



All Active All the Time? What are the Implications of Teaching a Traditional Content-Rich Machine Components/Mechanical Systems Design Course Using Active Learning?

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Abstract

This paper examines the use of research-proven Active Learning techniques to transform the teaching of a traditional Machine Components/Mechanical Systems Design class. We know from research in Active learning that use of these methods can often lead to greater conceptual understanding and greater engagement of the students with engineering course materials, yet a common concern among engineering faculty is that the adoption of Active learning techniques will not allow the full breadth and depth of traditional content coverage. In this work, the authors reimagined one of the most content-heavy courses in a traditional Mechanical Engineering curriculum by including many Active Learning teaching and learning techniques. In this practice-based research project, the authors attempted to answer the following questions: 1) Could the students learn the breadth and depth of the content via Active Learning, 2) How do the students value the Active Learning experience as compared to a traditional approach and 3) Is the faculty experience such that it would motivate them to use Active Learning techniques in the future? In order to answer these questions, the course was redesigned to eliminate traditional lecturing and the solving of example problems by the instructor. Instead example problems are placed online to be reviewed by the student at their convenience (an element of the Flipped classroom) thus freeing up class time for various Active Learning experiences including conceptual questions, Think-Pair-Share activities, Ranking tasks, individual and team quizzes, and collaborative problem solving. Project Based Learning (PBL) was used through two large team-based design projects undertaken during a weekly laboratory session. A mixed-methods assessment strategy was employed to evaluate the success of these approaches. Quantitative data was obtained from final exam performance for both conceptual understanding and problem solving competency which was compared directly to the same class taught in a traditional manner. Other quantitative and qualitative data, including student's attitudes and experiences, was gathered through a post class survey.

Introduction

Important publications from the last 15 years such as Sheppard *et. al.*'s *Educating Engineers*¹, Bransford's *How People Learn*², Duderstadt's *Engineering for a Changing World*³ and the NAE's *Educating the Engineer of 2020*⁴ have all called for a deep and introspective look at how engineering education is currently "delivered" and what changes might be necessary to improve student outcomes. One movement that has emerged as promising pedagogy is that of Active Learning. Active Learning consists of a set of teaching/learning classroom strategies that engage the students directly in the learning process and requires them to think about what they are doing.⁵ This is contrasted with the efficient yet relatively ineffective passive learning strategy of traditional lecturing. The physics education community has extensively studied the positive impacts of using Active Learning techniques especially to enhance conceptual understanding (e.g. Mazur⁶ and Hake⁷). A survey article by Prince provides definitions and ample evidence of the effectiveness of various Active Learning strategies.⁵ In engineering, active learning has been studied and shown to promote deeper conceptual understanding than more passive forms of education in introductory

mechanics courses such as Statics⁸ and Dynamics,⁹ Fluids Mechanics¹⁰ and Thermodynamics¹¹⁻¹³. Adoption of Active Learning in upper division courses has been slower with typical faculty concerns including not being able to cover all course content, possible negative responses by the students and the time and effort required to develop new Active Learning content.

The goal of this study was to determine whether Active Learning techniques could be effectively applied to a traditional and content-heavy course such as Machine Component/Mechanical System Design (MS/MSD) class. This course is usually taught in the third year of mechanical engineering study. Typical content includes discussion of the function, sizing and selection of mechanical components such as gears, shafts, bearings, springs, and fasteners; and the integration of these components into machine designs. Nationally, many programs have adopted various Active Learning techniques to enhance and improve their Machine Components Course. Campbell and Schmidt¹⁴ describe the use of open-ended, hardware based design projects to support the traditional lecture content. More recently, Stalworth¹⁵ reported on a project/team based approach to traditional paper-based machine components selection and system design and analysis and Monterrubio and Sirinterlikci¹⁶ and Youssef and Kabo¹⁷ both report on the use of a more formal design process and projects in the course. Many programs take a balanced approach between active project work (with or without hardware) and traditional advanced analysis and simulation.¹⁸. Finally, some programs are emphasizing more design methodology integrated into the junior year (see Lamancusca and Pauley¹⁹).

For this study, we set out to answer three research questions:

- 1) *Could the students learn the breadth and depth of the content via Active Learning?*
- 2) *How do the students value the Active Learning experience as compared to a traditional approach?*
- 3) *Is the faculty experience such that it would motivate them to use Active Learning techniques in the future?*

The first question is a common concern of faculty teaching engineering. At California Polytechnic State University – San Luis Obispo (Cal Poly), the MC/MSD class is one of the most content-heavy in the curriculum with students often getting overwhelmed by not only the breadth of mechanical component coverage, but the depth of understanding it takes to analyze and effectively select components to use in machine design. In addition, the students are expected to integrate this knowledge into the design of functioning machinery.

The second research question is related to the student affective response to the class. By the third (and sometimes fourth) year in the curriculum students are familiar and comfortable with the traditional lecture and homework style of teaching and learning and are sometimes uncomfortable with the more active classroom making change difficult. We wanted to determine if students become comfortable with the active approach to MC/MSD and whether they might even prefer it to a traditional format.

Lastly we wanted to understand the faculty experience of switching from a traditional approach to an Active Learning approach in this class. Would the experience be positive for the instructor and would they continue to apply and expand elements of active learning in this and other classes?

Research Design

In order to answer the research questions posed here, a mixed-methods assessment strategy was employed. First, quantitative data was obtained from final exam performance in the Active Learning MC/MSD class and was compared directly to the same final exam questions given to a class taught in a traditional manner by one of the same instructors in a previous year. The final exam assessed both conceptual understanding and problem solving competency in machine design.

For the Active Learning version of the MC/MSD class, two instructors taught the class in the Spring quarter of 2015. Both instructors have extensive experience with teaching the course. Instructor A has taught the course seven times since 1997 and Instructor B has taught the class eleven times since 2004. Instructor A has extensive experience teaching using Active Learning techniques in fundamental mechanics courses (both Statics and Dynamics) and had used them in the MC/MSD class previously. Instructor B historically used a more traditional approach to the lecture portion of the class and has experience using Project Based Learning in the Laboratory portion of the class. Additionally Instructor B was interested in learning to use Active Learning techniques for the lecture portion of the class and welcomed the opportunity to partner with Instructor A to develop course materials to make the course activity-based. The two instructors delivered the active MC/MSD course to three lecture sections and four laboratory sections. Instructor A led two lecture sections of 32 students each and Instructor B led a single lecture section. Each instructor led two weekly, three hour laboratory sections of 24 students each. A summary of the instructors' experience and teaching load for the study is given in Table 1. Each instructor followed the same syllabus and led their lectures and laboratory sections in as identical manner as possible throughout the 10-week quarter. Any support material was identical including power point slides, in-class problems, homework problems, quizzes, and exams.

Questions from the final exam from the MC/MSD class taught in a traditional lecture format by Instructor B from the winter quarter of 2011 were used again in the Active Learning class in spring 2015 for comparison. Questions were designed to test both quantitative problem solving and conceptual understanding of machine design.

Table 1: Instructor Differences

	Experienced with Active Learning in Lecture	# of Lecture Sections	# of Laboratory Sections	Academic Rank	# of times teaching course
Instructor A	Yes	2	2	Full Professor	7
Instructor B	No	1	2	Full Professor	11

Other quantitative and qualitative data was gathered for this study through a post-class survey. The survey was designed to capture student's attitudes concerning the use of Active Learning in the MC/MSD class and also to assess the overall student experience. To answer the final question, Instructor B was asked to reflect on his experience of using Active Learning and his plans for future implementation.

Typical Class

For the MC/MSD class described here, the student receives four credit units. They meet in 50-minute lecture sections on Monday, Wednesday, and Friday; and a three-hour laboratory section

on either Tuesday or Thursday of each week. The students in the laboratory sections are not necessarily the same cohort as the lecture sections so some students might have had Instructor A for lecture and Instructor B for laboratory. The topics and the order in which they are covered are in the syllabus in appendix A.

Winter 2011 – Traditional Lecture

In the MC/MSD course taught by instructor B during winter quarter 2011, the course topics and lab structure were very similar to those in the spring 2015 course. However, what happened in lecture was very different. Most of each lecture period was spent in the traditional lecture mode, with the instructor presenting new material on the chalkboard and students taking notes. Each class period began by writing two to three key learning objectives for the day. Examples were worked in class by the instructor. Student participation was encouraged during class by asking individuals to identify the next step, provide the appropriate equation, or interpret from a table or figure from the text.

Grading was based on a final exam, three mid-term exams, lab project work, and weekly homework assignments. Each exam included both analytical and conceptual (mostly ranking) problems. Most homework assignments were completed in the McGraw-Hill CONNECT online homework system, though one problem each week was collected on paper. Students had access to the CONNECT solutions online after the homework was due. No multimedia examples were provided on the course learning management system (LMS).

The laboratory portion of the course consisted of two standalone labs and two related design projects. The two standalone labs were a one-week introduction to motor performance curves and two weeks to dissect and re-engineer a hand power tool. The two projects both related to the design of a self-propelled cable climber (space elevator). The first project (three weeks) was to develop a working scale model using Lego® Technics components coupled with hobby motors. These were tested to see how efficiently they could climb up 20-feet of vertical cable. The second project (4 weeks) was to develop a full-scale paper design for a space elevator based on what they had learned from the first project. The final deliverable was a formal design/analysis report.

Spring 2015 – Activity Based Lecture and Laboratory

For the new Active Learning MC/MSD class, formal lecturing was minimized. When lecturing or explaining content, every attempt was made to keep the instructors' speaking time limited to 10 minutes or less between activities where the students were asked to participate. Before each class, students were asked to watch a multimedia example problem posted on the course LMS. Class began with an update on the status of activities (reminders about homework, project schedules, quizzes etc.) then practical examples of the topic to be discussed were given (for example a short video on how a clutch works). Next the students were given the opportunity to ask questions about the online multimedia example problem followed by a short lecture (interspersed with conceptual questions) that reviewed the important aspects of the new topic. Finally student teams would work on one or two problems related to the current topic. The instructor usually guided the students along asking and answering questions.

Interspersed in the usual class process were times for students to explain homework problems to each other (team homework), weekly quizzes, short concept questions followed by class discussions (Think, Pair, Share) or ranking tasks presented as team quizzes. Notably missing from the lecture portion was the solution of example problems by the instructor. Instead the students were given a multimedia example problem online to review before class and one or two problem solutions online after class for the problems worked on during class. Additionally the students were given weekly homework assignments with traditional textbook problems to solve. Instructor written solutions to these problems were provided after they were due on the LMS.

The first half of the laboratory portion of the class consisted of a hands-on introductory laboratory on teamwork, and the fundamentals of electric motors followed by a four week design project involving the design and construction of a small Lego®-based machine. The second half of the laboratory portion was kicked off by a three-hour dissection of a hand-held power tool and a four week “paper” design of a more complex mechanical system (in this case a personal tracked vehicle). The first project ended in the demonstration of the Lego® machines and the second ended with a formal design review and written report.

Multimedia Example Problems

Although students will often say that they prefer to watch their instructor work out example problems similar to those that would appear on the exam, in the updated course the instructors took the approach of putting these examples online to free up time for the Active Learning elements of the class. The student’s desire makes sense from the standpoint that modeling the thought process of experts is one of their educational goals. Unfortunately students don’t typically pay attention during this time in class or often only ask superficial questions while frantically trying to copy down what the instructor is presenting. This leaves no time for thoughtful reflection. Later the students may use their notes to simply search for the equations that they can apply to their homework by simply substituting new numbers.

In place of the traditional example problems, the instructors created PowerPoint® files with audio overlay that explained how to solve a typical problem. When played as a slideshow, the instructor talks through the problem with elements appearing as they would on the board during a class. Additionally the students could eliminate the audio and step through the problem with the slideshow stopping at points where the students could try and perform the next step in the solution. Then by hitting the space bar they can see what the next step is to check themselves. A final advantage to these online example problems is that the students can access them later in the course when they are preparing for exams or trying to analyze their project designs. They could also print the entire example on a single page for offline review.

In-Class Problems

For each class period, the instructors provided a handout that contained relevant equations or figures/graphs that supported the day’s lesson. Typically this handout was the only place where students took notes for the class. Also handed out was an in-class problem that the students would work on in teams with occasional guidance from the instructor. Typically the problems were too complex to complete in the allotted time, but teams of students could begin the problems, set up the governing relationships and see a path to the final solution while getting questions answered. After class the full written solution to the in-class problems was provided online.

Online Quizzes

Conceptual knowledge has been shown to be a key ingredient to thinking as an expert (see Streveler *et al.*²⁰). Each weekend prior to the Monday class, an online quiz was posted to primarily get the students to think about the concepts involved in the class as well as force them to do the reading. The questions were typically multiple choice or True/False to allow automatic grading. Other questions were short response or required a short calculation.

Think-Pair-Share

Other concept questions were posed during class to keep students actively engaged. These questions were given in a Think-Pair-Share format and classroom discussion technique introduced by Lyman²¹. Questions were posed to the class and the students were asked to think by themselves for a couple of minutes, then pair with another to discuss and then finally to share their findings and explanations with the class. An example question posed early in the quarter was: “Which is larger – the geometric stress concentration factor of the fatigue stress concentration factor?”

Team Ranking Tasks

Each Wednesday in class the students were given quizzes which were more focused on formative rather than summative assessment. Three of the quizzes were in a team format where students were asked to rank alternative scenarios according to some criteria. Introduced by Maloney²² to the Science Education community, ranking tasks have gained attention in the Physics community²³ as well as in engineering (see Brown²⁴ for examples) as a way of promoting conceptual understanding. In a ranking task, students are presented with four to eight pictures of scenarios of slightly varied physical condition and asked to rank them based on some performance criteria. Using a team format promotes lively discussion and peer learning opportunities. An example of one of the Ranking task quizzes developed by the authors is shown in appendix B.

Project Based Learning Laboratory

The weekly three-hour laboratory presented the opportunity for project based learning. As mentioned previously, the students undertook two major design projects throughout the quarter. The first Lego-based project involved the students designing an Adaptive Ring Toss machine for people with disabilities. To complete the project the students worked in teams and had to select a small DC motor and design a gear system to “toss” carnival rings onto soda bottles (see Figure 1 for photos). The second project was a paper design that required the teams of students to develop software analysis tools to aid in component selection. The laboratory experiences for the Winter 2011 (control class) and the spring 2015 (Active Lecture) classes were similar in content and approach.



Figure 1: Demonstration of the Adaptive Ring Toss Machines

Results

1) Could the students learn the breadth and depth of the content via Active Learning?

In order to answer the first research question concerning student outcomes, we compared the results of both analytical and conceptual questions from the final exam given in Winter 2011 (traditional) and the Spring of 2015 (Active). Questions for the Spring 2015 final exam were taken from the two versions of the Winter 2011 final exam. One analytical question was taken from the first version of the 2011 final exam and two analytical questions were taken from the second version. The first question involved the selection of a threaded fastener for a tension loaded joint and was marked out of 30 points. The second involved the analysis of a shaft driven by two pulleys and the third question required the selection of rolling element bearings to support a rotating shaft. These two problems were marked out of 25 points. All analytical questions were graded with partial credit based on a consistent rubric to minimize grading variation between the two years. The concept questions were of several varieties. The first asked the students to develop a complete requirements list for a gearbox for a portable air compressor. Next there were eight short answer questions followed by eight true/false and six multiple choice questions. A copy of the exam can be found in Appendix C.

A comparison of the results from the 2011 and 2015 final exams is shown in Table 2. Note that mean scores on all problems did not vary much, with the largest gain of 6.44% for the Concept questions and a 9.05% decrease in the bolted joint (1) question. There was no significant statistical difference of student performance on questions two (2) and three (3). The p-value for the t-test for the Concept questions and the first question were 0.064 and 0.053 for these two populations, which indicates that there is not quite a statistical difference on those either.

In order to remove further variations between instructors, a further look at the data is provided in Table 3, which contains the 2015 exam performance from Instructor B only. In looking at these populations we find that the p-value for the bolted joint (1) and Concept questions is now below 0.05 indicating that there may be a significant difference due to the approach made in 2015. It should also be noted that there are many other factors besides the Active Learning components that are different between the 2011 and 2015 classes which could explain the exam differences.

For example, in 2011 bolted joints were covered earlier in the course and tested on a midterm exam. In 2015, they were the last topic covered and therefore were not included on a midterm prior to the final exam. Other differences, such as the amount of class time and number of homework problems spent on bolted joints may have led to differences in performance on the bolted joint question. The improvement in the conceptual questions; however, do support findings of other researchers like Hake⁷ cited earlier who have found that Active Engagement does lead to improvement in conceptual understanding

Table 2. Comparison of Final Exam performance between Winter 2011 and Spring 2015

	Question	N	Points Possible	Mean	Median	Std Dev	% Change	p-value from t-test
Traditional Lecture (Winter 2011)	1	36	30	23.2	25	6.04		
	2	25	25	18.5	19	4.39		
	3	25	25	20.6	21	4.14		
	Concept	61	40	23.3	23	6.16		
Active Learning Format (Spring 2015)	1	92	30	21.1	23.5	7.33	-9.05%	0.053
	2	92	25	18.3	19	4.88	-1.08%	0.432
	3	92	25	21.2	22	3.58	2.91%	0.261
	Concept	92	40	24.8	25.5	5.83	6.44%	0.064

Table 3. Spring 2015 Final Exam Performance for students taught by Instructor B

	Question	N	Points Possible	Mean	Median	Std Dev	% Change	p-value from t-test
Instructor B Novice with Active Learning	1	31	30	20.7	22	6.44	-10.78%	0.048
	2	31	25	18.7	20	4.04	1.08%	0.445
	3	31	25	21.4	23	3.31	3.88%	0.228
	Concept	31	40	25.9	26	4.81	11.16%	0.021

2) *How do the students value the Active Learning experience as compared to a traditional approach?*

To answer the second research question concerning student opinions about the experience, students were surveyed at the end of the quarter. The first set of survey questions asked the students about the effectiveness of the various teaching techniques employed. These results are shown in Table 4 with the Active elements located at the top and the more traditional teaching elements at the bottom. On average the students felt both the Active and the traditional elements were effective at helping them learn the material. The two techniques that the students thought were not helpful were the weekly online quizzes and the individual in-class quizzes. This is not surprising as most students do not view assessments as formative; however, it is interesting that the students thought that the in-class team quizzes were effective at helping them learn the material. Finally, the students thought that the tracked vehicle project was the most effective, followed by the traditional solving of individual homework problems and the in-class team homework problem solving.

The next two questions in the survey asked the students to compare the active learning classroom to a traditional one. As shown in Table 5, the students felt on average that the active learning

techniques were more effective with 74% rating it the same or more effective than a traditional classroom. There was even stronger agreement that the Active Learning was more engaging than a traditional classroom. It is interesting that the students do not necessarily associate this higher level of engagement as identical to effectiveness for teaching/learning the material.

Table 4. Subjective survey responses regarding the effectiveness of the class activities.

Active Learning Elements How effective was....	Very (5)	Effective (4)	Neutral (3)	Not very (2)	Not at all (1)	Avg
.. the Think-Pair-Share activities in helping you learn	16	47	16	11	2	3.70
... the online audio PowerPoint example problems in helping you learn.	35	32	17	4	4	3.98
.... the online quizzes before class in helping you learn	4	31	27	18	11	2.99
... the in-class individual homework problems in helping you learn	23	36	22	8	2	3.77
... the in-class team homework problems in helping you learn	31	50	3	6	1	4.14
.... the in-class team quizzes in helping you learn	20	53	15	3	1	3.96
... the Adaptive Ring Toss project in helping you learn.	8	25	40	17	2	3.22
... the Personal Tracked Vehicle project in helping you learn	58	30	3	1	0	4.58
Traditional Class Elements How effective was...						
... the lectures (professor discussing PowerPoint slides) in helping you learn	21	44	16	8	3	3.78
... the homework (completed outside of class) in helping you learn	47	44	6	3	2	4.21
... the in-class individual quizzes in helping you learn	7	31	29	20	5	3.16
... reviewing the in-class PowerPoint slides in helping you learn	18	51	15	7	1	3.85
... reading/reviewing the textbook in helping you learn	26	33	25	6	1	3.85

Table 5. Subjective survey responses comparing the active learning classroom to traditional.

	Much More (5)	More (4)	The Same (3)	Less (2)	Not (1)	Ave
How effective for learning you think these techniques were compared to a more traditional approach	18	34	19	18	3	3.50
Rate how engaging (keeping you involved) you think these techniques were compared to a more traditional approach.	35	42	10	3	2	4.14

Finally, the students were asked for any comments they had about the Active Learning approach used in the class. Not surprisingly, the results were mixed. Mirroring the ratings of effectiveness, a thematic analysis of the comments indicated that 72% were neutral to positive. Many students were very enthusiastic about the approach. Some typical comments included:

"I love the active learning approach. I have an incredibly short attention span when it comes to lectures where the teacher just talks the whole time. I usually just play games on my phone in the back of the classroom because I can't stay focused on the lecture. In this class, I was rarely tempted to pull my phone out because the lectures were engaging and concise and the many in class assignments really helped me grasp the material. Also, the audio example problems were THE most helpful tool I had when doing the homeworks. I loved this class, thanks a bunch!"

"The lectures for this class were awesome. It's really frustrating that all my engineering lectures aren't like this, even my public high school had figured out a structure similar to this."

"The active learning approach is WAY more engaging than a traditional classroom. This method puts the onus on the student to do more work outside of the classroom, but overall I think this shapes students into being more effective."

"I never felt like I was wasting time in that class, which almost never happens; classes always waste time."

"Normally, I'd consider myself a proponent of the traditional learning approach, where lecturers simply lecture for the full time and do example problems, then students go home and practice those on homework problems to learn how to do them. But, this is the first class that I have never really taken notes in, yet I feel like I learned the material just as well as I would have in the traditional setting. I think this method of learning is very effective, and I enjoyed it very much. With this learning style, it feels more like the student is learning the material during the lecture, instead of just copying information down into their notes, and learning it later when doing the homework problems. Because if this, I had to put in much less time outside of class, yet feel like I have an equally solid understanding of the material. ..."

Other students were negative on the approach, commenting:

"I felt like time spent on the weekly quizzes could be better spent on more learning time. We just don't have much in class time and I would rather spend that time reviewing new information and being able to ask questions. That's why I think the team quizzes are more effective than the individual quizzes because then I can talk to my classmates and have them help me if I don't understand something."

"I don't really learn this way. With the amount of perceived and actual work given for this class, I was exhausted by the time I got to the actual homework and reading for the next class. This made it difficult for me to understand problems conceptually as I felt rushed in class to "just get the work done" with my group, as opposed to being able to visualize the big picture. I felt like the theory behind the design was glazed over in preference to team-based learning, and I am a strongly individual learner. Lab was excellent, on the other hand, because we had time to ask questions and explore the problem before diving into analysis and calculation - and it provided real-world applications to work out. I strongly

prefer the traditional method of teaching in lecture, but this other method is suitable for lab activity.”

This last complaint about workload is historically a common complaint about this class. This was noted by a number of students who were positive about the Active Learning approach but felt too many topics were covered in the class. One final concern of teachers new to Active Learning, especially those who are in the tenure process, is the effect on their student evaluations. Table 6 contains the average student evaluation ratings from the MD/MSD course in Spring 2015 for the two instructors as compared to the average value the instructor received over his career while teaching this course. The results here are a little mixed. Instructor A, with experience with Active Learning techniques, received higher student evaluation ratings for the Active Learning course. However, Instructor B, a novice with Active Learning techniques, was assessed somewhat lower in the “ability to convey subject matter” and “overall rating” categories. So, it may be reasonable to expect somewhat lower student evaluation results when attempting this change for the first time.

Table 6: Student Evaluation Scores

	Evaluation Question	Average Career MC/MSD Rating	Spring 2015 Rating
Instructor A	How well prepared does the instructor seem to be in the subject matter?	3.78/4.00	3.96/4.00
	Evaluate the instructor on his/her ability to convey subject matter.	3.50/4.00	3.75/4.00
	Evaluate the instructor on his/her availability and effectiveness during office hours	3.63/4.00	3.88/4.00
	Overall, I would rate the instructor.	3.48/4.00	3.85/4.00
Instructor B	How well prepared does the instructor seem to be in the subject matter?	3.57/4.00	3.52/4.00
	Evaluate the instructor on his/her ability to convey subject matter.	3.40/4.00	3.14/4.00
	Evaluate the instructor on his/her availability and effectiveness during office hours	3.56/4.00	3.65/4.00
	Overall, I would rate the instructor.	3.50/4.00	3.29/4.00

3) *Is the faculty experience such that it would motivate them to use Active Learning techniques in the future?*

To answer the third Research question about future faculty motivation, instructor B was asked to reflect on his experience during the quarter. Specifically he was prompted to discuss what did and did not go well, what was easy and difficult, how time consuming preparation was and would he teach the class in an Active Learning format again. His response was:

“I really enjoyed trying Active Learning in this course, especially working with an instructor more experienced with the techniques. I know that my teaching can always be improved, so this was a great opportunity to try a different approach to see if it would yield improved results for the students.

What went well? Before the start of the term, we developed a generic plan for each class period (how much time in short lectures, how much think-pair-share, how much team work on problems, etc.). This gave us a target for what to prepare for each day. Because there were two of us, we took turns preparing materials for each week. The multimedia examples took some time to prepare, but they were very helpful for the students. I received a lot of informal positive feedback on them. Students were much more involved in class, since they worked together to solve specific problems. I had some concerns about not 'covering' material in class as much, but the similar results on the final exam were very positive. Although I was hoping for better performance (given the amount of additional preparation), the fact that we didn't hurt student learning was a good thing. As I continue to adapt this approach to my teaching style, I hope to see improved student learning results also.

What did not go well? In class, I struggled with keeping my lectures short. Before starting class, I would remind myself that they had already read the material – this was just a brief review. But, it was hard not to try to 'teach' the material anyway. The first few weeks were a little tough, while students were adjusting to (and resisting) the new approach. Because our example problems were too long to finish in class, the students sometimes were frustrated that they couldn't get to the end of the problem. Much of this is to be expected with the first time learning this way, and most of these issues got better as the term progressed. Next time, I will probably use shorter example problems.

What was easy? Nothing was easy about the transition. Working with an experienced colleague made it much more manageable, but the transition itself was a challenge. I almost gave up after the first week. However, this was primarily due to the extra preparation time. Now that these materials have been developed, on-going preparation for this class will be similar to that when teaching it using traditional methods. So, next time, many things should be easier!

Preparation Time. The daily preparation took much longer than I typically need for this class (since I already had the traditional lectures and handouts prepared). With Active Learning, for each class we prepared a multimedia example problem to post (3 hours), a handout for the students (1 hour), an in-class example problem with written solution to post after class (1-2 hours), and a short PowerPoint lecture to present (1-3 hours). In addition, each week we developed an online quiz, a homework with worked-out solutions, and an in-class quiz. The grading load for the quizzes and exams (a former student graded the homework) were similar to the traditionally taught course. Fortunately, since there were two of us we could share the preparation workload. And, except for the homework, quizzes, and exams, the rest of the course material can be re-used the next time the course is taught.

Would I teach the class using Active Learning again? Absolutely. Although the exam results were not significantly different, they were not significantly worse! And, since this was my first time teaching this way, I think those results will improve with experience. Beyond what was measured in the exam, I think the students gained experience with self-

teaching by reading material, which will help them become more effective lifelong learners. Also, the ability to take time during class to ask and answer questions of each other and of me should provide a deeper understanding. This teaching approach also should help those students who lack the motivation to do their homework. By doing more work in class, they can't help but to learn more of the material.

Conclusions and Recommendations

The techniques utilized in this MC/MSD course are not new, but have not been generally used in this course. Many instructors resist using more Active Learning or project-based assignments in their class for fear of not covering content. The results from this study show that a course can be taught using Active Learning techniques, cover the same content, and achieve similar student performance on the final exam. So, providing the material is provided in some form (online multimedia examples, in this case), covering content should not be a concern. Although scores did dip on one analytical problem, conceptual scores increased. A more important aspect to consider is the long-term retention and understanding of the students which unfortunately is difficult to measure and outside the scope of this study; however the students report being much more engaged in class which might promote longer term retention. Deeper conceptual understanding should also provide a framework upon which the students can build in their later courses and in their careers as professional engineers.

Some recommendations to those considering this approach:

- (1) Share the load with someone, if possible.
- (2) Change one part of the course at a time, even if it takes a few years to completely convert the entire course.
- (3) Prepare a lot of the material in advance of the term.
- (4) Be prepared for student resistance by gathering facts to show why this is a good change. Give them lots of opportunity for feedback, and respond to it.

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Appendix A: MC/MSD Class Syllabus

Lectures:	ME 329-01, MWF	8:10-9:00	192-24
	ME 329-09, MWF	9:10-10:00	13-109
	ME 329-06, MWF	10:10-11:00	38-225
Labs:	ME 329-07, T	8:10-11:00	13-124
	ME 329-08, T	12:10-3:00	13-124
	ME 329-03, R	8:10-11:00	192-134
	ME 329-04, R	12:10-3:00	192-120

Office Hours:

A	B
M: 10-11am	M: 1-3pm
T: 3-4pm	W: 11am-12pm
W: 10am-12pm	F: 8:30-10am
F: 11am-12pm	F: 12:30-1pm
(& by Appointment)	

Text: Shigley's Mechanical Engineering Design, 10th ed., Budynas & Nisbett, McGraw Hill 2015

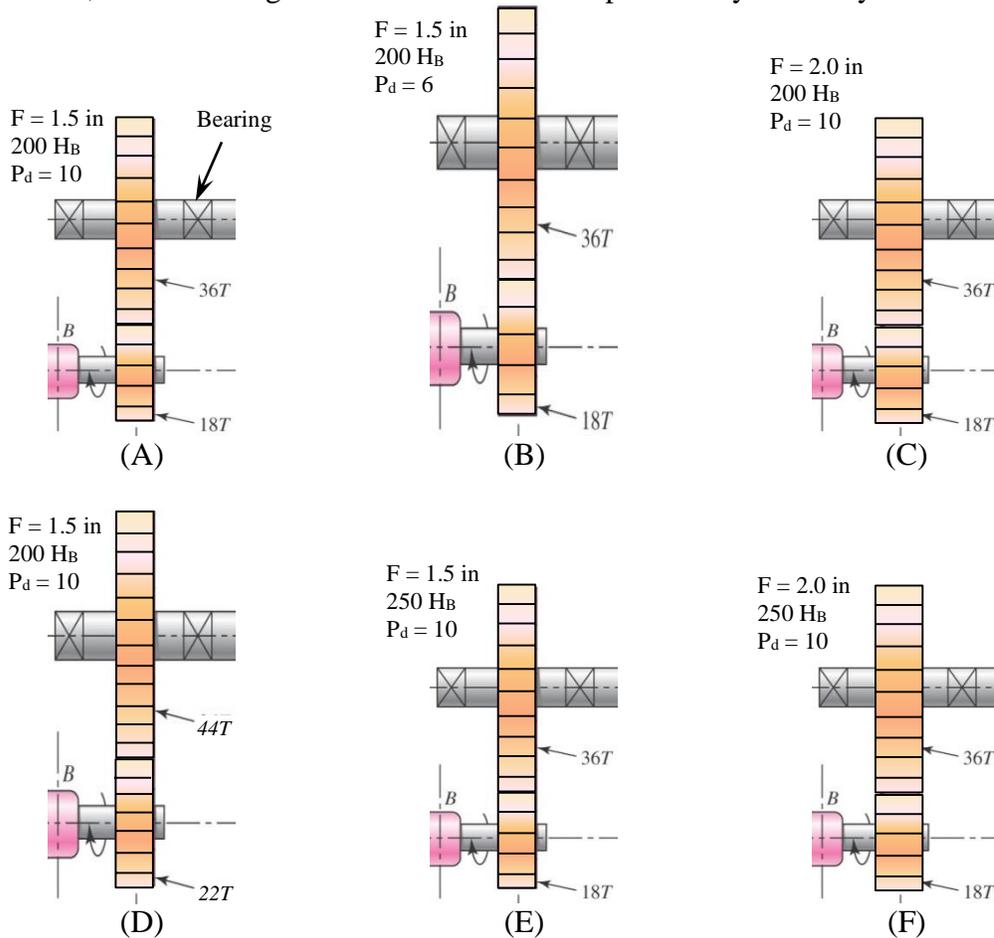
Moodle: Be sure to have access to Moodle for assignments, quizzes, grades and other information.

Wk	Date	In-Class Topic	Reading*	Due Dates
1	3/30	C1: Introduction, Fatigue Review	6.1-6.17	
	4/1	C2: Shaft Materials, Layout, Stress/Deflection	7.1-7.5	
	4/3	C3: Shaft Critical Speeds, Connections	7.6-7.8	HW #1
2	4/6	C4: Power, Electric Motors	See Polylearn	OLQ #1 before class
	4/7,9	Lab #1: Electric Motors / DP#1		Motor Data Sheet
	4/8	C5: Gear Fundamentals	13.1-13.8,10	Quiz #1
	4/10	C6: Gear Trains, Tooth Force and Stress	13.13-14,16,14.1	HW #2
3	4/13	C7: Selecting Spur and Helical Gears	14.2-14.19	OLQ #2
	4/14,16	Lab #2: Conceptual Prototyping		
	4/15	C8: Bevel Gears and Differentials	13.9,15.1-5	Quiz #2
	4/17	C9: Wormsets	13.11,17,15.6-9	HW#3
4	4/20	C10: Rolling Contact Bearings I	11.1-9	OLQ #3
	4/21,23	Lab #3: Tech Talks, Project Work		
	4/22	C11: Rolling Contact Bearings II	11.10-12	Quiz #3
	4/24	C12: Hydrodynamic Bearings	12.1-12.7	HW#4
5	4/27	C13: Designing Hydrodynamic Bearings	12.8-15	OLQ #4
	4/28,30	Lab #4: Prototype Presentations		
	4/29	C14: Bands, Clutches & Brakes	16.1-16.7	Quiz #4
	5/1	C15: Rim Brakes and Clutches	16.8-16.10	HW #5
6	5/4	Midterm (Book + Calculator + Eqn Sheets)		Midterm
	5/5,7	Lab #5: Tech Talks, Mechanical Dissection		
	5/6	C16: Helical Coil Springs	10.1-10.6	OLQ#5, DP#1 Report
	5/8	C17: Spring Fatigue	10.7-10.10	HW#6
7	5/11	C18: Flat Belts	17.1-17.2	OLQ#6,
	5/12,14	Lab #6: Tech Talks, DP#2 Week #1		
	5/13	C19: V-Belts	17.3	Quiz #5
	5/15	C20: Roller Chains	17.5	HW#7
8	5/18	C21: ACME Power Screws	8.1-8.3	OLQ#7
	5/19,21	Lab #7: Tech Talks, DP#2 Week #2		
	5/20	C22: Threaded Fasteners - Tension Joint	8.4-8.8	Quiz #6
	5/22	C23: Threaded Fastener Fatigue	8.9-12	HW #8
9	5/25	Holiday: Memorial Day. No Class		OLQ#8
	5/26,28	Lab #8: Tech Talks, Informal Design Review		
	5/27	C24: Bolt Shear, Bolt Groups	9.1-9.4	Quiz #7
	5/29	C25: Welded Joints – Stress Analysis	9.5-9.8	HW#9
10	6/1	C26: Fluid Power System Fundamentals	See PolyLearn	OLQ#9
	6/2,4	Lab #9: Formal Design Review DP#2		Presentations, DP#2 Report
	6/3	C27: More Fluid Power Systems		Quiz #8
	6/5	C28: Review		HW #10
11	6/9 T	Final Exam, all sections 7:10-10:00pm		

*Reading is to be done prior to class meeting. No Cell Phones should be visible during class.

Appendix B: Typical Ranking Task Quiz for the MC/MSD Class
 Names _____

1) Consider the following possible designs (A thru F) for a speed reducing gearset for a 6000-rpm motor. For all designs, assume $Q_v = 10$, $K_m = 1.2$, $K_s = K_B = 1$, $\phi = 20^\circ$, and Grade 1 through-hardened steel. For a life of 10^7 pinion cycles, and considering only PINION BENDING FATIGUE, rank the designs in terms of how much power they can carry.



Highest Power _____ Lowest Power _____

$$\sigma = W^t K_o K_v K_s \frac{P_d}{F} \frac{K_m K_B}{J}$$

2) Explain your rankings on the reverse.

$$\sigma_{all} = \begin{cases} \frac{S_t}{S_F} \frac{Y_N}{K_T K_R} \\ \frac{S_t}{S_F} \frac{Y_N}{Y_\theta Y_Z} \end{cases}$$

Appendix C: Spring 2015 Final Exam

Name: _____

Problem 1 (30 points)

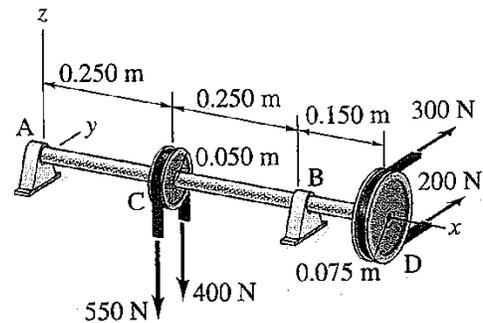
In an overhead crane platform, four 1/2-inch steel UNC bolts will be used to clamp a 1/2-inch steel plate to a 5/8-inch cast iron bracket. Each bolt will have a single 1/2" N (Narrow) washer, resulting in a joint material stiffness of 10.8×10^6 lb/in. During crane operation, each bolt needs to support a load of 2000 lb. Using a design factor of 2.5 on load and assuming a permanent joint in static loading,

- What minimum bolt length (standard size) should be used?
- What minimum SAE grade should be used?
- As the load increases, will yielding or joint separation occur first?

Name: _____

Problem 2 (25 points)

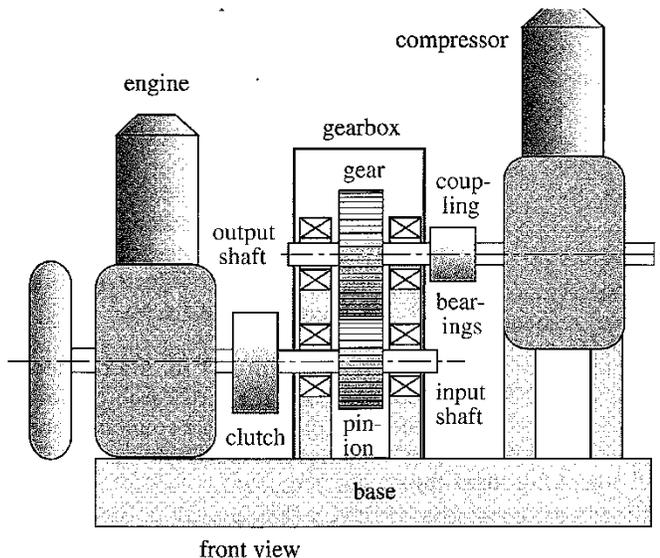
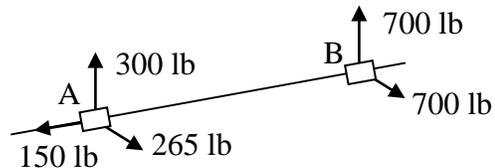
At room temperature, two belts apply tensile forces to the machined 1030 annealed steel shaft shown at right. For 95% reliability and a design factor of 2.0, determine the minimum shaft diameter for infinite life. End-mill keyseats are used to attach the pulleys. Don't forget to include appropriate diagrams, if applicable!



Problem 3 (25 points)

A 35-mm diameter steel shaft rotating at 1000-rpm is supported by two bearings at A and B, with loads as shown below. The shaft sees light impact and the desired bearing system reliability should be 96% for a life of 10,000 hours.

Select the smallest acceptable 02-series deep-groove ball bearing for location A and cylindrical roller bearing for location B. State any assumptions.



Concept Problem (10 points)

A portable air compressor is being designed for contractor use on remote construction sites. The 2.5 hp gasoline driving engine will rotate at 3800 rpm. The single-piston compressor needs to be driven at 1500 rpm. They are connected by a gear box.

Without performing calculations, develop a complete requirements list for the gearbox connecting the engine to the compressor. Make appropriate assumptions and put any numbers you are unsure of inside [brackets].

Short Answer (2 points each)

1. Explain what spring 'pre-setting' is. When should you avoid using it?
2. Define bolt 'Proof Strength' and 'Tensile Strength'. Use a figure if you think it would help.
3. Why is the pinion usually more critical to study during gear analysis? Under what conditions would the gear be more critical?
4. Why is the smaller pulley usually more critical to study during V-belt analysis? Under what conditions would the larger pulley be more critical?
5. If a gear needs to have a precise axial location on a shaft AND resist high torques, how would you locate and attach it?
6. In most designs, should power screws be loaded in compression or tension? Why?
7. What are two good reasons why you might specify roller bearings over hydrodynamic bearings?
8. On a worm gear-set, the single-thread worm spins at 1000-rpm and has a 1-in pitch diameter. The gear has a pitch of 10 and a 5-in pitch diameter. How fast does the gear rotate?

True/False (1 point each)

T **F**

- ___ ___ 1. Oil viscosity decreases linearly with increasing temperature.
- ___ ___ 2. The dedendum is the depth of a gear tooth inside its pitch circle.
- ___ ___ 3. You can predict shaft critical speed only in horizontal shafts.
- ___ ___ 4. A power screw's efficiency is greatest when the load is being lowered.
- ___ ___ 5. In a butt weld, a crowned (convex) weld surface provides better fatigue resistance than one that has been ground flat.
- ___ ___ 6. A needle roller bearing is a good choice for a location where axial loads are approximately equal to radial loads.
- ___ ___ 7. The material in a helical coil spring experiences primarily bending stress.
- ___ ___ 8. Threaded fasteners in fatigue applications should use only rolled threads.

Multiple Choice – Choose the best answer (1 point each)

- _____ 1. Choose the best wording for a proposed crane system requirement:
- a) Must be capable of lifting all planned loads to a height of 50 m.
 - b) Must lift 5000 lb.
 - c) Must result in no user complaints about lifting for first 3 years of use.
 - d) Must lift 5000 lb up to a maximum 50 m height.
- _____ 2. Choose the best wording for a proposed bicycle brake subsystem requirement:
- a) Capable of stopping bicycle and rider from 20 mph within 30 ft.
 - b) Exerts a 50 ft-lb braking torque for a 50 lb hand lever clamping force.
 - c) A 50 lb lever force will stop bicycle and rider in 10 seconds.
 - d) An average rider will be able to stop from 20 mph within 10 seconds.
- _____ 3. Once in the hydrodynamic range, the power loss in a journal bearing:
- a) Is unaffected by the speed
 - b) Increases with increasing speed
 - c) Decreases with increasing speed
 - d) Increases or decreases with speed, depending on the viscosity
- _____ 4. Which of the following is a valid reason to use helical gears?
- a) They are quieter than spur gears
 - b) They do not impose axial loads on the shaft
 - c) They can transfer high power through a 90° turn
 - d) None of the above
- _____ 5. Hydrodynamic lubrication refers to the condition when:
- a) The bearing and journal do not come into direct contact.
 - b) The bearing and journal are always in direct contact.
 - c) The bearing and journal are occasionally in direct contact.
 - d) None of the above.
- _____ 6. Which of the following would reduce the bolt tensile load (F_b) in a clamped joint subjected to external tensile loading, P ?
- a) Increase the external tensile force
 - b) Increase the bolt diameter
 - c) Decrease the bolt diameter
 - d) None of the above