# Experience with Mastery Learning in Engineering Courses

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**Abstract**

As previously reported, mastery learning has been used by the author to provide instruction to more than 750 students in a total of 24 separate offerings of five different semester-long courses. In prior publications, the results of anonymous student feedback collected at the end of the semester have been reported, including: quantitative results of Likert-scale responses to five common questions; and representative comments to open-ended questions. These prior results suggest that at least two responses are predominant, namely: 1) rejection of mastery learning as "unfamiliar"/"unfair", or "lazy on the part of the professor"; or 2) welcoming of mastery learning as "empowering", or "an opportunity for self-ownership of learning on the part of the student". To improve our understanding of the attitudes of students towards mastery learning, a qualitative approach was employed in the current study. Through discussions with experts in qualitative methods, a structured interview guide was constructed by the author and included questions about: 1) "Seven Principles for Good Practice in Undergraduate Education"; 2) "Principles of Adult Learning"; and 3) ABET student outcomes. The structured interview guide also included an opportunity for free response to open-ended queries about flipped classroom, blended delivery, modified mastery learning, and flexible summative assessment. Experts in qualitative methods recommended an initial pilot study with a population of ten students. These ten alumni were selected from a subpopulation of the 750 students who previously completed at least one course employing mastery learning. The subpopulation was identified as individuals who earned a grade of "A" in a course with mastery learning and subsequently completed a semester-long course of "Independent research" with the author. The subpopulation included approximately 50 individuals students. Ten random individuals were selected from this subpopulation, contacted via email and follow-up telephone call, and invited to voluntarily participate in a one-on-one structured interview with the author. The interviews were transcribed and analyzed for themes by two individuals. The summary results of thematic analysis from these structured interviews are reported as a preliminary pilot study. In brief, these ten alumni provided a favorable view of mastery learning, and the results of this pilot study suggest that the structured interview guide is an appropriate starting-point for a more robust qualitative study employing a more formal approach such as interpretative phenomenological analysis or narrative discourse analysis.

## Introduction

Mastery learning, also known as "learning for mastery", was first formally described by Bloom in 1968[1]. The central idea behind mastery learning is that all students are capable of learning material if provided with quality instruction and sufficient time.

In a conventional course, students are taught material and then assessed "once". In the conventional format, performance on student assessment (i.e., midterms and final exams) is dependent upon two variables, namely: a) the effectiveness of teaching (i.e., "some teachers are easy to learn from"); and b) the inherent capabilities of the student (i.e., "some students always earn an A"). Time on task is defined by the course schedule, and students must learn material according to an external timetable with little opportunity for control.

In a course that adopts mastery learning, students are taught material and then assessed "multiple times". In the mastery format, performance on student assessment (i.e., quizzes) is dependent upon one variable, namely: a) the time (or number of attempts) needed to achieve a mastery result (i.e., "a grade of 100%"). Time on task is defined by the prioritization that a student places among multiple objectives, and students internalize the timetable based upon the ease of "groking" a concept[2]. Students have maximum control over the timetable and commit only the amount of effort needed to master the material.

Mastery learning is often employed in professions where "partial credit" would not be allowed, for example: a) qualifying for marksmanship with a firearm in the military or law enforcement; or b) determining a patient's blood pressure in healthcare. Mastery learning is readily applied to "low-level" Bloom's cognitive taxonomy where "knowledge" (i.e., remembering facts) and "comprehension" (i.e., stating the main idea) are the primary objectives.

Over the past seven years, the author has employed a modified mastery learning approach to provide instruction to more than 750 students in a total of 24 separate offerings of five different semester-long courses, including: 11 offerings of "2601 Fundamentals of Environmental Engineering and Science" required of sophomores[3]; two offerings of "5001 Science Diplomacy" elective for juniors, seniors, and first-year graduate students[4]; three offerings of "5605 Environmental Modeling" elective for juniors, seniors, and first-year graduate students[5]; four offerings of "5650 Public Health Engineering" elective for juniors, seniors, and first-year graduate students[6]; and four offerings of "Environmental Microbiology" required of first-year graduate students (not previously reported). Previous publications have independently documented lessons learned with mastery pedagogy in each of these five courses using quantitative methods including anonymous student feedback collected at the end of the semester such as results of Likert-scale responses to five common questions, and representative comments to open-ended questions.

As previously reported,

1. *"many students enjoyed the 'modified' format. In particular, sophomores using the course [2601 Fundamentals of Environmental Engineering] as a 'point of entry' for studying environmental engineering appreciated the clear expectations and the ability to 'contract' their grade (earning no less than a 'C' and completing 'optional' assignments to earn a grade of 'B' or 'A', for the course). Also, seniors in civil engineering who had voluntarily opted to delay taking the*

*course until later in their academic career appreciated the flexibility of the course format as a 'survey' of the field of environmental engineering.*

2. *a significant and vocal minority of students 'hated' the 'modified' format because, 'they felt it placed all of the responsibility for learning on the students and did not require the instructor to teach the material'.*
3. *the instructor should continue to explore the 'modified' format using blended, flipped, and mastery approaches because, 'different ways of teaching are interesting and that helps to keep students engaged in the material.'*" [3].

And,

"*Appendix 3. Representative student comments provided during assessment in Spring 2017 [for 5650 Public Health for Environmental Engineers].*

*D. The grading policy is a weakness - it stressed me out so much that sometimes it made it hard to focus on the information I was learning instead of the quickest way to get through the quizzes.*

*M. I never took a course that was structured this way and I really enjoyed it. The minimum workload wasn't too much and there was room for the students to earn more if they wanted.*" [6].

And,

"*About the course [5605 Environmental Modeling] format:*

*C. Please spend less time going over the 'rules'. Yes, the class has a unique structure, but students should read the syllabus.*

*D. A major strength in this class is the grading system - any student who doesn't earn an 'A' is either lazy or stupid or both.*

*E. The grading system encourages students to take 'risks' and explore the assignments without worry about 'math mistakes'.*" [5].

These prior results suggest that at least two responses are predominant, namely: 1) rejection of mastery learning as "unfamiliar"/"unfair", or "lazy on the part of the professor"; or 2) welcoming of mastery learning as "empowering", or "an opportunity for self-ownership of learning on the part of the student". Although useful, these prior results were limited and did not explore the breadth of attitudes of students towards mastery learning.

To better understand the attitudes of students across the range of course content (i.e., five different courses) and the range of students (i.e., from sophomores to graduate students), a qualitative approach was developed. In discussion with experts in qualitative methods, a structured interview guide was developed and a population of alumni was selected to voluntarily participate in a one-hour-long telephone interview conducted by the author. Each interview with transcribed and subjected to thematic analysis. In this paper, the qualitative results are summarized to document the experience of the author and students in the use of mastery learning in engineering courses.

## Methods

The structured interview guide used for each telephone interview is provided in Appendix 1, and was developed from discussions with experts with significant experience in qualitative methods. This current study was viewed as a "pilot", and the results collected here within are being used to inform a more extensive follow-up study to be conducted and analyzed by a larger team of experts.

The author has used mastery learning to teach more than 750 total students in 24 separate course offerings. The majority of these students were sophomores pursing baccalaureate degrees in civil engineering, architectural engineering, or environmental engineering, who were required to enroll in "Fundamentals of Environmental Engineering and Science". The author invites any student who receives a final grade of an "A" in this required sophomore course to participate in a subsequently semester of "Independent Research" for 3-credit hours. To date, more than 50 students have taken advantage of this opportunity for follow-up independent research. It was from this self-selected pool of students – those who had received a grade of an "A" in "Fundamentals of Environmental Engineering," and had opted to complete a subsequent semester of, "Independent research" – that ten random alumni were selected for telephone interviews. The author approached each alumnus via email and a follow-up telephone call to schedule a one-hour-long time for the telephone interview. Participation was voluntary and the results are reported in aggregate to maintain anonymity. All ten alumni who were contacted agreed to participate.

This research was determined to be exempt from Institutional Review Board (IRB) because it represents, "Benign behavioral interventions in conjunction with the collection of information from an adult subject or audiovisual recording if subject agrees prospectively to intervention / collection," and data reporting is provided anonymously and in aggregate.

## Results

The author conducted semi-structured telephone interviews with ten random alumni from a highly specialized sample pool of fifty individuals. The ten alumni were identified from a student population who had received a grade of an "A" in a required sophomore course (i.e., "Fundamentals of Environmental Engineering and Science"), and had subsequently completed an additional optional semester of research (i.e., "Independent research") working with the author. It should be noted that these students would be considered "high achieving" and are potentially likely inclined to provide a positive response to the telephone interview. Furthermore, because the author had developed a close working relationship with each of these students, a significant impact from the "Hawthorne effect" would be expected and these results should be interpreted with this in mind[7]. In other words, the responses of the alumni is likely biased by the personal relationship with the author, and therefore the results reflect a combination of both the views of the alumni on mastery learning as well as the views of the alumni on the author (i.e., some alumni may seek to provide a "positive" response in hopes of "pleasing" the author).

Of the ten alumni: 1) seven were male and three were female; 2) the ages ranged from 22 to 26 years of age; 3) all were employed in the practice of engineering; and 4) all had household incomes between $42,000 and $125,000 and self-identified as "middle class".

With regard to the success for implementing Chickering and Gamson's "Seven Principles for Good Practice in Undergraduate Education,"[8] all ten alumni felt that: 1) active learning was achieved; 2) prompt frequent, informative feedback was achieved; and 3) high expectations were adequately communicated. Eight alumni agreed that: 1) diverse talents and learning styles were respected; and 2) time on task was emphasized. The majority of the alumni felt that engagement – between peers and between the students and the author – should be improved. But these alumni also noted that larger class size (i.e., "Fundamentals of Environmental Engineering and Science" is offered to 70 or more students in a single section and a large lecture hall) created a barrier to interaction. Alumni who had completed an additional course with the author commented that "in smaller classes, the approach *definitely* (*emphasis added*) enhanced engagement."

With regard to the success for achieving Lieb's "Principles of Adult Learning,"[9] all ten alumni felt: 1) students in the class were treated as autonomous and self-directed, and in particular, the use of blended, flipped, mastery encouraged these behaviors among students. Eight alumni noted that: 1) goal-oriented teaching was achieved because the syllabus was very clear and the expectations were very high, and combined with the buffet style of assessment, each student had the opportunity to earn the grade they desired. The majority of alumni did not feel that the additional aspects of adult learning – namely connecting to life experiences and prior knowledge, matching personal interest, linking to practical job knowledge, and showing respect with teachers and students as equals – were achieved in the "Fundamentals of Environmental Engineering and Science," but they felt that these additional aspects of adult learning were achieved through the additional semester of "Independent Research." For example, a number of alumni noted that sophomores lack substantial prior knowledge and therefore it is difficult – if not impossible – for a required sophomore-level course to link first-time exposure to environmental engineering with prior knowledge. Similarly, a number of alumni noted that a required survey-course, such as 2601 Fundamentals of Environmental Engineering, is specifically designed to cover a broad cross-section of the field, and therefore many of the alumni noted that it is difficult for such a course to be viewed as "relevant" or "practical" because the content of a required survey course lacks the specificity to achieve relevance or practicality. And finally, a number of alumni noted that sophomores have difficulty viewing "teachers as peers", and therefore, the one-on-one experience of research was significantly more powerful in promoting mutual respect among students and the author. In summary, all ten alumni agreed with the statement, "a two-step process, including blended, flipped, mastery for an introductory course to be followed with open-ended learning on a topic of personal interest is an optimum strategy for meeting the needs of adult learners."

With regard to simultaneously supporting of learning "engineering skills" and "professional skills" (i.e., ABET student outcomes)[10], all ten alumni agreed that skills from "both-sets" were included successfully in the course. Specific skills mentioned by the majority of alumni, included: 1) application of math, science, engineering; 2) analysis of data; 3) multidisciplinary teams (from the lab portion of the course); 4) professional and ethical responsibility; 5) effective oral and written communication; 6) recognition of need for and ability to engage in life-long learning; and 7) knowledge of contemporary issues. In particular, a number of alumni specifically emphasized the *tremendous* (*emphasis added*) value of the flipped, blended, mastery format to promote life-long learning; specifically describing that the mastery approach taught them the value of sticking with a new subject until it was "mastered" in the workplace – a "professional" skill that impressed employers.

Representative comments received in response to the inquiry of "most favorite" and "least favorite" memory of the following approaches are included in the bulleted lists, below (number of individuals expressing a "similar" statement):

1) flipped classroom
    a. "It was stressful to read things before they were explained, but I now realize that this is very typical in my job, and I'm grateful that I had this experience in college." (N=6)
    b. "I'm really surprised that more teachers don't use this approach because it makes learning much better." (N=4)
2) blended format
    a. "Sorry, but I still HATE listening to videos – I prefer the face to face lecture!" (N=2)
    b. "Online is flexible, but it doesn't keep my attention as well as face to face." (N=3)
    c. "I've done a masters degree online, and I don't think I would have tried it if I didn't have your class before." (N=1)
3) modified mastery learning
    a. "You know that a lot of students HATED your approach! Personally, I thought it was a great to be able to work at my own pace." (N=7)
    b. "You class is EXACTLY like my job – my boss just wants me to get the job done." (N=4)
4) flexible summative assessment
    a. "Easiest A ever – not because the work was easy, but because I could earn the grade doing assignments that fit my personal style – so much easier to do extra homework rather than to ace an exam." (N=3)
    b. "Honesty, I was always confused by the optional assignments." (N=2)

**Conclusions**

Previously, the author has reported on the results of end-of-semester assessments of student satisfaction in courses the employed mastery learning. These quantitative results – and limited open-ended responses – suggest that students either "strongly like" or "strongly dislike" the mastery learning approach. To improve our understanding of how engineering students respond to mastery learning, a structured interview guide was created and the author conducted telephone interviews with ten alumni. Overall, the results were positive and suggested that many of the alumni felt that the mastery learning approach – coupled with blended delivery, a flipped classroom, and buffet assessment for assigning a final grade – was a successful pedagogy. In particular, the results from the alumni strongly supported the notion that mastery learning trained students in the skills and attitudes of autonomous, life-long, adult learners, and that these skills and attitudes were highly beneficial in the workplace environment. Future research should explore if student knowledge was enhanced through mastery learning, and future research should explore if the views of the alumni are reflected in the evaluations of the employers (i.e., do employers of students who experienced mastery learning find a benefit in the skills and attitudes of their employees). While it is unclear if mastery learning provides specific benefits in terms of imparting knowledge, the results of this pilot study strongly suggest that mastery learning provides benefits in the skills and attitudes of students as autonomous, life-long, adult learners.

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## **Appendix 1.** Structured interview guide used as part of a telephone interview.

1) Demographic information:
1. Name:
2. Gender:
3. Age:
4. Current occupation/employer:
5. Current salary range:
6. Date of graduation:
7. One or more courses with blended, flipped, modified mastery learning with buffet assessment:

2) A purpose of the course format was to implement Chickering and Gamson's "Seven Principles for Good Practice in Undergraduate Education."[8]

How well do you feel each of the following principles was achieved by the course format?
1. Encourage student-faculty contact – examples such as "in-class and out-of-class; social media; faculty and students as people"?
2. Encourage cooperation among students – examples such as "think-pair-share; small group break-out during regular lecture"?
3. Encourage active learning – examples such as "structured exercises; challenging discussions; team projects; and peer critiques"?
4. Give prompt, frequent, informative feedback – examples such as "online quizzes; prompt return of written homework"?
5. Emphasize time on task – examples such as "mastery learning; contract learning; computer-assisted instruction"?
6. Communicate high expectations – examples such as "poorly prepared; those unwilling to exert themselves; bright and well motivated"?
7. Respect and encompass diverse talents and learning styles – examples include "personality type; learning style preference"?

3) A purpose of the course format was to create an "optimum" environment based upon the characteristics of adult learning (as described in Lieb's "Principles of Adult Learning.")[9]

How well do you feel each of the following characteristics was incorporated into the course format?
1. Adults are *autonomous and self directed* – teacher as facilitator to guide rather than to supply facts
2. Adults need to connect new learning to their accumulated foundation of *life experiences and prior knowledge*
3. Adults are *goal-oriented* – syllabus must outline objectives and document path to achieving those objectives
4. Adults are *relevancy oriented* – participants must be provided a degree of choice to match their personal interests
5. Adults are *practical* – instructors must relate information to practical knowledge on the job
6. Adults need to be shown *respect* – teacher as equals alongside students

4) A purpose of the course was to simultaneously support learning in "engineering skills" and "professional skills" as described by ABET Criterion 3. Student Outcomes (a-k)[10].

How well do you feel each of the following criteria were achieved using the course format?

a. an ability to apply knowledge of mathematics, science and engineering
b. an ability to design and conduct experiments, as well as to analyze and interpret data
c. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d. an ability to function on multidisciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively (3g1 orally, 3g2 written)
h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

5) The course format included a number of novel approaches. What was your most favorite and least favorite memory of each of the following approaches?

a. Flipped classroom - an instructional strategy and a type of blended learning that reverses the traditional learning environment by delivering instructional content, often online, outside of the classroom.
b. Blended format - combines online digital media with traditional classroom methods.
c. Modified mastery learning - a method of instruction where the focus is on the role of feedback in learning. Furthermore, mastery learning refers to a category of instructional methods, which establishes a level of performance that all students must master before moving on to the next unit.
d. Flexible summative assessment - to evaluate student learning at the end of an instructional unit by comparing it against some standard or benchmark including standards imposed by the teacher and preferences expressed by the student.

6) Open-ended opportunity – anything else you would like to add?