Integration of Active Learning Exercises into a Course on Probability and Statistics

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1. Introduction

The benefits of active and cooperative learning exercises have been promoted in workshops, education journals, and entire scholarly monographs.[1-8] In particular, the benefits of these teaching methods have been studied and endorsed in recent years,[9-12] including publication of results that show these methods to increase the effectiveness of teaching and the retention of the material by the students.[13-17] Critics have stated that such methods detract from the time available for presenting new material to their classes, but proponents counter with evidence that active learning exercises allow instructors to cover at least the same amount of material as a traditional class, if not more.[18]

One area that seems very appropriate for the application of these ideas is in mathematics courses taught to an exclusively engineering audience. An example of such a situation is a course on probability and statistics taught exclusively for electrical and computer engineers. Since the Accreditation Board for Engineering and Technology specifically requires electrical and computer engineers to demonstrate an ability to apply the laws of probability and statistics to electrical and computer engineering problems,[19] such courses are frequently taught within engineering departments by engineering faculty.

2. A Challenging Teaching Assignment

ECE 465, Probability and Statistics for Electrical and Computer Engineers, has been taught in the department of Electrical and Computer Engineering (ECE) at Valparaiso University for a number of years. As outlined above, this course is designed to introduce Valpo ECE students to the principles of probability and statistics and also to show them how those principles can be applied to their engineering work.

The course learning objectives for ECE 465 are as follows:

After successful completion of this course, the student will be able to:

1. Calculate descriptive statistics such as the mean, standard deviation, and variance for both continuous and discrete probability distributions.
2. Apply the fundamental concepts of probability such as conditional probability, independence, counting methods, total probability, and Bayes's theorem to solve probability problems.

3. Use probability density functions (PDFs) and cumulative distribution functions (CDFs) for common random variables to solve probability problems.
4. Use jointly distributed random variables to compute quantities such as expected value, marginal distribution functions, covariance, correlation, and correlation coefficient.
5. Calculate and apply the probability distribution of the sampling mean for a particular statistical experiment.
6. Calculate point estimates and confidence intervals for a variety of different statistical experiments, including normal distributions and non-normal distributions with large sample size.
7. Set up and draw conclusions from statistical tests of population mean and proportion at a particular confidence level.
8. Perform inferences based on measurements of two samples given information about the probability distribution of each.
9. Perform a variety of analysis of variance (ANOVA) calculations, including single-factor ANOVA and two-factor ANOVA.
10. Calculate the parameters of a simple linear regression, including inferences about whether or not the slope is zero.

As these learning objectives demonstrate, this course provides thorough coverage of the topic with significant breadth in both probability and inferential statistics.

In Spring 2004, the author was presented with the opportunity to teach this course for the first time after the retirement of a more senior colleague who had been teaching it for more than two decades. This was a very challenging assignment for at least three reasons:

- The material in this course is conceptually difficult, and the course had developed a reputation among students as very theoretical and esoteric.
- It is very mathematically intensive, which can lead to challenges for students who have struggled to retain the material they learned in their earlier calculus classes.
- It had been traditionally taught at 8:00 in the morning, which led to student dissatisfaction, disinterest, and absenteeism. Due to scheduling conflicts, it was not possible to move the course out of this time slot.

Based on previous experiences in his own course and a review of previous course evaluations for ECE 465, the instructor was faced with two choices: Either to continue to teach the course the way it had been taught for a number of years with very limited success or to radically change the structure and methods used in the course in an effort to improve student performance and attitudes.

3. A New Strategy: Active and Cooperative Learning

Having just received tenure, the author decided to exercise his newly certified academic freedom in an attempt to improve the course. The problems identified with student performance and attitudes in the course's previous incarnation were:

- Failure to complete assigned textbook reading assignments
- Failure to pay attention in class
- Sleeping in class

- Failure to attend class (approximately a 25% absentee rate)
- Poor performance on homework assignments
- Very poor performance on exams

In the author's opinion, a large proportion of these problems arose from a lack of immediate student accountability. They were not held directly accountable for completing the reading assignments, so most of them did not complete them. This meant that they were much less likely to understand the material in the lecture, and furthermore they were not held immediately accountable for that failure. Instead, accountability took place several days later when a homework assignment was distributed, as well as several weeks later when the exam date arrived. By that time, they were hopelessly lost and had no possibility of recovering from their earlier irresponsible behavior.

So, the strategy used in the new version of this course involved immediate, total, and personal accountability for every assignment and for understanding every class discussion. This was done by trimming the "lecture" content of every class section from 50 minutes down to just 20 minutes. At the beginning of every class meeting, the instructor gave a condensed presentation that reinforced (but did not reiterate) the reading assignment for that day. This presentation typically included board work, Power Point presentations, live demonstrations of calculations in Matlab, and demonstrations of statistical tools in Excel.

At the end of this twenty-minute presentation, students were immediately presented with a one-page double-sided "In-Class Project" (ICP), which they were asked to complete with a partner. Students were allowed to select their own partners, and most partnerships lasted the entire semester. Groups of two were used for two reasons. First, grouping students into pairs provided team-based benefits such as peer accountability, peer teaching, and paired problem solving, while it minimized the opportunity for one student to rely on his/her partners to complete all the work. Second, the classroom in which this class was taught included two-person tables, which meant that two-person teams could be easily supported without having to rearrange the furniture every day.

The questions on the ICP were broken down into three types. The first three or four questions were usually very straightforward fill-in-the-blank or multiple-choice questions addressing issues that appeared in the reading but not necessarily in the lecture presentation. In this way, students were able to "warm up" with a few easy questions, while still being held accountable for the day's reading assignment.

The second half of the first page was typically a routine calculation that required students to demonstrate a simple application of the material they had just seen in the presentation. Again, this was designed to be simple enough that students who had understood the lecture presentation would find the question to be very straightforward.

The second page of the ICP was usually devoted to one long or two shorter questions that required the students to stretch beyond what they had seen in the lecture examples, applying their new knowledge to different situations. Frequently, these problems demonstrated an application of probability and statistics to electrical and computer engineering problems.

Students were expected to complete these ICPs within the remaining 30 minutes of the class period, and each team was free to leave when they had completed their work. Both members of each team were required to submit their own copy of the ICP, which promoted individual participation by both team members as well as providing each with an archival record of their work when it came time to review for the exams.

These In-Class Projects were then followed up by a homework assignment that was due at the next class meeting. The homework assignments were similar to the ICPs, although they were typically three pages long instead of two. The homework assignments were also designed using the same strategy of asking easy, moderate, and challenging questions every day, mirroring three different levels of Bloom's taxonomy of learning on each assignment. Students were asked to do their own work on the homework assignments, encouraging both members of each team to individually demonstrate their mastery of the material.

The ICPs were printed on brightly colored paper, which was done for two purposes. It made them very visibly different from the homework assignments, which were printed on white paper, preventing confusion among the students or the instructor. It was also intended to help excite the students and to encourage them to stay awake during class.

All ICPs were graded and were returned to the students at the next class meeting, which is also when each homework assignment was due. Homework assignments were then returned to the students at the next upcoming class meeting, providing students with two stages of very rapid feedback at each class meeting.

The workload associated with grading these assignments was minimized both by their design and by the use of a student grader. Each assignment included a mixture of short answer, multiple choice, and problem-type questions, so it typically took about one minute to grade each assignment. Two assignments per day for a class of 32 students meant about one hour of grading three times a week. A student grader was hired to complete this grading. Approximately two hours a week of the instructor's time was needed preparing the solution for each assignment and similar tasks.

So, students were held accountable to themselves, to their teammate, and to the instructor at each class meeting. They could not sleep or daydream through the brief lecture presentation, because they knew that they would be expected to demonstrate their understanding of that material in a matter of minutes rather than days or weeks. They could not skip the reading assignments, because doing so would have made the "easy" questions take too long, leaving too little time to complete the more challenging problems.

Furthermore, they had four distinct opportunities to learn the material for each class session:
1. While reading the material the night before class
2. While listening to the twenty-minute lecture presentation
3. While completing the in-class project with a partner
4. While completing the homework assignment on their own

Actually, there were two additional opportunities to learn the material, because the three mid-term exams were also modified so as to make them both an opportunity to develop mastery and also to demonstrate that mastery. Rather than attempting to require students to solve three or four relatively short problems in a fifty-minute class period, the exams were written to be open-book, open-note, take-home exams.

The first exam was seven pages long, with 18 separate questions or sub-questions, while the second exam was 11 pages long with 23 separate questions and sub-questions, and the third was 11 pages long with 26 questions and sub-questions. Students reported that it routinely took them six or more hours to complete each exam, and that their understanding of the material after completing the exam was much greater than it had been before the exam. Class was cancelled one day for each of the three exams, representing the day when the traditional in-class exam would have been given and indirectly compensating students for the additional out-of-class time they were spending to complete each exam.

In order to provide at least one in-class evaluation opportunity, the final exam was given in class during the normal two-hour window assigned to the course by the registrar.

4. Results and Assessment of Course Outcomes

The success of this educational experiment can be measured in four ways:

- Student attendance records
- Student performance on course assignments, such as ICPs and exams.
- Student responses to Likert-style questions on the final course evaluation survey
- Student responses to open-ended questions on the final course evaluation survey

As mentioned earlier, student attendance was a significant problem in the previous incarnation of ECE 465. Absentee rates were routinely 25% or higher, with more than half of the class absent on more than one occasion. In Spring 2004, with the structure and methods outlined above, the average absentee rate was just 10.3%. That is to say that, on an average day, 28.7 of the 32 students in the class actually attended it.

This number was highly skewed by three students who decided that they would simply accept zeros on several in-class projects. The median attendance rate was 34 of the 36 class meetings, a significant improvement over the attendance rate the previous year.

The following table summarizes mean and median scores assigned to four different categories of student work:

	Mean Score	Median Score
In-Class Projects	83.7%	87.9%
Homework Assignments	76.0%	80.4%
Take-Home Exams	92.4%	93.0%
Final Exam	94%	95%

As hoped, challenging questions on the ICPs and the homework assignments prepared the students to excel on the take-home exams. Students worked very hard on those take-home exams, but they did not complain about the additional time required to complete them, because they knew that they would receive better scores on those exams than they would have on in-class exams. The performance on the final exam further demonstrated that students actually did learn the material, because they demonstrated their mastery in a controlled setting on the last day of class.

Students were asked to complete a final course evaluation on the last day of class before the final exam. The results of this survey are not made available to the instructor until the deadline for submitting final grades has passed, so students are typically very honest in their evaluation of the course policies and procedures.

Students were asked to respond to each of 26 questions according to a five-point Likert-type scale, and their responses were then averaged to obtain a single “Performance Index” (PI), which varied from 1 (a very negative response) to 5 (a very positive response). Students were asked to evaluate both particular components of the course (such as homework or the textbook) as well as performing a self-assessment of their own ability to complete each of the ten course learning objectives. Figure 1 summarizes selected important results of this survey, comparing the results from 2003 (when the course was taught in a traditional lecture-based format) with the results of 2004, when much greater emphasis was placed on daily active and cooperative learning exercises.

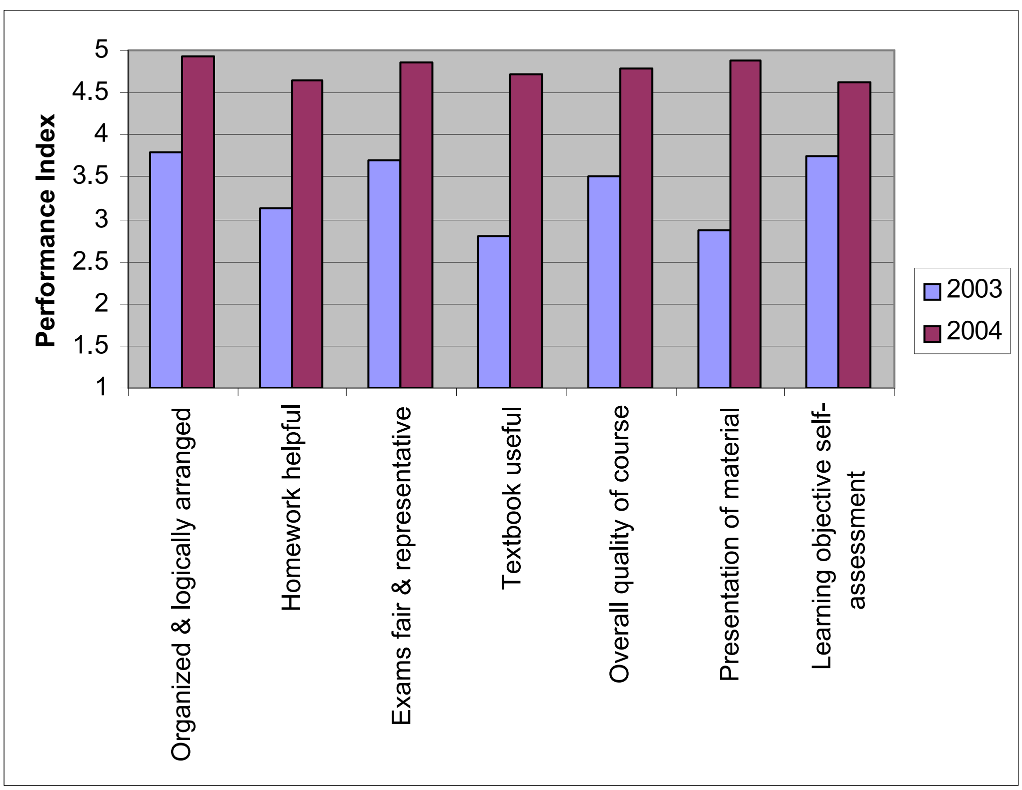

Figure 1. Selected Responses from ECE 465 Course Evaluations.

The first six pairs of bars in Figure 1 demonstrate students' perceptions of the organization of the course, the helpfulness of the homework in learning the material, the fairness of the exams, the usefulness of the textbook, the overall quality of the course, and the presentation style used to convey the material to the students. The seventh bar shows the average self-assessment scores reported by students on the ten learning objective questions. In 2004, these ten questions ranged from a low of 4.32 on objective #2 to a high of 4.82 on objective #1, accurately reflecting the instructor's perception of the difficulty of those topics. Students were also asked two additional specific questions on the 2004 course evaluation. The question "Did the in-class projects improve your learning?" resulted in a PI of 4.38, while the question "Did the take-home exams improve learning?" resulted in a PI of 4.73.

Student responses to open-ended questions such as "What aspects of this course were most beneficial to you?" and "What do you suggest to improve this course?" revealed that students recognized the multiple learning opportunities for each topic (reading, ICP, homework, take-home exam, and final exam). Students were particularly complimentary of the in-class projects and the take-home exams. However, students loudly voiced a preference to move the class later in the day, some expressed an opinion that there were too many ICPs and homework assignments, and some expressed concern over the similarity between the ICPs and the homework assignments. One student pointed out that it would have been very helpful to have the ICP graded and returned when the homework was being completed, which is an excellent point and one that is being considered for the upcoming semester.

5. Conclusions

This experiment in active/cooperative learning and immediate accountability was very successful. In fact, its success far exceeded the author's expectations. The active learning exercises did not slow down the class's coverage of material; the class was able to cover 13 of the 16 chapters in a textbook designed for a two-semester sequence.[20] Student perceptions of the course turned around completely in a single semester, and students are actually looking forward to this course in Spring 2005.

The success of this experiment was so complete that the course will definitely be taught again using the same structure in future years. In fact, the instructor would like to try this strategy with other traditionally challenging and unpopular courses such as electromagnetic field theory to see whether similar positive results can be obtained.

One of the primary objections to the use of active learning exercises is that they substantially increase the workload for both the students and the faculty. However, the workload for both students and faculty in this class remained approximately the same as in the previous year. As described earlier, the instructor spent approximately two hours a week supporting the efforts of a student grader, who was paid by the department for grading the actual assignments. Most of these two hours were spent preparing solutions to the assignments and rubrics to ensure uniform grading. Students saw their workload shift from a major assignment that took four to six hours to complete once a week to three smaller assignments that took one or two hours to complete. Although this added two more assignments to the students' schedule every week, it did not increase their total homework load for the course.

One caveat is in order, though. When comparing results between 2003 and 2004, it is important to note that those two courses were taught by different faculty. There was no control group in which the new instructor taught the material in the old-fashioned way, so we cannot be completely certain what caused the turn-around in student performance and perception. However, focusing just on the results from 2004, it is apparent that the new strategy was successful, so it is unlikely that the author will ever perform such a controlled study using old-fashioned teaching methods.

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