AC 2007-2469: INCORPORATING ACTIVE LEARNING INTO ENVIRONMENTAL ENGINEERING

Tracy Thatcher, Cal Poly San Luis Obispo

Incorporating Active Learning Into Environmental Engineering Lecture Courses

Introduction

The benefits of incorporating active learning into science and engineering classes have long been recognized. Traditionally, the active learning portions of courses have been primarily relegated to laboratory and 'discussion' sections. However, during recent years, there has been a recognition that the same techniques that make laboratory classes so valuable can also transform the traditional lecture environment. Active learning has been shown to aid understanding and improve retention of information in a variety of courses from chemistry[1] to electrical engineering[2] and hydraulics[3].

The redesign of courses to take advantage of what we know about learning and knowledge retention has been suggested by Furse[4]. As the impetus for her revision of standard teaching methods, she cites the work of David Sousa[5] which summarizes the average adult retention rate for different learning methods. Lowest retention is from the typical lecture (5% retention), whereas retention from activities like discussion (50%) and teaching others (90%) are much higher. This concept can be leveraged by reformatting the typical class period and dividing the time into different activities that stimulate different types of learning and promote a deeper understanding and better retention rates. Optimally, lectures which explain the important concepts and methods would be followed by a group discussion, demonstration, or other active learning opportunity. This optimal format is designed to provide opportunities for students to 'discover' new ideas and refine their own understanding of complex concepts.

Although the benefits of adding active and cooperative learning to engineering lecture courses are fairly clear, many introductory environmental engineering courses are still taught primarily in a lecture format. The reasons for this are many and vary depending on the course and the instructor. When discussing this issue with colleagues, the most commonly cited concern has been that time devoted to active and cooperative learning will reduce the amount of material that can be covered in class. Since this type of introductory course typically has a large number of topics that need to be covered, it can be difficult to see how "additional" activities can be incorporated. However, it has not been our experience that this concern is a significant issue. The time required for the activities was balanced by increased comprehension, less time needed for repetition of ideas, better attentiveness during lecture periods, and an increase in preparation requirements for students before lectures.

This paper discusses a project which developed and implemented a series of active learning modules into a traditional lecture based "Introduction to Environmental Engineering" course and analyzes the results in terms of meeting the desired learning outcomes for the course. The primary learning outcomes enhanced by this change are in the areas of teamwork, communication, and problem analysis. Results from the first quarter of implementation show that the project is generally quite successful. However, as would be expected of any major course redesign, there are areas that still need further development and refinement. A course development grant from the university paid for 3 units of release time for development of the modules and about $500 in supplies.

Project Overview

Introduction to Environmental Engineering was redesigned to incorporate in-class activities and co-operative learning into the traditional lecture only format. The course is required for all civil and environmental engineering majors and is typically taken during the junior year. The original format of the class was two - 2 hour lectures a week. This course is taught by the ENVE faculty on a rotating basis. Therefore, one important aspect of the course redevelopment was to provide a format and materials that could be implemented by any of the faculty in the department, as well as outside lecturers. The concepts presented in the course help these future engineers to recognize, evaluate, and mitigate the environmental impacts of engineering projects. As a consequence, it is critical for all students to retain the principles from this introductory course through their school years and into their professional practices.

The course redevelopment provided activity modules and worksheets that employ the latest teaching strategies and techniques to enhance learning outcomes. The activities for the modules are structured to correspond to the major units covered in the course (e.g. water chemistry or material balance) and are design to allow students to gain experience in working in teams through collaboration on activities, hypothesis generation, and problem solving. Students evaluate results, synthesize these results to understand the greater impacts, and then debate the results in small groups to obtain a consensus on issues. Consensus building and positive group dynamics are stressed. In addition to the activity modules, the redesign also incorporated many opportunities for in-class problems solving and short discussion breaks.

The redevelopment of the course will also help better align the learning objectives with the learning outcomes listed in the ABET Course Classification, which are used be ABET to determine if the course is meeting desired accreditation outcomes. Although many of the ABET outcomes are enhanced in the format, the most significant learning outcomes impacted are:

1. Ability to design & conduct experiments; analyze, interpret data
2. Ability to function in multi-disciplinary teams
3. Ability to communicate effectively

The new format provides multiple opportunities for students to engage in activities that give students experience and improve their abilities in the above areas. In addition, their understanding of the impact of engineering solutions in a global and societal context (learning outcome #4) should be significantly enhanced if the desired goals of the project (improving understanding and retention of concepts) is met.

The addition of hands on activities provides students with active and co-operative learning opportunities that enhance learning outcomes and improve long term retention of these important concepts. The activities provide students with the opportunity to conduct simple experiments and then analyze and interpret their results (learning outcome #1). This opportunity was lacking in the previous lecture only format for this course. Typically, the class activities are performed and analyzed in small teams. Since this course is taken by both civil engineers and environmental engineers, as well as other engineers as an elective, these teams are typically multi-disciplinary and with members that have a variety of backgrounds and experiences. Consequently, students gain experience working with multi-disciplinary teams (learning outcome #2) through collaboration on activities, hypothesis generation, and problem solving. As part of each activity, students evaluate results, synthesize these results to understand the greater impacts, and then debate the results in small groups to obtain a consensus on issues. In addition to requiring effective communication between team members, many of the activities require students to 'report-out' their results to the class. Regular practice with public speaking improves confidence and leads to more effective communication skills (learning outcome #3). The activities and worksheets also encourage students to explore the global and societal impacts of engineering decisions by providing open-ended questions and the opportunity to analyze these impacts in a small group setting (learning outcome #4).

Exercises were prepared and administered by the instructor (including setup and clean up) in a normal classroom without graduate students or other assistants. Ten such exercises were conducted during the 10 week, 20 session, class of 30 to 40 students in groups of 2 to 4 students, depending upon the nature of the activity. Typically, the activities were not designed to be very complex, however the analysis required students to integrate ideas and concepts. Each hands-on activity required 10 to 30 minutes, and the example described required about 20 minutes. During each activity, worksheets were used to guide students through the activity and provide open-ended, complex questions to facilitate a more enduring understanding of concepts. Students also explore ways in which they can incorporate the principles of environmental engineering into other aspects of engineering practice. The activity worksheets are designed not only to guide the learning process, but also to provide an assessment of learning outcomes. Grades were assigned for completeness and effort, but not for correctness, with the intention of promoting the exercise as a learning process. These grades counted for about 10% of the final grade. The impact of this enhanced program is analyzed by comparing concept understanding between students taking the course before and after the changes and via survey results. Student understanding is also assessed by more traditional methods, such as homework and exam problems. This is the first course in our department to incorporate this teaching approach, however we are working to incorporate the idea into other courses.

How Activity Modules Work

Each activity module provides a hands-on activity that lets students explore one or more of the concepts explored in class. The activities for the modules are structured to correspond to the major units covered in the course (ecosystems, material balance, risk assessment, water chemistry, hydrology, water quality, water treatment, wastewater treatment, and air quality). In addition, the principles of active learning and co-operative learning have been incorporated into the design of the activity modules.

After the activities were defined and refined, activity worksheets were developed for each activity. These worksheets describe the purpose and methods for the activities, layout the analytical structure for interpreting the results, and then provide discussion points to support the hands-on activity. The discussion points are designed to help the students investigate the implications of their results more thoroughly. For example, an activity measuring dissolved oxygen levels in samples from different sources requires students to predict the results of the measurements before performing the tests, to provide reasons for their predictions, and then to discuss how their predictions compared to the measured values and why they are similar or different. As a final stage of the activity, groups compare dissolved oxygen levels with dissolved oxygen deficits and hypothesize situations in which one type of reporting value might be more useful than the other.

As an example of how the activity module works, I will focus on the activity module investigating the concepts that lead to summertime stratification of deep lakes. In this activity, students work in groups to make a ‘stratified lake in a cup’ using ice cubes of one color and warm water of a different color. The worksheet for this activity is shown in Figure 1. The worksheet process is designed to lead students up the levels of Blooms Taxonomy, starting with knowledge and proceeding to understanding, application, analysis, synthesis, and evaluation. The first two instructions help the students understand how cold water behaves in an ecosystem (knowledge) and explain what they see (understanding). For the third question, students must apply this knowledge to a more generalized situation (application). Questions 4 and five require the students to compare different situations (analysis) and show relationships for new situations (synthesis). Question 7 requires students to apply previously learned principles (mass balance) to a new problem (application) and problem 8 requires students to make judgments integrating a wide range of criteria (evaluation).

The activities are structured to encourage equal participation by providing multiple ‘roles’ in the activity, so that each student has a task. Consensus building, open ended questions, and positive group dynamics are stressed. For some activities, groups ‘report out’ to the class, thereby allowing the students to become not only learners but also teachers. This process also provides both an assessment opportunity and the possibility for immediate feedback if concepts are not completely grasped. An additional benefit of the hands on activities is that during the activity time, the instructor is able to move between groups and provide individualized instruction and assistance, thereby fostering a more personalized atmosphere than is typically provided in a lecture class.

Analysis of Effectiveness

Objectively assessing the effectiveness of course changes is always difficult. In general, the variations of physical facilities, class times, and particular student make-up cause each class to be slightly different, even if no major changes are made in the curriculum or teaching methods. In the case of this course, two major factors, in addition to the course redesign, may have had an impact on the class during the evaluation quarter. The first is that both sections of the course were held early in the morning (one from 7 to 9 am and the other from 8 to 10) and the second was that construction of a new building directly outside the classroom caused high ambient noise levels inside the classroom. The effectiveness of the course redesign has been assessed in terms of meeting the learning outcomes, student ability to apply course concepts, and student survey results.

The first assessment, meeting of course learning outcomes, is arguably the most subjective of the of the assessment criteria. While it is certain that the course redesign provided the students with an opportunity to practice their experimental, teamwork, and communication skills, determining whether these skills improved over the course of the quarter and whether the improvement was due to this course or other courses they were taking concurrently is less obvious.

Lake Stratification Exercise

Names: ____

Each group will be making a stratified lake model in a clear cup. Follow the instructions below and answer the questions. For best results, read each instruction completely and follow it carefully.

1. Fill your cup about ¾ full with lukewarm water. Set the cup down and allow time for the water to stop moving before continuing and all bubbles to rise to top (at least 1 minute).

2. Carefully add one colored ice cube to the top of the cup. Try to place the ice cube in the water as gently as possible, so the water is not stirred or mixed. Record your observations of the melting process and draw a sketch of the container below. Hold a white paper behind the cup, to aid viewing.

3. One of the most unusual properties of water is that the solid phase (ice) is less dense than the liquid phase. For almost all other materials the solid phase would sink to the bottom of the container. If solid ice were denser than liquid, what impact would this have on lake ecosystems in regions with winter temperatures below freezing?

4. Using a pipette, carefully transfer several pipettes of warm, colored water to the top surface of your stratified lake model. Try to add the water as gently as possible to prevent mixing. It should be discharged very slowly, just at the surface of the water. This system now represents a stratified summertime lake. Holding a white paper behind the cup, to aid viewing, record your observations and sketch your container below. Label the epilimnion(upper layer), thermocline (middle layer), and hypolimnion (bottom layer) on your sketch. Estimate the relative temperature of each layer and write that information on your sketch.

5. Wind provides the mixing energy for fall turnover, once stratification is reduced by cooler weather. Gently blow across the top of the lake model to simulate "fall turnover" on you stratified lake system. Record your observations.

6. How do you think your "stratified lake" might vary from actual stratified lakes?

7. A truck filled with barrels of toxic chemicals is driving along the edge of a lake and overturns. A barrels rolls to the lake edge, breaks, and the contents spill into the lake. Assume the lake can be adequately described as a cylinder and that the following data describes the system:

   Lake Area = 40,000 m^2
   Lake Depth = 42 m
   Mass of Chemical Spilled = 320 kg
   Stream flow into lake = 0.7 m^3/s
   Toxicity to deep water fish = 12 µg/l
   Toxicity to surface water fish = 35 µg/l

   Assume that during the summer, the lake is stratified with a 2.5 m epilimnion and a 1m thermocline. What would be the difference between a spill during summer stratification and fall turnover. Make quantitative comparisons of initial concentrations and clearance times. Estimate and compare the effect on the two fish species listed above.

8. Hypothesize what other effects (from the above spill) might be of concern. Consider all species including (but not limited to) plants, birds, fish, and downstream ecosystems.

Figure 1: Worksheet questions and instructions for stratified lake activity

Observationally, by the end of the quarter students were able to complete the activities more independently, form groups more quickly, and complete the required tasks more completely by the end of the quarter. In addition, students asked and answered questions more readily as the quarter progressed. It seems reasonable that at least some of this improvement can be attributed to the active and cooperative learning tasks completed during the quarter.

The second criteria, application of course content, can be assessed more directly. Although, of course, the exams for each quarter were not the same, the students in the redesigned course were able to answer qualitative and perception questions better than students in the previous lecture only course. A more quantitative assessment can be made on homework scores, since homework questions vary less between quarters. In the quarter using traditional lectures the average homework score over the quarter was 69%. In the 2 sections using the active learning based approach, average scores were 78% and 76%. This improvement represents a substantial increase in comprehension of the class material.

The third assessment method was class survey. The students in each section were given time to complete a specific evaluation of the new course material. The survey consisted of a numerical section and a narrative section. In the numerical section, students assigned two numerical score between 1 and 5 for each of the activities in the class. One of the scores was to assess whether the activity increased their knowledge and retention of concepts and the other was whether they found the activity interesting. Students were told to give a score of 1 if the activity was 'useless' and 5 if it was 'great'. Section 1 gave an average score over all activities of 3.8 for knowledge and 3.7 for interest. Section 2 gave a score of 4.0 for both knowledge and interest. For both sections the standard deviation of the scores was around 1. The narrative section asked students whether they would remember things from the course and whether the activities were useful in understanding the course concepts. The narratives were overwhelming positive and often indicated that the things that the students believed they would remember most were concepts that had been explored in one of the activities. In addition to the class specific surveys, students completed the standard College of Engineering Faculty Evaluation for the class for sections both before and after the redesign, but with the same instructor. On it, students rate the instructor on an A(4) to F(0) scale for 4 questions. The results of the Faculty Evaluations are shown in Table 1. In general, the evaluations for the redesigned course showed improvements in the scores for all 4 questions, although the second section of the course showed much larger gains. Responses to question 2 (ability to convey subject matter) would be expected to relate most directly to the changes in class format. This correlates to the observation that for both sections of the redesigned course, the percentage of score improvement is greater for question 2 than for the other questions, which relate only indirectly to the course redesign through overall student satisfaction.

Question	Lecture only	Redesign 1	Redesign 2
How well prepared does the instructor seem to be in the subject matter?	3.34	3.34	3.88
Evaluate the instructor on his/her ability to convey the subject matter	2.69	2.82	3.28
Evaluate the instructor on his/her availability and effectiveness during scheduled office hours	3.29	3.41	3.46
Overall, I would rate this instructor	2.93	3.00	3.50

Table 1: Results of the Faculty Evaluation before and after the course redesign.

Conclusions

An introductory environmental engineering course was redesigned to incorporate active and cooperative learning into what had previously been a lecture only format. Overall, the redesign was a success both in terms of student learning and in terms of providing a more enjoyable student learning experience. Students achieved a higher level of competence with the course material, had better attendance and attentiveness, self-reported an improvement in retention and interest in environmental engineering, and had an opportunity to practice communication, experimentation, and teamwork skills. These positive outcomes were achieved without reducing the scope of the course content or the depth of coverage.

References

1. Mason, Diana S (2006) *Students remember what they do*, Journal of Chemical Education, V83:4, 521

2. Eugene, Christian (2006) *How to teach at the university level through an active learning approach? Consequences for teaching basic electrical measurements*, Measurement: Journal of the International Measurement Confederation, V39:10, 936-946

3. Nirmalakhandan, N., Ricketts, C.; McShannon, J.; Barrett, S. (2007) *Teaching tools to promote active learning: Case study*, Journal of Professional Issues in Engineering Education and Practice, V133:1, 31-37

4. Furse, Cynthia (2003) *Teaching and Learning Combined (TLC)*, IEEE Antennas and Propagation Magazine,V45:3

5. Sousa, Davis (1995) *How the Brain Learns*, The National Association of Secondary School Principles, Reston VA ISBN 0-88210-301-6