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Mastery Learning and Assessment Approach in Operations Research Course

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Introduction

Students' learning is the ultimate goal that instructors aim to achieve. The learning process is influenced by the teaching and assessment styles that teachers use. Teachers provide learning material that involves lectures, assignments, and other activities with the expectation that students will work out these assignments and activities and satisfy the learning objectives of the course. Teachers require feedback about their students' learning. Thus, teachers use multiple assessment methods to evaluate students' learning. To provide meaningful feedback, the assessment methods should be informative and provide suggestions for improvement in timely manner. Mastery learning and assessment approach is one of these methods that can evaluate and assess students' learning and suggest remediation actions[1].

For decades, mastery learning and assessment has been used to improve students learning and outcomes. Mastery learning can be divided into two main approaches: Bloom's Learning for Mastery (instructor-controlled pace) and Keller's Personalized System of Instruction (student-controlled pace) [2-4]. In both approaches, the course material is divided into a sequence of modules. Each module represents a concept or a group of similar concepts. The student has to master each module before he/she can continue to the next module in the sequence. The mastery of a module is measured by a set of test, assignment, or any assessment tool that is focused on a certain concept. Mastery learning and assessment approach allows the students to resubmit their test, assignment, or any activity as many times as needed until the student is satisfied, the course is finished, or the student cannot improve his/her performance[5]. Mastery learning and assessment approach is based on the idea that the instructional time and resources should be varied to bring all students up to an acceptable level rather than submitting to the idea that differences in student performance are a result of differences between student's abilities[6].

At Penn State Behrend, mastery learning and assessment approach has been successfully used in many fundamental courses within the School of Engineering, i.e., Statics, Strength of Materials, Thermodynamics, and Engineering Economy[7-10]. The approach has shown improvement in students' learning and outcomes. There was a clear evidence that students who passed mastery courses with a grade of "C" or more could solve engineering problems correctly and were more prepared for advanced courses when compared to students who were taught by the conventional learning and assessment approach.

The approach has never been used in any operations research (OR) course before at Penn State Behrend. In Fall 2017, the approach was implemented in a second course in OR (Stochastic Models in OR). This study implements a variation of Bloom's learning for mastery approach at this large U.S. public University. The instructor controls the teaching pace and not all the assignments in the course are mastery based. An important component of mastery learning and assessment approach is periodic and brief formative assessments to promote learning and instruction[1]. In this study, small online quizzes are used as formative tests. These tests offer three trials based on the student's performance. If the student passes the test with a grade of B (80%) or more on a trial, s/he does not have to take the next trial. Each new trial involves new questions that have similar difficulty levels to the previous trial. Therefore, if the student retake a trial, his/her grade will be reduced in the successive trials. The student will not receive a grade until he/she successfully solves the trial or exhaust all the trials. In other mastery applications, resubmission would involve an assignment or evaluation instrument that is slightly harder than the previous one; therefore, students who resubmit do not receive a reduced grade. The complete detail of the grade breakdown is explained in the paper. Reducing the grades for next trials is done for two reasons: 1) to be fair with the students who master the concepts in the first trial, and 2) to avoid the situation where some students would intentionally try the first and second trials to get an idea about the questions and then do the last trial knowing that their grade will not be reduced because of that.

This study investigates the following question: Does mastery learning and assessment approach positively impact students' learning and outcomes compared to the conventional learning and assessment approach? The data analysis shows that the implementation of mastery learning and assessment approach (intervention group) has improved students' performance in all exams when compared to conventional learning and assessment group (control group). A two-sample t-test was performed and the differences were statistically significant.

The following sections present the methodology and experimental setup followed in this study. Finally, the conclusions, recommendations, and future research suggestions are presented.

Methodology

Mastery learning and assessment in operations research (OR) course

The Industrial Engineering (IE) Department at Penn State University requires undergraduate students to complete two courses in OR. The courses are divided into deterministic and stochastic models. The first course is dedicated to deterministic models and the second course is mainly dedicated to stochastic models with some deterministic models such as deterministic inventory models. The study was implemented in the second course. The course is offered in fall semesters at Behrend campus. The class hosts IE students only. The IE students in this class are usually in their senior year. The mathematical and stochastic models, and solution techniques introduced in this course involve, inventory models, Markov chains, queuing models, and dynamic programming (DP). Table 1 presents the topics that are covered in this course. The learning objectives of this course involve the student ability to: 1) apply solution strategies and mathematical models to inventory systems, Poisson processes, Markov chains, dynamic programming, and queueing systems, and 2) interpret these solutions and evaluate multiple alternatives in order to provide recommendations to manufacturing and service systems.

The class involves lectures, online quizzes, two midterm exams, in-class problems, a case study, and a final exam. The course grade reflects the student performance in six quizzes (15%), two midterm exams (40%), in-class questions and attendance (10%), case study (15%), and final exam (20%). The instructor of the course does not provide homework assignments. In previous offers of this course, the instructor noticed that many students received perfect grades in the homework assignments but they received low grades in the high stake assignments and/or exams. This rendered the homework assignments ineffective in this course and other courses taught by this instructor. Nowadays, students are able to get problems answers through paid or free online services and/or solution manuals, especially when they are given ample time to solve assignments. The class size is between 20 and 25 students each semester.

Table 1. Breakdown of Topics in the Operations Research Course

Topics
Inventory models: deterministic economic order quantity (EOQ) models, EOQ with quantity discounts, stochastic inventory models, stochastic single-period model for perishable products, ABC classification.
Markov chains: Markovian and stationary properties, transition probabilities and Chapman-Kolomogrov equations, discrete-time Markov chains, steady-state probabilities, first-passage times, classification of states, absorption probabilities, continuous-time Markov chains, Markov chains applications.
Queueing models: Little's law, Exponential and Poisson distributions, balance equations, single server and multiple servers queues, infinite queues in series, Jackson networks, machine repair problem, waiting times distributions.
Dynamic programming (DP): deterministic and probabilistic DP models.

Mastery learning and assessment approach was implemented in an OR course at the Department of Industrial Engineering and Management Systems at the University of Central Florida[5]. Armacost and Julia Pet-Armacost[5] applied mastery-based grading to a part of the OR course evaluation, i.e., two in-class exams. The results showed an evidence of improved student learning when mastery-based grading was used. Figure 1 shows a graphical representation of mastery learning and assessment used in this study. We are implementing a variation of the mastery learning and assessment approach. The approach is implemented throughout the semester compared to two exam in Armacost and Julia Pet-Armacost[5]. We are using online tests that provide immediate feedback and fast grading compared to time consuming grading and delayed feedback of paper-based exams. In addition, the mastery learning and assessment approach is applied to low stake activities (i.e., quizzes) and partial credit approach is used for other high stake activities such as midterm exams. The reasoning behind using low stake activities with mastery approach is to reduce frustration that might result from receiving low grades and from multiple trials.

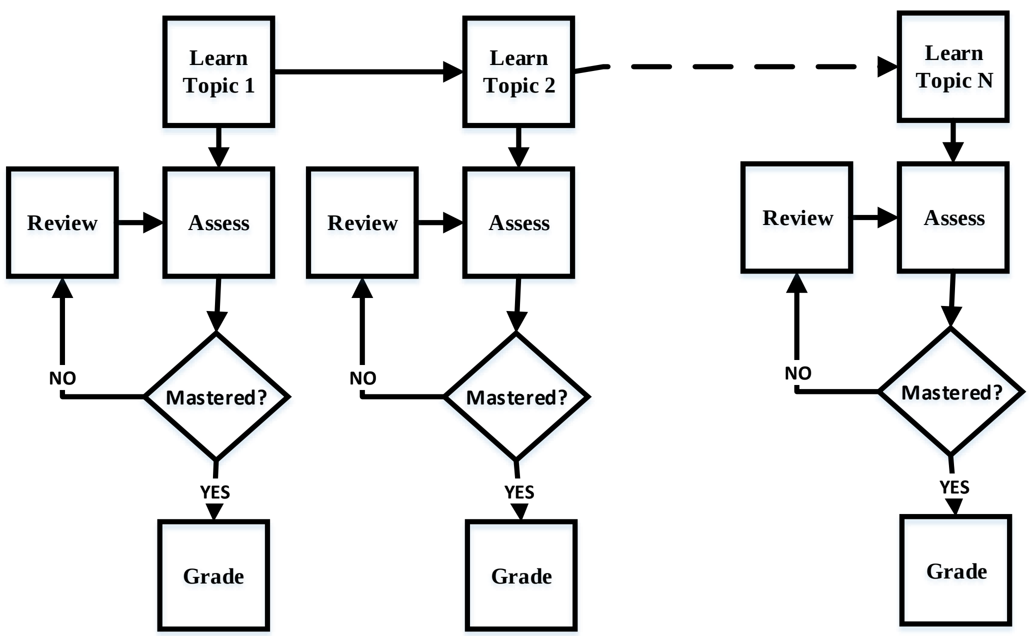

Figure 1. Mastery Learning and Assessment (adopted from [10])

As mentioned earlier, the mastery approach can be applied to any activity in a class. In this class, the approach was used with the online quizzes. Students are required to take online quizzes for a maximum of three trials each. The student will not receive a credit unless he/she finishes a trial successfully, i.e., receives 80% or more (B grade), or finishes the maximum number of trials. Students receive a reduced credit for trials after the first one. If the student consumes all three trials without receiving 80% or more, his/her grade for that quiz will be according to Table 2. Six quizzes are delivered in the mastery learning and assessment throughout the semester. The trials involve a first attempt, retake attempt, and final attempt. The trials involve new questions with similar difficulty level. Figure 2 presents an example of two questions from the first and second trials of the third quiz. Each quiz includes other qualitative questions to test if the student understands the concepts behind quantitative calculations.

A firm experiences demand with a mean of 100 units per day. Lead time demand is normally distributed, with a mean of 1,000 units and a standard deviation of 200 units. It costs $6 to hold one unit for one year. If the firm wants to meet 90% of all demand on time, what will be the annual cost of holding safety stock? (Assume that each order costs $50.)

a) First Trial

Chicago's Treadway Tires Dealer must order tires from its national warehouse. It costs $10,000 to place an order and $400 to review the inventory level. Annual tire sales are N~(20,000, 2,000). It costs $10 per year to hold a tire in inventory, and each order arrives two weeks after being placed (52 weeks= 1 year). Assume that all shortages are backlogged. Determine the optimal (R, S) inventory policy. Assume that the shortage cost is $100 per tire.

b) Second Trial

Figure 2. Questions from a) First and b) Second Trials of the Third Quiz

Table 2. Mastery Grading (adopted from [10])

Trial	Criteria	Grade
First attempt	The grade should be ***greater than or equal 80% (B)***, If not, the student should retake the quiz	Same grade
Second attempt	The grade should be ***greater than or equal 80% (B),*** If not, the student should retake the quiz	0.80*grade
Third attempt	N/A	0.65*grade

Each quiz involves 3 – 4 quantitative questions and 5 – 6 qualitative questions. The students can start the quiz anytime, within a 48-hour window, and anywhere through the learning management system (LMS). Once the quiz is started, the student has a limited time to finish it (the time depends on the quiz). The quizzes are not administered in a classroom environment and the students can use their notes and textbooks to answer the questions. The students receive an immediate feedback after finishing the quiz. Final answers are provided after the 48-hour window. No detailed solution is provided. The purpose of not providing the detailed solution is to encourage the students to check back their solution and investigate their mistakes. The instructor is available to provide help if a student still could not figure out his/her mistake. A retake quiz will usually open 24 hours after finishing the previous trial.

Experimental setup, analysis, and discussion

Study population

The study took place in this course at Penn State Behrend in Fall 2017. Before Fall 2017, the mastery learning and assessment approach was not used. The data from Fall 2017 (intervention cohort) was compared to data collected in Fall 2016 (control cohort). Table 3 presents the statistics in each semester. There were 20 and 21 students in Fall 2016 and Fall 2017, respectively. This is a typical engineering class where male students are the majority.

The prerequisite preparation of the control and intervention groups was tested. The prerequisite preparation was tested by the students' grade point average (GPA) just before enrolling in this class and the grade of the needed background knowledge in probability and statistics. Table 4 shows the means and standard deviations of the students' GPAs and grades in the prerequisite course.

Table 3. Study Population

Gender	Semester	Sample Size
Male	Fall 2016	18
	Fall 2017	14
Female	Fall 2016	2
	Fall 2017	7

To perform two-sample t-test, the normality and variability assumptions have been tested. Based on Anderson-Darling test, there was no statistical evidence to conclude the data do not come from normally distributed populations at $\alpha = 0.05$. The p-values were greater than 0.05. Levene's test showed that the variability in both groups was not statistically different at $\alpha = 0.05$. The p-values were 0.760 and 0.504 for GPA and prerequisite, respectively. The two-sample t-test showed that the two groups were statistically indifferent at $\alpha = 0.05$ with p-values equal to 0.530 and 0.831, for GPA and prerequisite course, respectively. This result indicated that the two groups could be assumed to have the same level of preparation to this class.

Table 4. Mean and Standard Deviation of Students' GPAs and Prerequisite Grades

	GPA				Prerequisite Grade			
Semester	N	Mean	Std. Dev.	P-Value	N	Mean	Std. Dev.	P-Value
Fall2016	20	2.962	0.412	0.530	20	3.150	0.578	0.831
Fall2017	21	2.884	0.376		21	3.190	0.629	

Learning measure

The difference between students' performance in three exams (two midterms and a final exam) before (Fall 2016) and after (Fall 2017) implementing the mastery learning and assessment approach were analyzed. For consistency purposes, same exams were used in both semesters. To make sure that questions were not carried from one semester to another, the exams papers were collected back from the students after handing out the grades.

Analysis and discussion

Both groups (control and intervention) were taught by the same instructor at the same pace. The only intervention was the mastery learning and assessment for the intervention group. To statistically analyze the difference in students' performance between the control and intervention groups, two-sample t-test was implemented to test the difference between students' grades in three exams (two midterms and one final). Before implementing the t-test, the normality and variability assumptions were tested. Based on Anderson-Darling test, there was no statistical evidence to conclude the data do not come from normally distributed populations for all the exams except Exam II for Fall 2016. For this exam, the normal probability plot was checked and it was decided that the normality assumption is accepted visually. Levene's test was used to test the variability assumption. Table 5 shows the results of the Levene's test. The test showed that the assumption of equal variance is valid for all exams.

Table 6 and Figure 3 summarize the results of the tests. It is shown that the averages of students' grades in the intervention group for all exams were higher than the control group. The differences between the averages were 28.84, 5.93, and 9.41 for the first, second, and final exams, respectively. The differences were statistically significant at $\alpha = 0.05$. The highest difference was observed with the first exam. Low grades are typical in this class especially in the first exam. The instructor usually provides an extra exam or curves the grades if needed. The differences for the second and final exams may not be practically significant; more data should be collected to confirm the results.

Table 5. Levene's Test of Students' Scores in the First, Second, and Final Exams

Exam		Fall 2016	Fall 2017
First	**N**	20	21
	Variance	478.063	503.929
	P-Value	0.955	
Second	**N**	20	21
	Variance	94.302	70.990
	P-Value	0.738	
Final	**N**	20	21
	Variance	239.402	134.433
	P-Value	0.381	

Table 6. Two-Sample t-test of Students' Scores in the First, Second, and Final Exams

Exam		Fall 2016	Fall 2017
First	**N**	20	21
	Mean	40.8	69.6
	Std. Dev.	21.9	22.4
	P-Value	0.000	
Second	**N**	20	21
	Mean	76.47	82.40
	Std. Dev.	9.71	8.43
	P-Value	0.043	
Final	**N**	20	21
	Mean	62.9	72.3
	Std. Dev.	15.5	11.6
	P-Value	0.033	

Practical considerations

Logistics of running mastery learning and assessment approach

The mastery learning and assessment approach is not something new. This approach is usually not embraced for reasons related to the logistics of running the approach, i.e., preparing instructions and assessment tracking. The online quizzes used in this study required a relatively long time at the beginning to prepare the quizzes. However, once these quizzes are setup, the efforts needed to run the approach will be minimized. The quizzes are graded automatically; therefore, students receive the feedback instantaneously.

Nowadays, technology has overcome many obstacles that teachers used to face with mastery learning and assessment approach. Technology can be leveraged to generate multiple versions of the same test.

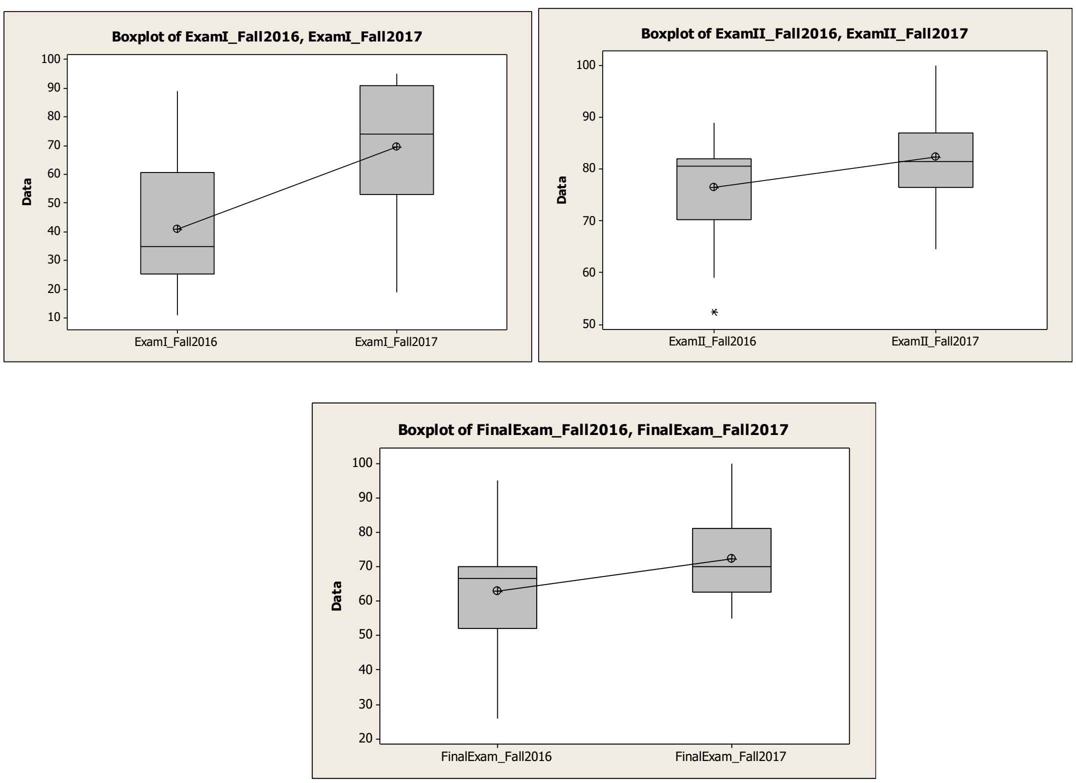

Figure 3. Boxplots of the Students' Scores in the First, Second and Final Exams

Students acceptance

Very few students complained about their grades when mastery approach was implemented. A simple explanation on how the setup of mastery approach provides the student with an opportunity to improve his/her grade was enough to elevate these complaints.

In other studies by the author of this paper, students' perspective about mastery approach was collected using a survey[8]. The survey was distributed to two groups of students: Students who were still enrolled in the mastery course at the time of the study and the other group of students who had previously been exposed to mastery learning and assessment approach and now were enrolled in a more advanced course. The results showed that the students had realized the benefits of the mastery approach when they enrolled in future engineering courses[8].

Conclusions and future work

The paper presented a case study of using mastery learning and assessment approach in a second course in operations research (OR). Mastery learning and assessment approach can be implemented in any part of the course. In this study, a low stake activity, i.e., online quizzes, was used to implement the mastery approach. The data collected for two groups: control and intervention groups. The control group was taught traditionally and the intervention group involved the mastery approach. The differences between the groups in terms of the average grades in the first, second, and final exams were statistically analyzed. The results showed that the mastery learning and assessment approach has resulted in higher average grades in all exams compared to the control group. These differences were statistically significant at a significance level of 0.05.

Future work should include collecting more data to confirm the results. Questions bank should be used to provide different questions for different students to reduce answers sharing between the students. With the advances of technology and digital media, the course could be student-paced. The instructor can provide lectures in video format. Students can visit and revisit these video as many times as they want and whenever and wherever they want.

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