Introducing Mastery Level On-line Assessments in a Blended Graduate Course

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Abstract

Graduate education in scientific and engineering fields requires learning detailed technical information that continues to be taught in a traditional lecture format. At the same time, students entering those graduate programs increasingly prefer on-line and social media to traditional classroom environments. Our research examines the following question: what is the quantifiable advantage of transitioning from a strict lecture based classroom environment to a more active, technology enabled classroom for introductory graduate level engineering coursework? We altered the teaching methods for a required foundational course and compared the students’ performance as measured by equivalent exams after the initial four weeks of a semester. The primary change was replacing a single large assignment set with a series of mastery level on-line assessments, while simultaneously encouraging the use of an online forum to facilitate learning through inquiry. Two major findings are that (1) the distribution of grades improved and (2) student engagement levels increased.

Keywords
Mastery learning strategy; blended education; assessment; quantitative research

1. Introduction

The Engineering Management & Systems department at the University of Dayton currently offers courses towards two degree programs – Master of Science in Engineering Management and Master of Science in Management Science. Each program of study consists of 36 semester hours which includes a culminating capstone experience. The Probability & Statistics for Engineers course, in addition to being a core requirement for each degree program, serves as either a pre- or co-requisite for seven other courses in our program. Currently, The Probability & Statistics for Engineers course is offered three times per year (fall, spring, and summer) in a 16-week semester in a traditional classroom setting. In order to accommodate working professionals, classes are delivered on campus and are also simulcast over the Internet via web conferencing software. The lectures are also recorded for asynchronous viewing by students that were unable to attend the live class sections.

The focus of the research discussed in this paper is an attempt to improve the students’ retention of critical early skills in probability and statistics by using a mastery learning approach. Particular attention is given to selecting a teaching method that addresses the needs of our non-traditional students and the multiple modes of course delivery. Below, we provide a brief review of mastery learning as well as the framework used to select and implement the on-line mastery assessments.

2. Literature Review

The mastery learning strategy was popularized by Bloom [1, 2]. The basic notion is summarized in the belief “that if every student had a very good tutor, most of them would be able to learn a particular subject to a high degree.” In effect, the mastery learning strategy replaces the bell curve of aptitude that preordains that half the students will achieve below average results with the philosophy that almost all students can master their subject, given the right opportunities to learn. One necessary condition for a mastery learning strategy is a firm understanding of the specific learning objectives that are to be mastered. It follows that we must also be able to assess whether a student has mastered the objectives. Frequent, formative testing with feedback is the prescribed approach, in lieu of individual tutoring.
The success of the mastery learning strategy has been documented in many studies. Kulik, Kulik and Bangret-Downs [3] provide a survey of the field. They identify the methodological differences in the studies they review and attempt to synthesize the findings. They note that while the mastery learning strategy has fallen short of Bloom’s “every student” standard it has shown a significant positive effect. On average, they report about a 0.5 standard deviation improvement in final examination scores. More recently, Marshall [4] reported on the results from a mastery learning implementation using the Blackboard system. Marshall observed that while scores did not improve significantly, student satisfaction did.

Davis and Arend [5] provide a framework for identifying the method of learning that is best suited for a given learning outcome. Since the Probability & Statistics for Engineers course is a foundational course and a pre-requisite for many other courses in the program, the primary learning outcomes for the course involve “building skills”. (Note that a complete list of learning objectives identified by the textbook authors for chapters 2-5 are provided in Appendix A.) Therefore, it is appropriate to incorporate teaching methods that correspond to “behavioral learning” such as practice exercises and quizzes. A very important aspect of teaching methods associated with behavioral learning is the use of timely and specific feedback. Advancements in computer-based instruction and learning management systems make it practical to implement practice exercises, provide immediate, formative feedback, and allow students to work at their own pace. The remainder of this paper discusses our motivation for the creation of a series of on-line practice problems intended to promote mastery of the basic probability concepts in the first third of the Probability & Statistics for Engineers course.

3. Probability and Statistics for Engineers
3.1 Course Description
This is an introductory graduate course in the concepts and applications of probability and statistics. Emphasis is on applications and examples that an engineer or analyst would encounter in practice. Probability is presented as the fundamental tool for modeling uncertainty as well as the logical connection between a population of data and its samples. The first one-third of the course focuses on basic probability concepts including random variables and useful discrete and continuous distributions. This part of the course is covered in chapters 2-5 of Montgomery and Runger [6]. A list of learning objectives adopted from the course textbook are included as Appendix A. The second one-third of the course covers statistical techniques for working with data including estimation, confidence intervals, and hypothesis testing. The final one-third covers single regression, logistic regression, multiple regression and analysis of variance. As presented, the material covered in the first one-third tends to be more conceptual, while the rest of the course tends to emphasize the procedural aspects suitable for engineers.

An exam is administered after each one-third of the course to assess how well the students can demonstrate achievement of the learning objectives from that part of the course. A comprehensive final exam is administered at the end of the course.

3.2 Fall 2013 Offering
A total of 38 graduate students were registered for the fall 2013 offering of the course at the time of the first exam. During the 2nd course session, the students were assigned a large homework set consisting of 56 questions from chapters 2-5. The final numerical solutions to all of the assigned problems, but not step-by-step solutions, were also provided so that the students could see whether they correctly solved the problems. The homework was collected and graded primarily on completion. Most of the assigned problems were worked in class during the 9th course session in final preparation for the first exam. The homework counted as 5% of the total course grade.

The first exam was administered during the 10th course session. The exam covered basic probability, discrete and continuous random variables, and joint random variables. The format of the exam was a traditional, pencil and paper exam with calculation and short-answer questions, and students were allowed to use their books, notes, and computers in the completion of the exam. Students were allotted 75 minutes to complete the exam. The material covered in the exam spanned the associated learning objectives detailed in the Appendix A. The exam scores for all 38 students are shown below in Figure 1. The first exam counted as 20% of the total course grade.

As shown in the figure, only 7 students scored in the 90-100 range with an additional 3 students scoring in the 80-89 range. Using a traditional 90-80-70 scale, this means only 26% of the students earned a grade of “A” or “B” on the first exam. In general, earning a grade lower than a “B” has a negative connotation for graduate students. Perhaps even more alarming is that approximately 37% of the students scored less than 60% on the exam.
Initially, many students complained that the exam was too long and could not be completed during the allotted time. However, in a subsequent course session, the instructor worked through the entire exam (even typing the appropriate equations) in approximately 25 minutes. Student performance on subsequent exams improved significantly. Therefore, our initial focus was to develop on-line mastery resources for the early course material in order to better prepare the students for the first exam.

### 3.3 Spring 2014 Offering

This spring, a total of 38 students were registered for the course at the time of the first exam. For grading purposes, the large homework set that was administered in the fall semester was replaced by a series of on-line quizzes. In the style of mastery learning, each learning objective was represented by at least one question on a quiz. Separate quizzes were created for chapters 2, 3 and 4 that tested the learning objectives from the respective chapters. In addition, the large homework problem set from the fall offering was made available to the students but the students’ answers were not collected, graded or reviewed. Finally, the formal first exam was used to assess student learning and to culminate the learning experience.

The quizzes were created using our learning management system and were built using a variety of question types including true/false, fill in the blank, matching, and calculation questions. A small sample of quiz questions can be found in Appendix B. The lead faculty member for the course developed the questions from the student learning outcomes. The quiz questions were not validated by other faculty members. The quizzes were untimed and students were allowed an unlimited number of submissions prior to the due date. Students were also allowed to save their work and return to the quiz at a later time. Furthermore, students received immediate, question-level feedback on whether their answers to the questions were correct or not. The three quizzes had 20/25/15 questions that required a total of 50/55/39 user responses. The on-line quizzes counted as 5% of the total course grade.

In conjunction with the quizzes, we opened an on-line forum where the students could ask questions or discuss problems from the quizzes. The intent of the forum was to encourage student interaction and engagement. A total of 31 messages were posted on the forum and each message was read by around 20 other students. Anecdotally, the activity in the forum did not reduce the usual student-teacher interactions captured in office calls and email questions.

The first exam for the spring semester was scheduled for the 10th classroom session. Unfortunately, one classroom session was lost due to snow and cold, so the exam was effectively given during the 9th classroom session. Because of the lost classroom session, the first exam only covered chapters 2, 3 and 4. Even so, the exam was comparable to the previous exam in the number of questions asked and the level of difficulty. The first exam counted as 20% of the total course grade.
The results from the first exam are shown in Figure 2. Out of 38 students, 14 students scored in the 90-100 range with an additional 7 students scoring in the 80-89 range. At 55%, this is double the percentage of the students who earned a grade of “A” or “B” on the first exam. Fewer than 11% of the students scored less than 60% on the exam.

**Figure 2: Histogram of Spring 2014 Exam 1 Scores**

4. **Conclusions and Future Work**
The improvement in scores from fall 2013 to spring 2014 is visually apparent when comparing the histograms in Figures 1 and 2. The average score increased from 66.3 to 77.1. The standard deviation remained approximately equal, decreasing from 21.7 in the fall to 16.1 in the spring. In any case, this small decrease in the standard deviation can be attributed to the changing shape of the distribution. We used a two-sample t-test assuming unequal variances to compare the null hypothesis that the mean scores did not change versus the alternative hypothesis that the scores improved. The test yielded a p-value of 0.002. We therefore reject the null hypothesis and conclude that the scores have improved. The observed increase of approximately one-half standard deviation aligns with Kulik, Kulik and Bangret-Downs reported average increase in final exam scores.

The second desired effect of the mastery learning approach is improved student engagement. Unfortunately, we don’t have compelling measures for student engagement. In an optional, confidential feedback session, the students overwhelmingly stated the immediate feedback during the on-line quizzes used in the first part of the course helped them learn the material better than the delayed feedback inherent in the large problem set used in the second part of the course. The interactions seen on the on-line forum were encouraging. We also saw indications of student-to-student learning in the on-line forum. Anecdotally, the number of students regularly showing up and participating in the classroom also seems to have increased.

Overall, we consider the changes made to the course to be successful. We plan to extend the mastery learning approach to other parts of the course. One challenge going forward is developing on-line assessments of less quantitative student outcomes that might require explaining, justifying, interpreting or synthesizing quantitative results. Currently, the textbook publisher offers an interactive on-line tool that allows students to practice problems and master learning outcomes. The authors intend to investigate the adoption of this software in lieu of creating additional quizzes by hand.

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Zalewski and Schneider

References

Appendix A – Student Learning Outcomes

Chapter 2
1. Understand and describe sample spaces and events for random experiments with graphs, tables, lists, or tree diagrams.
2. Interpret probabilities and use probabilities of outcomes to calculate probabilities of events in discrete sample spaces.
3. Use permutation and combinations to count the number of outcomes in both an event and the sample space.
4. Calculate the probabilities of joint events such as unions and intersections from the probabilities of individual events.
5. Interpret and calculate conditional probabilities of events.
6. Determine the independence of events and use independence to calculate probabilities.
7. Use Bayes’ theorem to calculate conditional probabilities.
8. Understand random variables.

Chapter 3
1. Determine probabilities from probability mass functions and the reverse.
2. Determine probabilities from cumulative distribution functions, and cumulative distribution functions from probability mass functions and the reverse.
3. Determine means and variances for discrete random variables.
4. Understand the assumptions for each of the discrete random variables presented.
5. Select an appropriate discrete probability distribution to calculate probabilities in specific applications.
6. Calculate probabilities, and calculate means and variances, for each of the probability distributions presented.

Chapter 4
1. Determine probabilities from probability density functions.
2. Determine probabilities from cumulative distribution functions, and cumulative distribution functions from probability density functions, and the reverse.
3. Calculate means and variances for continuous random variables.
4. Understand the assumptions for some common continuous probability distributions.
5. Select an appropriate continuous probability distribution to calculate probabilities for specific applications.
6. Calculate probabilities, determine means and variances for some common continuous probability distributions.
7. Standardize normal random variables.
8. Use the table for the cumulative distribution function of a standard normal distribution to calculate probabilities.

Chapter 5
1. Use joint probability mass functions and joint probability density functions to calculate probabilities.
2. Calculate marginal and conditional probability distributions from joint probability distributions.
3. Interpret and calculate covariances and correlations between random variables.
4. Use the multinomial distribution to determine probabilities.
5. Understand properties of a bivariate normal distribution and be able to draw contour plots for the probability density function.
6. Calculate means and variances for linear combinations of random variables, and calculate probabilities for linear combinations of normally distributed random variables.
7. Determine the distribution of a general function of a random variable.
Appendix B – Sample Quiz Questions

Chapter 2
- (Text fill in the blank) Two events, denoted as E₁ and E₂, with the property that \( E₁ \cap E₂ = \emptyset \) are said to be ______
- (True / False) When two events are mutually exclusive, the probability of their union is equal to the sum of the probabilities of each event. Selections include True and False.
- (Matching) Suppose you have three sets: A, B and C. Match the following: The set of all items that are in both A and B; The set of all items that are either in A or in B; The set of all items that are not in C. Selections include The Intersection of A and B; The Complement of C; The Union of A and B. Note: the order in which the selections are offered changes from student to student.

Chapter 3
- (Numeric fill in the blank) Let the random variable B have a binomial distribution with \( n = 10 \) and \( p = 0.2 \). The mean of B is ______

Chapter 4
- (Numeric fill in the blank) The average pH of soil in the Miami Valley is 6.5 with a standard deviation of 0.3. Assuming pH is normally distributed and that grass grows best in the pH range of 6 to 7.5, what is the probability a homeowner will need to amend their soil to adjust the pH into the appropriate range? ______
- (Text Fill in the blank) If the cumulative distribution function for a distribution is given by \( F(x)=3x^2 \), the probability distribution function is given by \( f(x)=_______ \)