Board 98: Lessons Learned from an Integrated Class-Lab Approach to a Mechanics of Materials Course

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Introduction

A Mechanics of Materials course offers rich opportunities for new theoretical understandings, development of laboratory skills, and small design projects. The three-year old Campbell School of Engineering is promoting a class-lab approach in most of its courses. A traditional four credit laboratory course might meet for three hours per week of lecture/recitation in a large section and 2-3 hours per week of lab in smaller sections. In contrast, the class-lab meets for the same amount of time but does not distinguish between lab and lecture time. In our case, we meet in sections of 24 students in a room with six four-person tables surrounded by laboratory equipment on the outside walls.

In Fall 2018, we offered Mechanics of Materials to the mechanical engineering concentration students for the first time. It is a four-credit class that meets for three 110-minute sessions in a class-lab. This approach has the benefit of tighter coupling between lecture and laboratory content. Another benefit is the flexible class time that might be used primarily for non-laboratory activities one week and extensive laboratory activities another. A benefit that emerged over the course of the semester is that the longer class time enabled more options for learning activities that develop learning skills. However, transitioning from a traditional course framework to the class-lab format did present a number of challenges that will be described further.

Background

Laboratory time serves multiple functions in an engineering curriculum. Feisel and Rosa outline 13 potential learning objectives that include instrumentation, models, and data analysis, but also creativity, ethics, and sensory awareness [1]. Educators across science and engineering are working on shifting from cookbook laboratories to more authentic scientific experiences [2-4]. Round and Lom describe a “continuum of autonomy, responsibility, and immersion” in lab experiences, with cookbook labs at the lowest level and apprenticeship in a research lab at the highest level [5].

The integration of lecture and laboratory experiences is effective for linking the theoretical and practical and for increasing student engagement. Hall, et al. developed a first-year engineering curriculum, *Living with the Lab*, designed to provide authentic engineering experiences and thereby motivate student learning [6]. Physics courses have experimented with studio formats [7]. Round and Lom describe fused courses in biology and address issues of classroom layout, coordinating student attention, and accommodating different student paces [5].

Each course in the curriculum provides an opportunity for students to develop engineering knowledge and skills as well as independent learning skills. The proximity of laboratory equipment and the flexibility of course time in the class-lab setting opens up possibilities for experimenting with new approaches for developing independent learners. Weimer encourages

instructors to adjust their view of content to include its role as a means for developing independent learning skills and providing opportunities for students to take responsibility for their own learning [8]. She encourages faculty to identify disciplinary learning outcomes and learning skills outcomes.

Course Organization and Activities

Mechanics of Materials met three days a week for 110 minutes each class session. Meeting time per week was 5.5 hours. The primary activities that took place during the course were short lectures, pair problem solving, experimentation in groups of 2-4, quizzes, and homework. My overarching learning objectives for Mechanics of Materials were for students to have an ability to:

1. Make rough estimates of stress and deflection in real world structures that can serve as a reality check for more extensive computational analysis;
2. Formulate and solve problems without a procedure to follow.

While the first objective is a disciplinary learning outcome and the second a learning skills outcome, both involve development of independent learning ability.

Problem Solving Activities In a shorter class period, the instructor has time to present key concepts, work an example problem or two, and perhaps probe understanding with concept questions along the way. The 110-minute class period in the fall semester Mechanic of Materials provided significant time for students to practice solving mechanics problems with an instructor nearby for questions. The approach for this activity evolved as the semester went on:

1. At the beginning of the semester, I would do a short lecture that included an example problem and then provide a problem exercise handout to each student. I advised them to work with their neighbors to solve the problem. Some readily worked with others, and some did not.
2. In the next iteration, I asked students to find a partner and then passed out one handout per pair (or group of three when necessary). Some student pairs diligently worked on the problem while others did not.
3. The third iteration was the same, except that I asked pairs to turn in the exercise for a grade (one point all or nothing). This worked better; however, some pairs consistently struggled to complete the problems.
4. The next iteration was to randomly assign pairs and have them turn in their completed exercise after checking with me that they got the right answer. This worked quite well. Nearly all students were engaged in the work, and they regularly asked questions.
5. The next modification was to omit the example problem beforehand. This increased the number of questions that students asked me and generated productive struggle. Students used the extra in-class problem solving time to just try something and go down a wrong path or two.
6. In the final iteration, questions were added to the end of each exercise, such as “What mistakes are easy to make with this type of problem?” or “What advantage or disadvantage does this method have over [another method]?” These questions promoted metacognition about the student’s own learning process.

Student engagement in problem solving was high, and many students commented on the effectiveness of the approach in preparing them for quizzes and exams. The ability to ask questions right away was particularly appealing. Nevertheless, some elements could be improved upon. For example, some pairs would finish much earlier than others. More structure could be added that encourages the finished students to help other students or that encourages students to work on homework thereby reducing their out-of-class time. Another issue was that some students are not particularly good at working with others--they get distracted easily or work the problem on their own rather than collaboratively. At the end of the semester, the class voted on the best problem-solving partner, and that person received a small prize. This helped to highlight what makes a good partner but was too late to affect student behavior. Another way to raise awareness of desirable partnering behavior may be to ask students in an out-of-class or in-class assignment to reflect on what makes a good partner and which behaviors they themselves exhibit.

Laboratory Activities The course made use of a large material testing load frame. It also adopted table top experiments with strain gaged test beams. With up to 24 students in a section, there was not enough equipment for all student groups to perform experiments simultaneously. One of the challenges then was to adopt strategies for rotating students through the lab activities while keeping the rest of the students engaged in another course activity. Sometimes, two days were necessary to rotate all groups through. When students were not working with the equipment, they were working on other problems or the data analysis following the data collection. The timing for this type of activity requires careful planning and is an area I will target for improvement.

We also used beams instrumented with VPG Micromachines strain gages. These are relatively inexpensive and permitted multiple groups to work at the same time. Some groups were much faster than others. The fast groups were able to complete more of their lab reports in class leaving less work for outside of class. In future offerings of the course, we plan to adopt even more table top experiments. Subhash and Ridgeway [9] describe low-cost experiments on topics such as tensile loading, pressure vessels, adhesion strength, beam deflection and stress concentration.

The first offering of the course made little intentional effort to move students up the continuum from dependent to independent learners in the areas of “autonomy, responsibility, and immersion.” This is another area for improvement.

Quizzes and Homework The longer class time afforded the opportunity for a 30-minute quiz each week. Because of the wide availability of textbook problem solutions, homework did not count for a significant percentage of the final grade. The weekly quiz would be very similar to one of the homework problems thus motivating effort on the homework. Also, I collected one homework problem per week (specified ahead of time) so that I could ensure students were practicing a structured engineering problem solving approach. Quiz grades tended to be high, and the presence of the quiz seemed to achieve its intended purpose of motivating work on the homework problems. With the longer in-class time, my expectations for out of class time were lower. While I do not have direct evidence of whether that was the case, some students reported that the in-class problem solving helped them complete the homework problems more easily.

Summary and Recommendations

The class-lab approach integrates lab and lecture in both time and space. It offers avenues for exploring new educational activities that develop independent learners. In the first offering of Mechanics of Materials in Fall 2018, we explored various approaches for in-class problem solving. We used the time flexibility to have labs that were both shorter and longer than one class period. We did weekly quizzes to ensure that students were doing effective homework practice. In the future, the class could be improved upon by breaking down the independent learning skills goals into smaller pieces. As an example, Round and Lom [5] offer a progression in laboratory work from traditional verification (or cookbook), to guided inquiry, to open inquiry, to research projects, and finally to apprenticeship in a research lab. With this type resolution, learning activities could be sequenced to help students move along the continuum from dependent to independent learner.

We are fortunate to have small class sizes that lend themselves to experimenting with the class-lab approach. Some of the benefits of this approach could also transfer to larger class environments. For example, undergraduate or graduate teaching assistants could answer questions while students are practicing in-class problem solving. Moreover, the use of inexpensive table-top equipment could scale to larger environments.

To conclude, this first offering of Mechanics of Materials in our school showed the potential benefits of the class-lab approach and produced a positive change in the learning environment. The lessons learned will make the course even better the second time around.

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