Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45978

Case Study: Modified Mastery Learning Enables Instructors to Reduce Costs While Maintaining Learning Outcomes

Dr. Daniel B Oerther P.E., Missouri University of Science and Technology

Professor Daniel B. Oerther, PhD, PE joined the faculty of the Missouri University of Science and Technology in 2010 as the John A. and Susan Mathes Chair of Civil Engineering after serving for ten years on the faculty of the University of Cincinnati where he was head of the Department of Civil and Environmental Engineering. Professor Oerther is internationally recognized for leadership of engineers, sanitarians, and nurses promoting the practice the sustainable development, local to global. Dan is a Past President of the American Academy of Environmental Engineers and Scientists. He is a Diplomate of the American Academy of Sanitarians. Dan is a Fellow of the Association of Environmental Engineering and Science Professors, the American Academy of Nursing, and the National League for Nursing. In the United Kingdom, he is a Fellow of the Chartered Institute of Environmental Health, the Royal Society for Public Health, and the Society of Operations Engineers. Professor Oerther's awards as an educator include the Excellence in Environmental Engineering Education Award from the American Academy of Environmental Engineers and Scientists, the Gordon Maskew Fair Distinguished Engineering Educator Medal from the Water Environment Federation, the Engineering Education Excellence Award from the National Society of Professional Engineers, and the Robert G. Quinn Award from the American Society for Engineering Education.

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Daniel B. Oerther
Missouri University of Science and Technology, 1401 North Pine Street, Rolla, MO 65409

Abstract

Mastery learning – or learning for mastery – is not a new concept. In fact, the use of mastery learning in secondary education is supported by a robust literature. None the less, mastery learning has not been widely adopted in higher education. Reasons for this lack of uptake include the perception among faculty of the time and effort needed to switch from the traditional pedagogical format, such as lecture-discussion with grades assigned through summative assessments. Over a period of fifteen years, the author has demonstrated the successful use of mastery learning for a wide range of courses including required undergraduate courses offered primarily to sophomore students, elective courses that include enrollment of juniors and seniors as well as graduate students, and highly selective graduate-only courses. Leveraging a summary of the literature of the authors own work – and referencing a recent systematic review of mastery learning in engineering in higher education – this case study offers a "formula" that faculty may follow to incorporate modified mastery learning into their classroom or laboratory setting. The approach to modified mastery learning outlined in this article accomplishes two important items. First, the flexibility afforded to the instructor when adopting modified mastery learning means that cost savings may be accomplished in the use of institutional resources while accommodating a diversity of student learning preferences. Second, while traditional approaches fail to guarantee that every student master every concept, the modified mastery learning style not only maintains – but in fact ensures complete mastery – by EVERY student. These two advantages of modified mastery learning – cost savings and improved learning outcomes – are compelling, and the case is made that most learning in higher education should adopt a modified mastery approach.

Introduction

The king is dead. Long live the king. Historically, this proclamation was made when one monarch died, and a new monarch ascended to the throne.

In modern times, often this proclamation is used to note a sea change, which is defined as a notable transformation. For example when music downloads surpassed CD sales in the United States (US) in 2012, one might have heard the phrase, "The Sony Discman is dead. Long live iTunes," [1]. Or more appropriately for engineering educators in the fall of 2011 when Stanford's Sebastian Thrun and Peter Norvig offered their course entitled, "Artificial intelligence," one might have heard the phrase, "The chalk-and-talk lecture is dead. Long live the Massively Open Online Course (or MOOC)!" [2] [3]

In the current article, this proclamation of a sea change is being applied to the reliance on the widely employed summative assessment (aka the final exam) to assign grades after students complete a semester of lecture-discussion class meetings. Proponents of the approach advocated in the current article might be heard saying, “Grading on a curve is dead. Long live modified mastery learning!”

Historically, higher education cultivated a notion of exclusivity wherein phrases such as, “look to your left, look to your right, only one of you will pass this class,” were commonplace [4]. Or at least these phrases were symptomatic of exclusivity in higher education portrayed in popular culture such as the 1973 movie, “The Paper Chase,” [4]. In 1968, Benjamin Bloom proposed an alternative model known as “learning for mastery” [5]. Bloom noted, “Most students (perhaps over 90 percent) can master what we have to teach them, and it is the **task of instruction** [emphasis added] to find the means which will enable our students to master the subject under consideration,” [5]. Bloom argued that one of the major drivers for this alternative model was that, “the problem [of secondary and higher education] is no longer one of finding the few who can succeed. The basic problem is to determine how the largest proportion of the age group can learn effectively those skills and subject matter regarded as essential in their own development in a complex society,” [5].

The basic problem observed by Bloom remains true today; namely that the number of jobs available for those trained in secondary and higher education exceeds the available population of graduating students, and therefore education should be viewed as a societal investment rather than a screening tool. For example, consensus studies of the National Academies of Sciences, Engineering, and Medicine (NASEM) have concluded that to maintain a competitive advantage in the global economy, the US needs to increase its talent pool by vastly improving K-12 mathematics and science education (i.e., [6]). Increasing this talent pool includes attracting and retaining populations of students who have been historically underrepresented in STEM (science, technology, engineering, and math) professions.

One group of students who have been underrepresented include neurodivergent students, who are estimated to be as much as twenty percent of the population [7]. For many neurodivergent students an individualized education plan, or IEP, is required by the Individuals with Disability Education Act (IDEA) for elementary and secondary education but not for higher education. And for those neurodivergent students who enroll in higher education, an individual accommodation plan, or IAP, is required by the Americans with Disabilities Act (ADA) section 504. As the proportion of students in secondary education with IEPs has reached an all-time high [8], and the number of students in higher education with IAPs is on the rise [9], one of the challenges for faculty is to maintain academic rigor while supporting student learning. Unfortunately, the traditional lecture-discussion format accompanied by a traditional high-stakes summative final exam is ill suited to meeting the needs of neurodivergent students.

As observed by Guskey [10], “when compared to traditionally taught classes, students in mastery learning classes consistently have been shown to learn better, reach higher levels of achievement, and develop greater confidence in their ability to learn and in themselves as learners.” And yet despite the benefits of masterly learning, a search of the ASEE PEER database for mastery learning identifies a relatively small number of articles which include the term “mastery learning” (i.e., only 1 to 10 articles per year from 1996 through 2019, with a larger number of articles published in 2020 and beyond). Examples from the ASEE PEER database include case studies [11] as well as comparisons of mastery learning and traditional lecture-exam models in a large section service course [12]. To further emphasize the lack of a robust publication record regarding the use of mastery learning in higher education, a recent systematic review reported only a dozen articles that met inclusion criteria [13]. Yet despite the small sample size, Perez and Verdin were able to conclude, "students' self-reported evaluation of the course suggests that students prefer the mastery learning approach over traditional methods," [13].

Within engineering education, mastery learning may be traced to the US Military Academy and what is known as the Thayer Method, which has been summarized as, "[cadets] study the material prior to attending class. The learning is then reinforced in class through a combination of group learning and active learning…" [14]. A common misinterpretation of mastery learning includes instruction focused exclusively on "low-level cognitive skills" (i.e., Bloom's taxonomy such as define, describe, and explain) where "teachers [may be] regarded in these programs as little more than managers of materials and record-keepers of student progress," [10]. In the example of the US Military Academy, the Thayer Method is applied to all students for all course content, and therefore, it is clear that learning for mastery is appropriate for a wide range of subjects and aptitudes.

Building on our prior publication [15], in this current case study, one instructor's personal experience with mastery learning is reported for large sections of required undergraduate courses, in upper level undergraduate electives, and in a graduate-student-only highly specialized elective course. Leveraging this body of work, a pedagogical formula is provided for instructors to use modified mastery learning. This case study supports an approach that instructors may leverage to reduce costs while maintaining student learning outcomes; thereby providing an answer to the question of maintaining academic rigor while inviting diverse students to demonstrate mastery of complex material. Future work should specifically examine the benefits of the modified mastery approach to meet the needs of neurodivergent students.

Methods

<u>Institutional context.</u> Located in Rolla, Missouri, the Missouri University of Science and Technology was founded in 1870 as the Missouri School of Mines. In 2023, a total of more than 7,000 students (approximately 1,500 graduate and 5,500 undergraduate) are enrolled in approximately 100 degree programs. Recently re-characterized as a Carnegie R1, a doctoral university with the highest research activity, S&T is home to three colleges. Within the College of Engineering and Computing, the Department of Civil, Architectural, and Environmental Engineering (or CArE) is one of the largest and most research productive programs on campus.

Results and Discussion

Over a period of fifteen years, the author utilized mastery learning in a wide range of courses. Table 1 provides a list of courses, course descriptions, typical student population and class size, and references.

Table 1. Summary of courses, course descriptions, typical student population and class size, and reference(s) of prior publications describing the use of modified mastery learning.

Course Number and Title	Course Catalog Description	Typical student population and class size	Reference(s)
CArE 2601 Fundamentals of Environmental Engineering	Course discusses fundamental chemical, physical, and biological principles in environmental engineering and science. Topics include environmental phenomena, aquatic pollution and control, solid waste management, air pollution and control, radiological health, and water and wastewater treatment systems.	From 30 to 60 sophomores, plus 10 to 20 juniors or seniors	[16]
CArE5001 STEAM Diplomacy	The special topics course number is designed to give the Department an opportunity to test a new course (in this case, STEAM Diplomacy). Prerequisite: Junior standing (note: no prior experience with environmental science/engineering necessary and no prior experience with political science/international relations necessary).	Five juniors or seniors, plus 5 graduate students	[17] [18]
CArE5650 Public Health	A comprehensive course dealing with the environmental aspects of public health. Prerequisite: CArE2601 with grade of "C" or better.	30 juniors or seniors, plus 10 graduate students	[19] [20]
CArE5605 Environmental Modeling	Introductory course in modeling environmental systems. Course will focus on contaminant fate and transport in the environment. Models will be developed that will include physical, chemical and biological reactions and processes that impact this fate. Prerequisites: CArE2601, CArE2602, and CArE3603; or Graduate standing.	10 juniors or seniors, plus 5 graduate students	[20] [21]
CArE5619 Environmental Design	Functional design of water and wastewater facilities and other environmental cleanup systems. Prerequisite: CArE3615.	25 seniors, plus five graduate students	[22]
CArE6601 Biological Principles of Environmental Engineering Systems	Course covers the fundamental biological and biochemical principles involved in natural and engineered biological systems. Prerequisite: Graduate standing	10 graduate students	[23] [24]

A comparison of the published literature included as references in Table 1 with the list of 12 articles included in the recent systematic review by Perez and Verdin [13] offers a surprising result; namely, none of the nine articles in Table 1 are included in 12 articles appearing in the systematic review. This observation is not meant to call into question the validity of the previous report [13], but rather to note an important observation; namely, the search strings and inclusion criteria employed previously may be missing an important portion of the literature. Future efforts to systematically examine mastery learning in higher education, and in particular within engineering education, may need to employ a different search approach.

As nicely summarized by Perez and Verdin [13], the three key features that distinguish courses employing mastery learning from traditional pedagogy, include:

> *"A mastery learning class implementation can be characterized as possessing three key features that distinguish it from a traditional class. These three key features are (1) the specification of clearly defined learning units tied to ML [mastery learning] assessments, (2) the application of ML assessment, and (3) the delivery of feedback on each ML assessment,"* [13].

As previously reported in each of the nine articles referenced in Table 1, all courses offered by the author, include: (1) a course description; (2) course learning objectives; (3) multiple modules completed in sequence; (4) module learning objectives; and (5) mastery learning assessments for each module.

When comparing the articles in the systematic review [13] to the articles referenced in Table 1, the two unique features included in all courses offered by the author, include: (1) an introductory module is included where blended and flipped pedagogy as well as modified mastery learning assessments are explained to the students, and the syllabus – with dates for mastering required assignments – is reviewed at length; and (2) a modification of mastery learning where a combination of mastery assessments plus traditional assessments are offered as a "buffet" (i.e., [25]). This buffet of assessments includes both formative mastery assessments (i.e., either an assignment selected randomly from a bank of assignments, or a single assignment that all students must complete), which must be completed to a score of 100% before the deadline, as well as traditional summative assessments (i.e., homework's, lab reports, and extended in-class quizzes similar to mid-terms), which may be attempted once. The final assignment of grades in modified mastery learning, includes: (1) students earn an "F" for the entire course if they fail to complete ANY mastery assessment; (2) students earn a "C" for the entire course once they complete ALL mastery assessments (i.e., [15]); and (3) students may choose to complete – all or a portion – of optional traditional assessments where the points earned on each assessment contribute towards earning a course grade of "B" or "A". Thus, "modified mastery learning" [15] includes BOTH mastery assessments and traditional assessments. In the view of the author, this is a critical aspect for the successful implementation of mastery learning in higher education, and future research should explicitly explore this hypothesis.

As noted by Perez and Verdin [13], the 12 articles included in the systematic review applied mastery learning to a variety of assessments instruments, including: (1) mid-term exams; (2) final exams; (3) quizzes; (4) homeworks; and (5) projects. In contrast, the articles referenced in Table 1 only apply mastery learning to formative quizzes and homework's (which may include both written homeworks solving problems or written homeworks that include lab reports). In the articles referenced in Table 1, traditional summative assessment is applied to quizzes, exams, and projects. The points available to earn a final grade of a "B" or an "A" through the completion of optional, traditional assessments is twice as many as needed to actually earn the grade. This "modification" of the mastery learning approach is based on the concept of "contract grading" (also known as "labor-based grading" or "hybrid grading") [26]. Table 2 provides the key terms and definitions for the reader to consider a comparison of traditional lecture-discussion teaching versus modified mastery learning.

Table 2. Key definitions

Term	Definition	Reference
Mastery learning or learning for mastery	"Most students (perhaps over 90 percent) can master what we have to teach them, and it is the task of instruction to find the means which will enable our students to master the subject under consideration."	[5]
Formative assessment	Low stakes activities primarily used to monitor student learning such as think-pair-share with peers	[27]
Summative assessment	High stakes activities primarily used to evaluate student learning such as midterm exam or final project.	[27]
Assessment buffet	Redundant activities used to evaluate student learning according to a range of summative assessment – including written homework's, written lab reports, quizzes, midterm, final exam, and final project – allowing the student to select the assessment method that best suit learning style and strengths	[25]
Grading	A measure of individual student learning, which may incorporate assessment as well as indirect criteria such as attendance, participation, and effort	[27]
Contract grading	A student earns a grade solely on the completion of specified activities, which are independent of the evaluation of student learning by the instructor	[26]
Modified mastery grading	A student earns a minimum grade solely on the mastery of specified activities, which are independent of the evaluation of student learning by the instructor, and then earns a final grade based on completion of a buffet of optional assessments evaluated by the instructor	[15]

Unliked traditional assessment, where student performance is mapped to a subjective standard imposed by the instructor, the hybrid contract grading approach allows students to select how much effort they wish to invest to demonstrate their learning [26]. For example, in a traditional assessment, the instructor may assign points such as: (1) 2 points for a correct answer to a True/False question; (2) 6 points for a correct short answer; or (3) 15 points for a correct answer, with appropriate units, and showing all necessary steps to a design problem. While these grading schema may appear objective, the reality is that these grading schema represent a subjective view of the instructor as to the value of various types of assessments. In contract grading, a student provides effort to earn the grade they desire as a demonstration of the level of competency in the course content. By providing a buffet of optional assessment instruments, modified mastery learning combines the benefits of contract grading with the benefits of mastery learning. An extended example of how grading works for modified mastery learning is provided in Table 3.

Table 3 is meant to represent a generic semester-long course, which is divided into five equal modules (i.e., presuming a fifteen week semester, each module would be completed approximately every three weeks). Each of the five modules includes a homework assignment, a quiz, and a lab exercise. The overall course assessment includes a mid-term exam, a final exam, and completion of a semester-long project. While variations on the pedagogical theme presented in Table 3 are possible, this base case serves as a point of comparison that the reader may use when adopting modified mastery learning for their own course.

The traditional student who earns a final course grade of "C" when graded on a curve might complete approximately one-half of the total assessments in the course; whereas a student who earns a final course grade of "A" might complete a super majority (i.e., approximately 80%) of the total assessments in the course. Again, while variation in student performance and grade assessment will vary from course to course and instructor to instructor, this base case is provided for comparison to the alternative of modified mastery learning.

Table 3. A side-by-side comparison of a traditional grading schema and a grading schema for modified mastery learning. Example student performance to earn a final grade of "C" or a final grade of "A" are provided for both the traditional grading and grading for modified mastery learning.

Traditional				**Modified Mastery Learning**					
Assessment	**Points possible**	**Points earned C**	**Points earned A**	**Mastery (Optional or Required)**	**Points possible**	**Points earned C**	**Points earned A1**	**Points earned A2**	**Points earned A3**
Homework 1	2	1	2	O	2	0	2	2	0
Lab 1	2	1	2	R	70*	R	R	R	R
Quiz 1	2	1	2	O	2	0	2	0	2
Homework 2	2	1	1	R	70*	R	R	R	R
Lab 2	2	1	1	O	2	0	0	2	2
Quiz 2	2	1	1	R	70*	R	R	R	R
Homework 3	2	1	2	O	2	0	2	2	2
Lab 3	2	1	2	R	70*	R	R	R	R
Quiz 3	2	1	2	O	2	0	2	0	0
Homework 4	2	1	1	R	70*	R	R	R	R
Lab 4	2	1	1	O	2	0	0	2	0
Quiz 4	2	1	1	R	70*	R	R	R	R
Homework 5	2	1	2	O	2	0	2	2	0
Lab 5	2	1	2	R	70*	R	R	R	R
Quiz 5	2	1	2	O	2	0	2	0	2
Midterm exam	20	10	15	O	8	0	4	0	4
Final exam	35	18	25	O	8	0	4	2	4
Project	15	7	15	O	8	0	0	8	4
Total points	**100**	**50**	**79**		**70* + 40**	**70**	**90**	**90**	**90**

The grading for modified mastery learning includes both Required as well as Optional assessments. To pass the class, a student must complete ALL of the Required assessments before the deadlines listed on the syllabus. By providing the deadlines at the beginning of the course, the instructor allows the students maximum flexibility in self-paced learning to complete the Required work. Also, please note that a Required assignment is included as part of every learning module. This is essential to ensure that every student has mastered the content in the module, regardless of their preferred learning style.

In the case of grading for modified mastery learning, three alternative versions of student performance to earn a grade of "A" are provided as examples of accommodating diverse student preferences for assessments. A1 corresponds to a student who completed optional written homeworks, quizzes, and exams, but avoids optional labs and projects. A2 corresponds to a student who prefers homeworks, labs, and projects but avoids quizzes and exams. And A3 corresponds to a student who opts to complete a variety of optional assessments throughout the course.

Cost Savings

While modified mastery learning is designed to accommodate diverse learning styles, a key aspect of modified mastery learning is that the instructor of a course designed in this manner can ensure colleagues that EVERY student has mastered the entire subject matter when earning a grade of "C". This is because there is at least one Required assignment as part of each unit.

In contrast, even a student who earns a grade of "A" in the traditional approach is NOT guaranteed to have mastered all content. For example, imagine a student who learns all but one of the learning objectives in the course. Clearly, that student has not mastered all of the content, because one of the learning objectives has not been met. It would be possible for a student to systematically miss all of the points associated with a learning objective in a traditional course, and yet still earn a grade of an "A". This fact of learning deficiency often is observed by faculty, and it corresponds to those students who "unexpectedly" struggle with a concept in a subsequent course in a series when they have earned a grade of an "A" in an earlier required course. All too often, faculty members run across these types of students; those who are high performers yet lack mastery of at least one critical topic. In contrast, it is impossible for any student to pass a course using the modified mastery approach outlined in Table 3 without demonstrating minimum mastery of ALL critical topics included in the learning objectives of the modules.

This fact, that traditional assessment allows some students to "slip through the cracks" to earn "good grades" while not fully understanding all of the material, is a central motivation for the importance of adopting modified mastery learning. This avoiding students slipping through the cracks is a cost savings in terms of the time and effort invested by faculty in follow-up course to offer remedial instruction or review of prior concepts. Consider the investment of faculty time in office hours to review content that has been covered in a prior course. Ensuring that every student has a minimum of mastery of required content should reduce the need for remedial instruction.

Second, because modified mastery learning includes 100% mastery of every concept – at least at a rudimentary level of assessment – the instructor of a course designed using modified mastery learning has the luxury of adjusting the rigor and the approach used in the Optional assignments. In this way, modified mastery learning allows the instructor greater flexibility to pursue a variety of pedagogical techniques of active learning in the classroom and laboratory where students may choose to attend or not (i.e., optional learning opportunities).

This flexibility of the instructor allows an additional cost savings for the institution. For example, attendance at optional laboratories reduces the need for large quantities of expense laboratory equipment and supplies. Attendance at optional recitation sessions – in place of large, required lectures – allows the use of many smaller classrooms to accommodate large course enrollments (i.e., two courses can share the same scheduled time with one course using the larger lecture hall in alternating sessions with the second course). In the experience of the author, the cost savings of room scheduling is an important motivation for faculty to consider the adoption of mastery learning [16].

Third, modified mastery learning is learner centered rather that instructor centered. In other words, each student has a variety of ways to learn content and a variety of ways to demonstrate learning. Because of the self-paced approach and the integration of a flipped classroom, neurodivergent students – including those who previously excelled in elementary and secondary education with IEPs or those who request IAPs in higher education – may be more easily accommodated within the existing teaching effort of the instructor. As universities increasingly compete for a limited pool of existing students, the original concept noted by Bloom, namely that education should be viewed as a societal investment rather than a screening tool, means that faculty in higher education increasingly are being asked to be experts in teaching as well as subject matter experts in discipline specific content. Accommodating a more diverse student population using similar instructional resources is an inherent cost savings for institutions of higher education who depend upon enrollment to support sustainable funding models.

Conclusion

Based upon the experience of the author over fifteen years of teaching using modified mastery learning, the "formula" for success includes the use of online quizzes implemented in an available learning management system for students to master low-level content in a flipped classroom format. Readiness assessment is conducted at the start of each lecture-discussion section using think-pair-share exercises that leverage peer learning. Active learning in the classroom is subsequently assessed for the assignment of grades through a buffet of options including homework, quizzes, mid-term and final exams, as well as term-length projects that may be completed individually or in cooperation with other students. Because students may opt to attend a mixture of required and optional lecture sessions, there is a cost savings to the institution as a multiple courses may be scheduled to use the same large lecture halls – for required classes – with the use of smaller facilities for recitation – for optional classes. As reported by the author, student performance in follow-up courses demonstrate the same or better learning outcomes as compared to students participating in traditional sections of the same course [15] [16].

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