitously had relatively few students in it, compared to the potential enrollment that can occur in ME211. From the perspective of the author, the dynamics of teaching a class of twenty-five is similar to teaching a class of fifty, in terms of learning names, interacting, and noticing participation, performances and absences.

Probably of more significance than any imbalance in class size was the relative motivation between the students in each section. The self-selected students in the experimental section may have had a greater interest in the educational experience, and a tendency to assume from the outset that they would benefit from the slower pace. Therefore, the positive results may reflect a beneficial effect to a positively predisposed population. However, in this context, the demographic metrics of the students volunteering for the section suggest a possibly important aspect that may merit further study.

A significant limitation imposed by taking students out of a standard route to graduation is the administrative burden placed on a department. This limits the repeatability of the experiment. Although repeated experiments over a number of years would be desirable to explore the robustness of any observed effects, the use of a single faculty member to teach both a control and experimental section of a required lower-division class, and the additional close advising of students that the experiment entails, requires an administrative commitment to the experiment that may not be easily replicated on a sustained basis. However, it is noted that there is an inverse experiment that might be done. Many colleges regularly run fast-paced versions of required classes during the summer. One of the important questions that the present study raises is whether such classes are desirable if the intent is to allow students to develop a deep understanding of the material, rather than merely meet graduation requirements.

Another limitation of the present study was the nature of the final exam. This had to be fair to the students in the control section, and be similar to exams from previous years. Therefore, it could not focus too heavily on probing the problem-solving skills that might benefit from long-term exposure to the material. For example, there were two questions on beam deflections that were derived from the last homework of the semester. As can be seen from the scores in Table 2, an excessive use of questions such as Question 5 might have distorted the grading system for the control section. If this experiment were to be repeated, it would be useful to identify a protocol that could test problem-solving abilities without affecting students in the control section.

If one were to try and repeat this experiment and encourage greater enrollment, it would probably be necessary to couple it with another related class. For example, combining a slow section of ME211 with a slow section of an introductory class on dynamics would reduce scheduling complications associated with 2-credit classes. It might also provide synergy and time to reinforce concepts concurrently across the curriculum.

With the benefit of hindsight there are additional procedures that one might wish to put in place in future studies. The most important of these is to provide the appropriate following classes with protocols to evaluate long-term retention. A formal survey instrument should, perhaps, be developed to assess the students' perception of the format of the class. However, an appreciation of possible benefits might not be expected until students gain the perspective of comparing themselves to others from the traditional routes. Since the procedures would require experimentation in subsequent classes, the process of IRB-approval would need to include such extensions to the experiment.

An unexpected and interesting question that arose from the experiment is why the possible benefits of distributed study were not manifested in the first assessment or in any of the homeworks. The first mid-term did not assess problem-solving skills; it only tested conceptual knowledge. However, it also became clear during the study that many students in the experimental section did not make use of the full two weeks allocated to each homework. It appeared that, with few exceptions, the students were optimizing their time-management by focusing on the immediate pressures of other classes. Much of the homework was done the night before it was due.

Since the intention of the study was to keep all the variables constant, except for the pace of the class, additional strategies to encourage distributed practice (other than providing the time) were not explored. However, a more deliberate approach about how to address this particular issue might be desirable in future studies. One possibility would be to require a small fraction of the homework, focusing on carefully chosen basic questions, to be completed after the first week, with the more advanced questions being completed a week later.

One final comment about teaching a class at a slow pace should be made from the perspective of the instructor. The benefits of having time to take stock of how the class is being taught, what one is really trying to do, and how the class is being received, should not be ignored. The qualitative impression of the author was that, as the result of this reflection, the control section got a superior presentation of the material than had been given in previous semesters to equivalent classes.

7. Conclusions

A study has been conducted into the effects of slowing down the pace at which information is transmitted in a required mechanics class, and teaching the class as a unified whole over two semesters, rather than over a single semester. The results of this experiment were assessed by means of a common final exam given simultaneously to the experimental section and to a control section taught by the same instructor. In this experiment, the goal was to explore the effects of simply doubling the time-frame over which learning could occur, with all other variables (such as total work load) being kept as constant as possible.

The results of the experiment indicated that providing additional time for students to interact with complex material in a basic engineering-science class allowed them to develop a deeper level of understanding needed for advanced problem solving. While the benefits seemed to accrue to the students slowly over the course of the experiment, the benefit seemed to be significant enough to indicate that additional studies in other classes might be an interesting avenue for future research.

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Table 1: Demographics of students in each class.

	Experiment ME499 (F2016)	Control ME211 (W2016)
Number of students	25	50
Declared needing ME211 as a required class	48%	50%
Undeclared	36%	42%
Female	44%	18%
Male of apparent European descent	32%	68%
Mean of incoming GPA	3.17	3.27
Standard deviation of incoming GPA	0.33	0.54

Table 2: Performance on final.

		Experiment ME499 (F2016)	Control ME211 (W2016)
Question 1	Mean /20 (Std. Dev.)	**10.8** (6.0)	**8.6** (6.3)
Question 2	Mean /20 (Std. Dev.)	**13.9** (4.9)	**14.9** (4.9)
Question 3	Mean /20 (Std. Dev.)	**12.1** (4.5)	**13.9** (4.7)
Question 4	Mean /20 (Std. Dev.)	**12.7** (4.0)	**12.0** (3.7)
Question 5	Mean /20 (Std. Dev.)	**15.9** (3.5)	**8.9** (6.3)
Total	Mean % (Std. Dev.)	**65.4%** (16.0%)	**58.7%** (16.3%)
Final GPA for class	Mean (Std. Dev.)	**3.1** (0.6)	**2.8** (0.9)

ME 211 INTRODUCTION TO SOLID MECHANICS

COURSE OUTLINE – Winter 2016

Optional textbook: Hibbeler, (3rd edition)

Class	Date	Topic	Reading	Homework
1	W 1/6	Introduction	Chapter 1	
2	F 1/8	Forces	Chapter 2; suppl. A	None
3	M 1/11	Vector products and moments	§3.1–§3.6; suppl. B	
4	W 1/13	Equilibrium (2D)	§4.1–§4.4; suppl. C	
5	F 1/15	Equilibrium (3D)	§4.5, §4.6; suppl. D	HW 1
	M 1/18	**MLK Day**		
6	W 1/20	Friction	§4.7–§4.8, suppl E	
7	F 1/22	Two-force member structures	§5.1–§5.4	HW 2
8	M 1/25	More general structures	§5.5; suppl. F	
9	W 1/27	Centroids and distributed loading	§6.1, §6.3; suppl. G	
10	F 1/29	Internal loading	§7:1, §7.2	HW 3
11	M 2/1	Shear force and bending moment diagrams	§11.1,§11.2; suppl. H	
12	W 2/3	Shear force and bending moment examples		
13	F 2/5	Concept of stress	§7.3–§7.7	HW4
14	M 2/8	Concept of strain	§7.8,§7.9; suppl. I	
15	W 2/10	Material behavior	Chapter 8; suppl. J	
16	F 2/12	Review of Lectures 1–12		HW 5
17	**M 2/15**	**Mid-term #1 — Lectures 1–12**		
18	W 2/17	Axial loading (determinate problems)	§9.1–§9.3; suppl. K	
19	F 2/19	Indeterminate problems and thermal strain	§9.4–§9.6; suppl. L	HW 6
20	M 2/22	Torsion of cylinders	§10.1–§10.4; suppl. M	
21	W 2/24	Torsion examples, including indeterminate problems)	§10:5	
	F 2/26	TBD		HW 7
	M 2/29	**Spring Break**		
	W 3/2	**Spring Break**		
	F 3/4	**Spring Break**		
22	M 3/7	Bending stresses	§11.3, §11.4	
23	W 3/9	Centroidal second moments	§6:2, §6.4–§6.6; suppl. N	
24	F 3/11	Bending stresses (examples)		HW 8
25	M 3/14	Eccentric loading	§13.2; suppl O	
26	W 3/16	Pressure vessels	§13.1	
27	F 3/18	Review of Lectures 13–24		HW 9
28	**M 3/21**	**Mid-term #2 — Lectures 13–24**		
29	W 3/23	Combined loading		
30	F 3/25	Examples of combined loading		HW 10
31	M 3/28	Stress transformation equations	§14.1–§14.3	
32	W 3/30	Mohr's circle and 3-D max. shear stress	§14.4, 14.5	
33	F 4/1	Max. shear stress in combined loading	suppl P	HW 11
34	M 4/4	Strain transformation, strain gage rosettes	§14.6–§14.9	
35	W 4/6	Multiaxial stress	§14.1; suppl. Q	
36	F 4/8	Relation between elastic constants		HW 12
37	M 4/11	Bending deflections (continuous loading)	§16.1, §16.2; suppl. R	
38	W 4/13	Discontinuity functions	§16.3; suppl. S	
39	F 4/15	Bending deflections (examples)		
40	M 4/18	Review of whole course		HW 13

N. B. There are also Discussion sections scheduled for every Wednesday. The final exam is on April 20.

Figure 1 Typical ME211 syllabus. This is the syllabus used for the control section of Winter 2016. This class is identified as ME211 (W16) in subsequent figures.

ME 499-098 INTRODUCTION TO SOLID MECHANICS (PART 1)

COURSE OUTLINE – Fall 2015

Optional textbook: Hibbeler (3rd edition)

Class	Date	Topic	Reading	Homework
1	W 9/9	Introduction	Chapter 1	
2	M 9/14	Forces	Chapter 2; suppl. A	
3	W 9/16	Vector products and moments	§3.1–§3.6; suppl. B	
	M 9/21	*Discussion*		
4	W 9/23	Equilibrium (2D)	§4.1–§4.4; suppl. C	HW1 (F-9/25)
5	M 9/28	Equilibrium (3D)	§4.5, §4.6; suppl. D	
6	W 9/30	Friction	§4.7–§4.8, suppl E	
	M 10/5	*Discussion*		
7	W 10/7	Two-force member structures	§5.1–§5.4	HW2 (F-10/9)
8	M 10/12	More general structures	§5.5; suppl. F	
9	W 10/14	Centroids and distributed loading	§6.1, §6.3; suppl. G	
	M 10/19	**Fall Break**		
	W 10/21	*Discussion*		HW3 (F-10/23)
10	M 10/26	Internal loading	§7:1, §7.2	
11	W 10/28	Shear force and bending moment diagrams	§11.1,§11.2; suppl. H	
	M 11/2	*Discussion*		
12	W 11/4	Shear force and bending moment examples		HW4 (F-11/6)
13	M 11/9	Review of Lectures 1–12		
14	**W 11/11**	**Mid-term #1 — Lectures 1–12**		
15	M 11/16	Concept of stress	§7.3–§7.7	
16	W 11/18	Concept of strain	§7.8,§7.9; suppl. I	
17	M 11/23	Material behavior	Chapter 8; suppl. J	
	W 11/25	*Discussion*		
18	M 11/30	Axial loading (determinate problems)	§9.1–§9.3; suppl. K	
19	W 12/2	Indeterminate problems and thermal strain	§9.4–§9.6; suppl. L	HW5 (F-12/4)
	M 12/7	*Discussion*		
20	W 12/9	Torsion of cylinders	§10.1–§10.4; suppl. M	
21	M 12/14	Torsion examples, including indeterminate problems	§10:5	HW 6 (F-12/18)

Figure 2a The syllabus used for the first part of the experimental section. This is identified as ME499 (F-2015) in subsequent figures.

ME 499-098 INTRODUCTION TO SOLID MECHANICS (PART 2)

COURSE OUTLINE – Winter 2016

Optional textbook: Hibbeler (3rd edition)

Class	Date	Topic	Reading	Homework
	W 1/6	*Review of torsion*		
	M 1/11	*Discussion (torsion)*		
22	W 1/11	Bending stresses	§11.3, §11.4	
	M 1/18	**MLK Day**		
23	W 1/20	Centroidal second moments	§6:2, §6.4–§6.6; suppl. N	HW-7 (F-1/22)
24	M 1/25	Bending stresses (examples)		
	W 1/27	*Discussion*		
25	M 2/1	Eccentric loading	§13.2; suppl O	
26	W 2/3	Review of Lectures 13–24		HW 8 (F-2/5)
27	**M 2/8**	**Mid-term #2 — Lectures 13–24**		
28	W 2/10	Pressure vessels	§13.1	
29	M 2/15	Combined loading		
30	W 2/17	Examples of combined loading		
	M 2/22	*Discussion*		
31	W 2/24	Stress transformation equations	§14.1–§14.3	HW 9 (F-2/26)
	M 2/29	**Spring Break**		
	W 3/2	**Spring Break**		
32	M 3/7	Mohr's circle and 3-D max. shear stress	§14.4, 14.5	
33	W 3/9	Max. shear stress in combined loading	suppl P	
	M 3/14	*Discussion*		
34	W 3/16	Strain transformation, strain gage rosettes	§14.6–§14.9	HW 10 (F 3/18)
35	M 3/21	Multiaxial stress	§14.1; suppl. Q	
36	W 3/23	Relation between elastic constants		
	M 3/28	*Discussion*		
37	W 3/30	Bending deflections (continuous loading)	§16.1, §16.2; suppl. R	HW 11 (F-4/1)
38	M 4/4	Discontinuity functions	§16.3; suppl. S	
39	W 4/6	Bending deflections (examples)		
	M 4/11	*Discussion*		
	W 4/13	Review of F-15 content		HW 12 (F-4/15)
40	M 4/18	Review of whole course		
	4/20	**Final - Lectures 1-40**		

Figure 2b The syllabus used for the second part of the experimental section. This is identified as ME499 (W-2016) in subsequent figures.

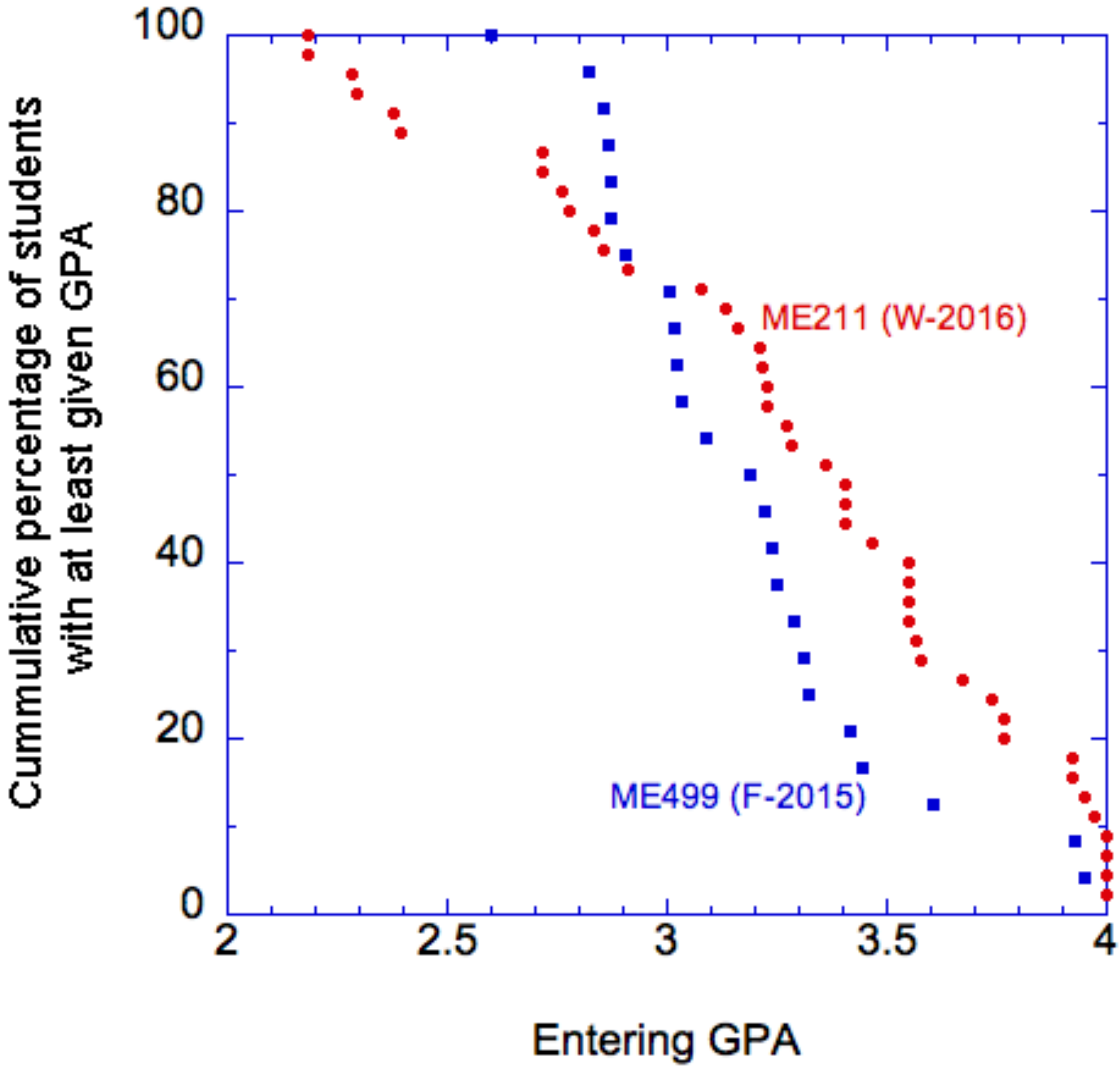


Figure 3 The median entering GPA of the control section, ME211 (W-2016), was slightly higher than that of the experimental section, ME499 (F-2015), but there was a somewhat less tight distribution.

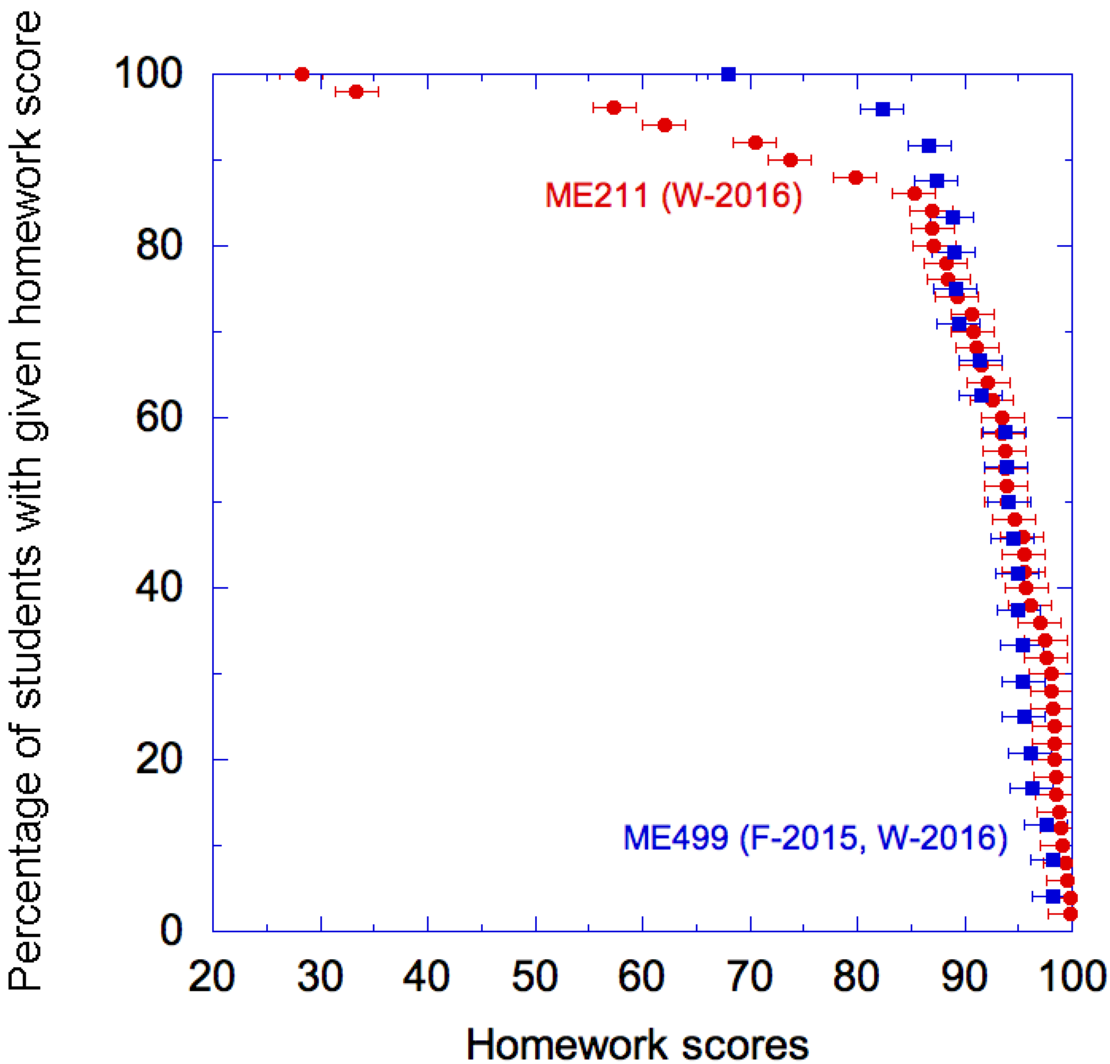


Figure 4 A comparison between the homework scores of the experimental sections, ME499 (F-2015) and ME499 (W-2016), and the control section, ME211 (W-2016). The error bars represent an estimate of the grading error. Overall, the distribution of scores follows the general form of the incoming GPAs.

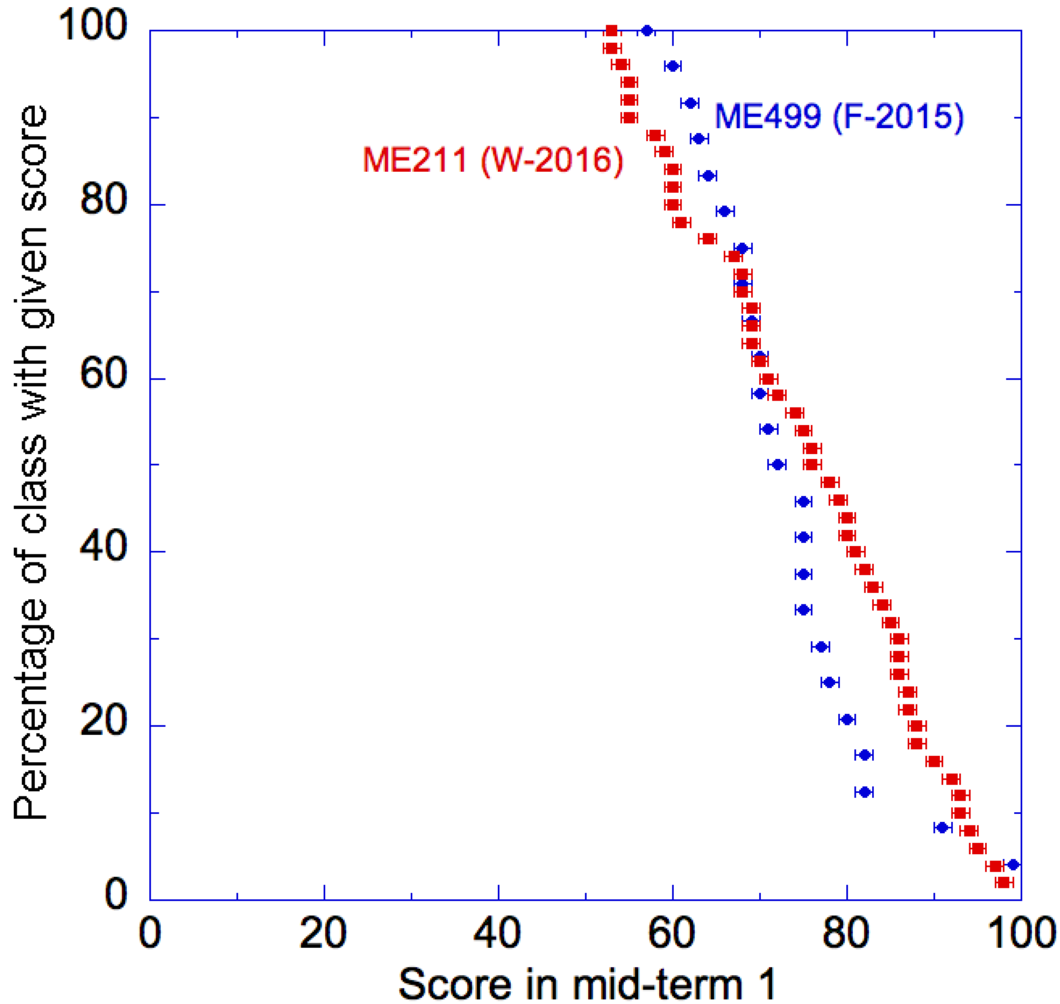


Figure 5 A comparison between the scores for the first mid-term of the experimental section, ME499 (F-15), and the control section, ME211 (W-2016). The error bars represent an estimate of the grading error. Overall, the distribution of scores follows the general form of the incoming GPAs.

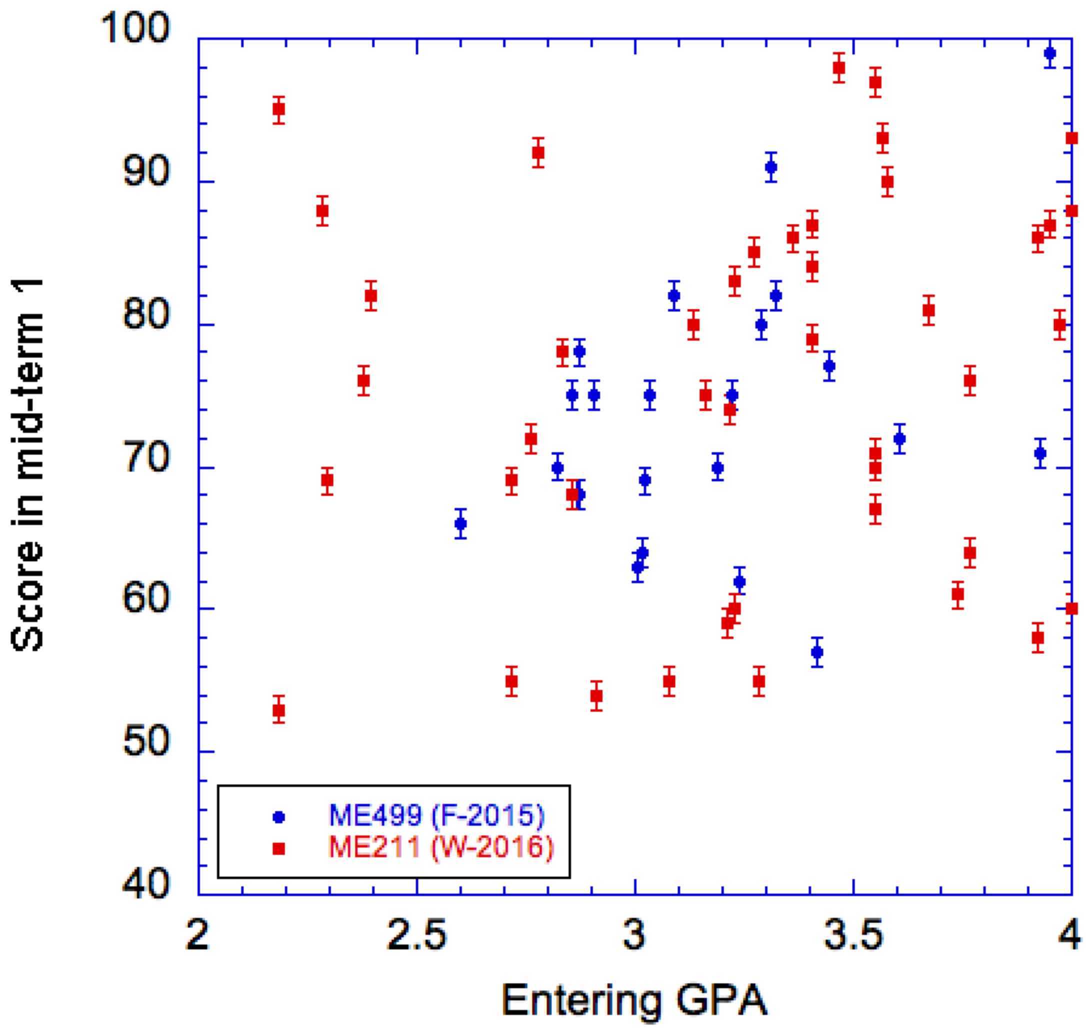


Figure 6 There is no obvious correlation between the incoming GPA of any individual student and the score they received in the first mid-term. This is in contrast to the apparent correlation indicated for the sections as a whole when comparing Fig. 5 with Fig. 3. The error bars represent an estimate of the grading error. The circular data points correspond to the experimental section, ME499 (F-2015), and the square data points correspond to the control section, ME211 (W-2016).

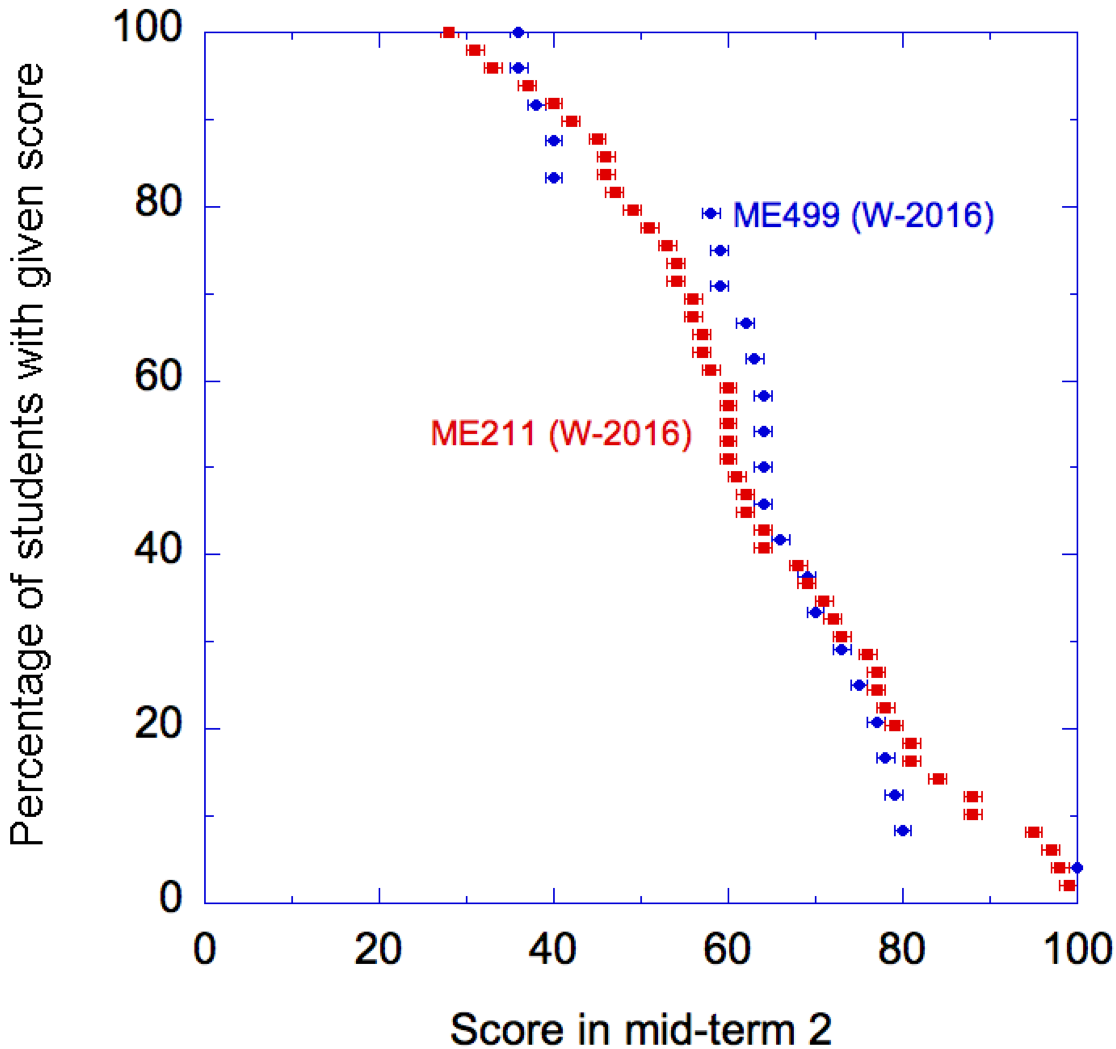


Figure 7 A comparison between the scores for the second mid-term of the experimental section, ME499 (W-2016), and the control section, ME211 (W-2016). The error bars represent an estimate of the grading error. The median of the experimental section is now slightly higher than that of the control section.

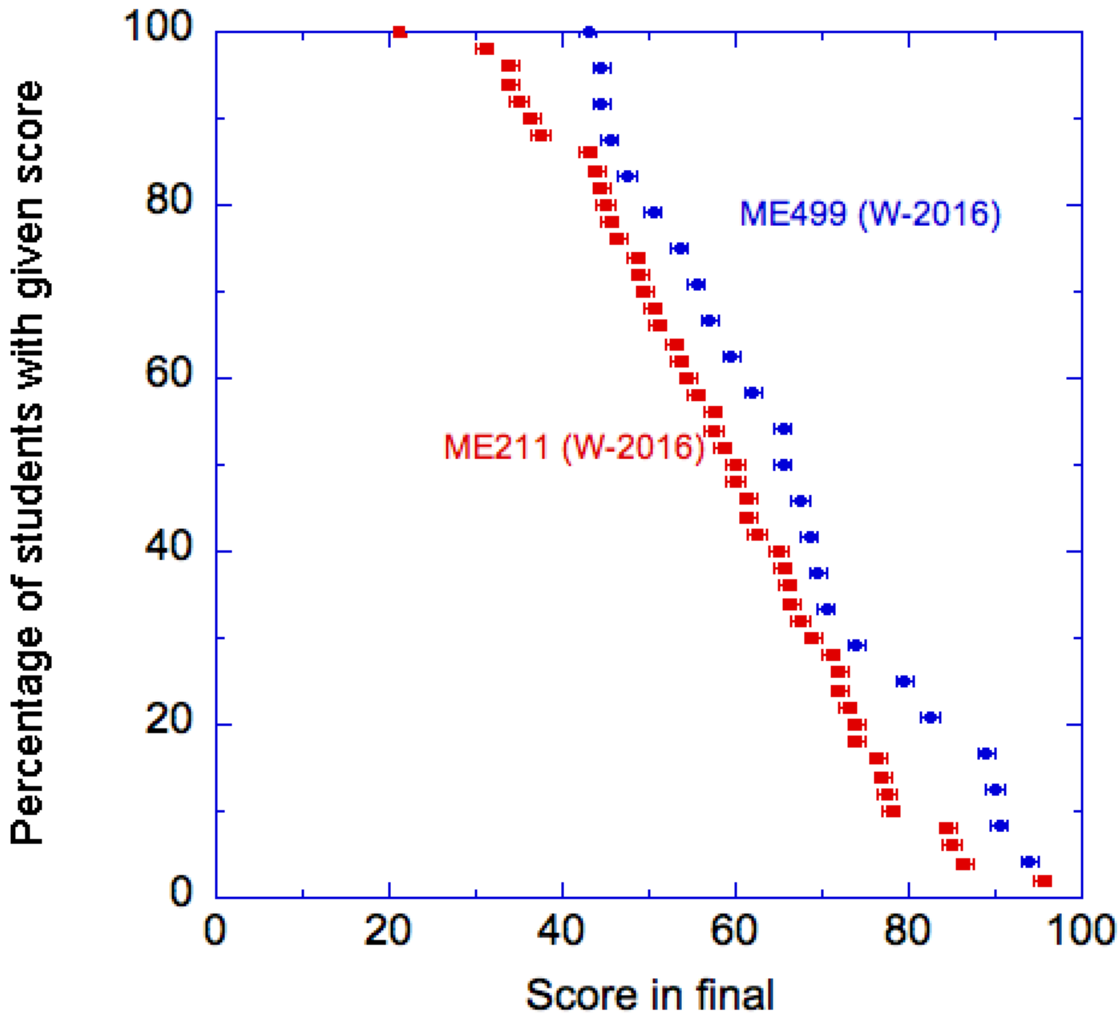
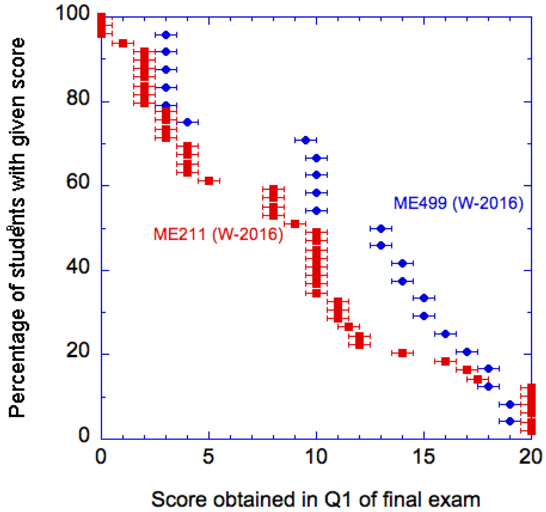
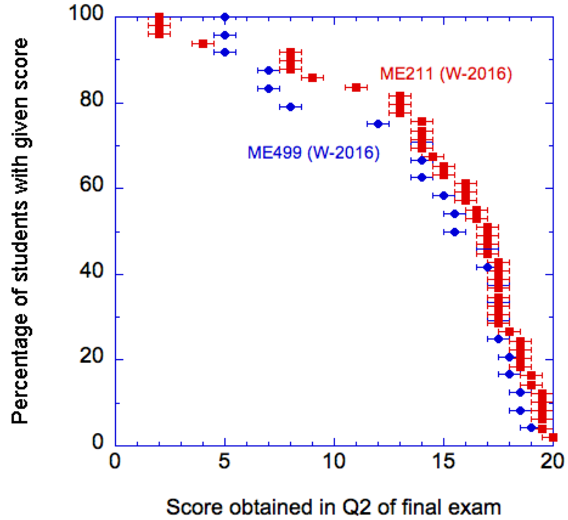


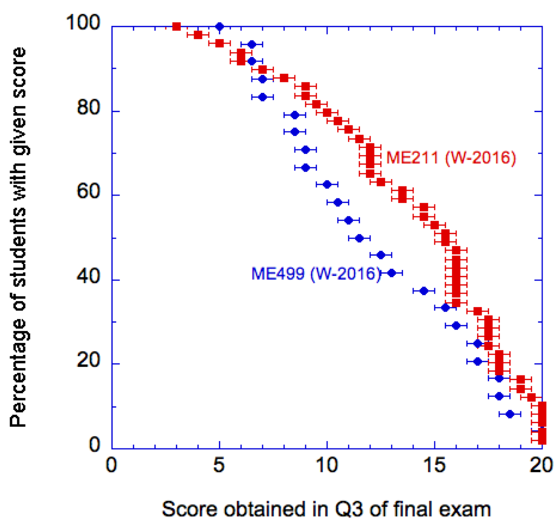
Figure 8 A comparison between the scores for the final of the experimental section , ME499 (W-2016), and the control section, ME211 (W-2016). The error bars represent an estimate of the grading error. The experimental section did significantly better than the control section.


Percentage of students with given score
Score obtained in Q1 of final exam
ME211 (W-2016)
ME499 (W-2016)

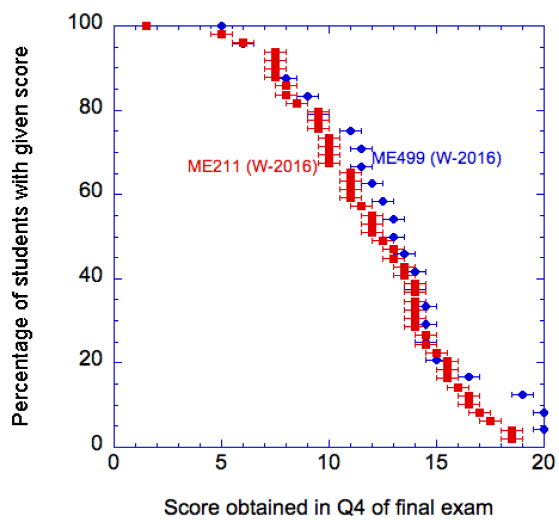
(a)


Percentage of students with given score
Score obtained in Q2 of final exam
ME211 (W-2016)
ME499 (W-2016)

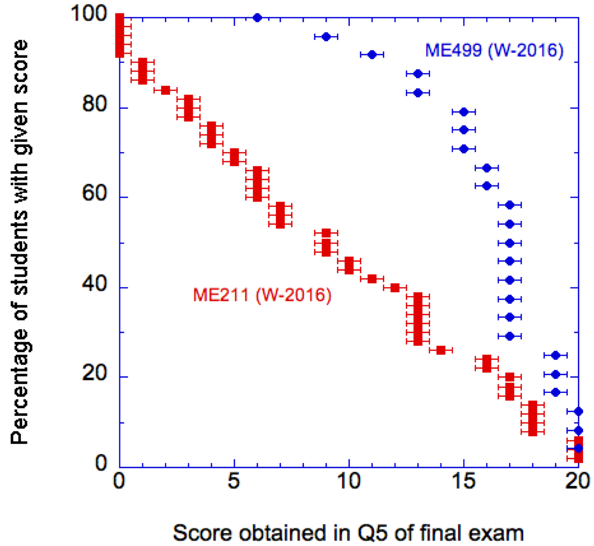
(b)


Percentage of students with given score
Score obtained in Q3 of final exam
ME211 (W-2016)
ME499 (W-2016)

(c)


Percentage of students with given score
Score obtained in Q4 of final exam
ME211 (W-2016)
ME499 (W-2016)

(d)



(e)

Figure 9 A comparison between the scores in **(a)** Q1, **(b)** Q2, **(c)** Q3, **(d)** Q4, **(e)** Q5 of the final for the experimental section, ME499 (W-2016), and for the control section, ME211 (W-2016). The error bars represent an estimate of the grading error for each question.