2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC

Host Sponsor UNC Charlotte

Paper ID #50929

Mastery Learning in an Introductory Materials Engineering Course

Dr. Derek Breid, Saint Vincent College

Derek Breid is an associate professor of Engineering at Saint Vincent College. His interests include integrating active learning techniques into classic engineering courses, and studying the mechanical behavior of soft materials.

Mastery Learning in an Introductory Materials Engineering Course

Abstract

Mastery learning is a pedagogical approach that has been gaining popularity in recent years, especially among courses focusing on teaching engineering fundamentals such as mechanics and thermodynamics. While it can be implemented in many ways, the defining feature of mastery learning is an approach to assessment that requires students to demonstrate thorough understanding (mastery) of key course concepts while also providing them with opportunities to re-test concepts that have not yet been mastered. For instructors, mastery learning helps ensure that students who pass the course do so with the capability to perform the most important course skills, rather than with a half-baked understanding of everything the course covers. For students, mastery learning offers clear expectations and a degree of control over their assessment schedule and ultimately their course grade.

This paper describes the implementation of mastery learning for a required sophomore-level Introduction to Materials Engineering course in the context of a general engineering degree program at a liberal arts college. Because of the unique context in which this course is offered, it differs from a standard introductory materials course in several ways. These include taking a bigger picture approach to the field (contrasting with the more traditional focus on metallurgical specifics), working from properties down to microstructures, and incorporating a course project on sustainability in materials selection. This paper discusses the motivation for these pedagogical choices and how the specific implementation of mastery learning incorporates these aspects. It first provides a review of mastery learning in engineering courses with brief discussion of its advantages and disadvantages. Then, the implementation of mastery learning in the current context is described, starting with the big picture pedagogical goals and working down from there to the determination of learning outcomes and the practical details of assessment. Finally, the course instructor offers some perspective on this approach, including student perceptions solicited through an end-of-term survey.

Introduction

"Mastery Learning" describes a family of pedagogical approaches whose unifying characteristic is that learners are required to demonstrate a high level of understanding (i.e. mastery) of the material being learned [1]. At its core, mastery learning addresses how student knowledge is *assessed*, although many implementations also shape how knowledge is presented and reinforced. For example, DeGoede's approach limits lecture time on each mastery concept to one class session, with subsequent classes serving as workshops for students to explore and build their mastery [2]. Implementing mastery learning in a course involves breaking down the course learning objectives into discrete outcomes that can be tested independently of each other. These outcomes are assessed on a pass/fail basis (or something resembling this) and the course grade is primarily based on the number of outcomes that a student masters, rather than the average level of mastery across all topics. Mastery learning sets high expectations for learners, but must also necessarily include pathways for students to re-assess topics where mastery has not yet been earned – otherwise it just becomes a very hard class. Common reassessment models include:

- A single reassessment opportunity following focused in-class review (with challenge or enrichment activities offered to students who achieved mastery on the first attempt) [1].
- "Unlimited" opportunities to reassess a given topic [3]. Of course, nothing in this world is truly unlimited, as each assessment comes at a cost of time and effort on the part of the grader, meaning that the number of actual assessment opportunities becomes the limiting factor to how far a student can advance. Thus, a student electing to reassess one outcome would potentially sacrifice a future opportunity to assess or reassess a different outcome.
- Unlimited reassessment within deadlines, in which each learning outcome has a limited time frame for reassessment. This approach can help foster a sense of urgency in students who might perceive "unlimited attempts" as an opportunity to procrastinate studying.
- Multiple, but not unlimited reassessments. These can be made on a rolling basis; for example, if assessment is offered weekly, then assessment X may be available for four consecutive weeks after the necessary material has been introduced.

The difference between mastery assessment and a traditional assessment scheme is most apparent when considering a C grade. In a typical course, a C would indicate that a student – having been tested on all concepts covered by the course – understands them on average at a basic level. If their understanding of course topics were thought of as glasses of water, all of the glasses would be about half-full. In contrast, a C in a mastery-based course would represent that the student has strong knowledge of some, but not all topics covered. Instead of all glasses being half-full, half of the glasses would be completely full.

The concept of mastery learning is not unique to engineering education, and in fact appears to have originated in the K12 pedagogical community. However, in recent years the concept of mastery learning has started to gain traction among engineering instructors [4]. Some of the pedagogical arguments in favor of mastery-based grading are:

- For courses whose content is highly sequential, where later concepts build upon earlier ones, using a mastery approach can help ensure that students gain the foundational skills necessary to tackle the more advanced material.
- Similarly, when students are expected to recall concepts in a future course, using a mastery-based approach can help ensure that those concepts are fully understood.
- Breaking the course down into specific outcomes, assessed individually, helps students to understand more specifically the knowledge or skills they will need to demonstrate, and to more effectively plan their preparation. Likewise, if at a certain point in the semester a student is satisfied with their course grade, they can choose not to undergo further assessment and focus their studying on other courses.
- Allowing reassessment of outcomes affords students some degree of flexibility of their assessment schedule. If a student does not feel ready to take a mastery assessment, they can opt to wait until the next assessment opportunity. Combined with the previous point, this offers students a stronger sense of control over their course grade, and a reduction in cramming and associated test anxiety.

Many other benefits of mastery learning have been identified, including shifting student mindset from grades to learning [5], stimulating growth and persistence through failure [6], [7], and increasing a student's sense of belonging in the field of engineering [8].

Implementation of Mastery Learning

This paper focuses on a mastery-learning implementation in a sophomore-level Introduction to Materials Engineering course, offered within a general engineering bachelor's degree program at a small liberal arts college. It is accompanied by a separate Materials Engineering laboratory which covers corresponding experimental skills, taught by a different faculty member, graded separately. Within the general engineering degree, students select an area of concentration in mechanical, materials, chemical, or environmental engineering. However, this course (and the lab course) is part of the required engineering core that all students must take. Therefore, the students in this course represent a wide range of engineering interests. For this reason, the course inverts the usual topic order found in most introductory textbooks. Rather than starting at the atomic structure level and building up to bulk properties, we start off by introducing the properties first, as this is the part of the course that is most likely to be used in the future by these students. This also serves to motivate curiosity about *why* materials might have different properties to begin with, which stimulates interest in learning about the atomic structures which are responsible. This properties-first approach also helps highlight the world of engineering materials more holistically, since students start by comparing metals, ceramics, and polymers using a common basis (their properties), avoiding the typical implication that metals are the main materials worthy of consideration.

A mastery-learning approach was selected for this course when it was taken over by the current instructor in 2024. The main motivation for doing so was to provide students some degree of control over their assessment schedule and course grade, reducing test anxiety and hopefully stimulating a more genuine interest in learning about materials engineering. A smaller factor, necessitated by the inverted topic order, was the need for students to start off with a strong conceptual understanding of mechanical properties of materials, so that they could connect back to these properties as they learned about microstructures and processing. Additionally, the instructor had had positive experiences using mastery learning in other engineering courses.

The course content was distilled into 10 mastery outcomes:

1. Classify materials according to key properties and features
2. Interpret a stress-strain curve and calculate key mechanical properties
3. Select material candidates for given design criteria
4. Select an appropriate processing method for a given material and product
5. Describe atomic bonding and structure of crystalline solids and relate these to macroscale properties
6. Interpret metallic phase diagrams
7. Describe atomic bonding and structure of polymeric solids and relate these to macroscale properties
8. Link changes in structure to processing method and resulting material properties (defects, grain size, chain alignment, etc.)
9. Describe failure mechanisms/modes for various materials
10. Describe and predict properties of composite materials

Each of these outcomes represented one to four 75-minute class periods worth of coverage. Homework sets were assigned weekly and corresponded directly to the material covered by the mastery outcome with the same number. Outcomes requiring more than one week were split into two homework assignments (e.g. HW4a and HW4b). Starting in week 2, 15 minutes of class time were set aside for pen/paper mastery quiz assessment. These weekly assessments were determined to take up the same amount of class time as three full-period exams, so there was no loss of instructional time compared to a typical assessment scheme. Each mastery topic was available for 4 consecutive weeks, providing a rolling window. Because of topical overlaps, students usually had either two or three (occasionally four) topics which were available to attempt in a given week. Each week, students were allowed to attempt two quizzes, with the opportunity to pick up the third if they had time. The quizzes were formatted to be answered in 5-7 minutes by a student with strong understanding of the topic. No notes were allowed, but students were provided with equations for key calculations (equations were NOT provided for simple stress, strain, and elastic modulus calculations, as knowing these from memory was seen as part of the mastery of this content).

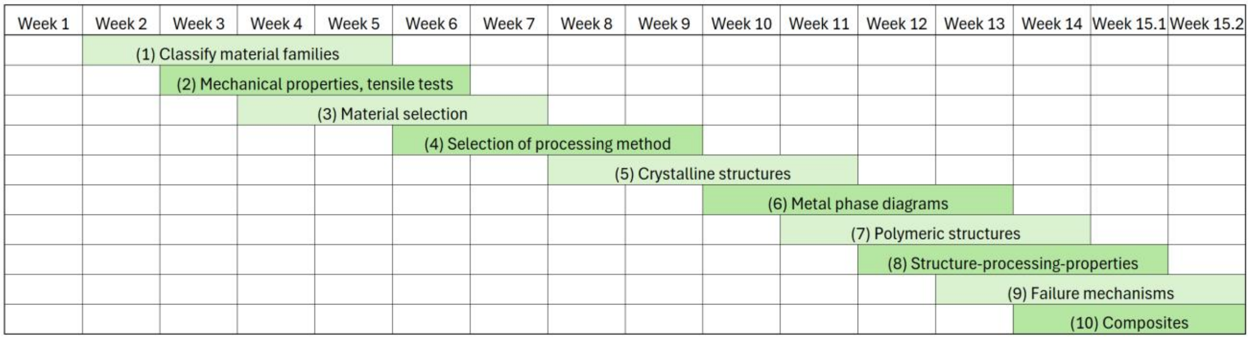


Figure 1: Availability of mastery quizzes throughout the 15 weeks of the semester. During the last week of class, an additional quiz attempt was available to ensure students received 4 opportunities to attempt each topic. One final opportunity was made available during the course's final exam timeslot, where students could attempt up to 4 quiz topics of their choosing, in order to make up for an earlier poor score.

Each quiz attempt was graded on a scale of 0-4 points, using the following general rubric:

0 points	Question unattempted or attempt has no merit
1 point	Answer demonstrates incomplete understanding of topic, including incorrect justification and/or poor execution of calculations
	-Mastery Line-
3 points	Answer demonstrates adequate understanding of the relevant concepts, evidenced with appropriate justification and/or calculations that are within minor fixes of validity
4 points	Answer demonstrates well-developed understanding of the concepts, thorough justification, and/or well-executed calculations

To provide more focused guidance to the students on what the expectations would be for each mastery topic, a customized application of this rubric was developed for each of the 10 topics, and provided to the students in advance, along with a list of expected knowledge or skills. One example of such a rubric, and a corresponding quiz question, is included in the appendix. The rubric includes a list of skills on which students can expect to be tested. Because of the need for questions to be answerable in 5-7 minutes, most quizzes only cover a subset of these skills. However, students do not know in advance which of the skills will be covered, and are instructed to be prepared to demonstrate mastery on any of them. Each mastery topic generates a new quiz question every week the topic is offered, so students cannot simply memorize a previous week's answer. Quizzes that focus on analytical skills like interpreting phase diagrams tend to be similar from week to week, while quizzes that rely more heavily on knowledge recall are more varied.

While some approaches to mastery grading rely on a pure pass/fail approach (often framed as "mastery/not yet"), the instructor for this course had observed that this could lead to significant frustration for students who repeatedly came close to mastery without achieving it. By mapping the levels of mastery to a point scale, this frustration could be mitigated to an extent, by recognizing the difference between attempts that demonstrate *some* rather than *no* understanding. Similarly, distinguishing between meeting and exceeding mastery expectations (3 vs 4 points) allows the instructor more freedom to consider edge cases while also rewarding work that shows clear and thorough understanding. The gap between 1 and 3 points is intentional, serving to reinforce to the students that a half-baked answer is not going to cut it.

To determine the course grade, a student's top *two* quiz scores for each mastery topic are tabulated. This was implemented to ensure that the student's knowledge in each topic persists through at least two consecutive weeks, following research that indicates the importance of spaced repetition/recall for learning. With 10 topics and each quiz earning up to 4 points, this results in 10 x 4 x 2 = 80 possible mastery points to be earned across the course. The number of quiz points earned thus mapped to a student's final course grade (Figure 2). The grade scale was set using the following principles:

- An A grade could be attained by a student who earned the full 8 points for 9 of the 10 mastery topics (72 total quiz points)
- Each 1/3 grade below this represented one fewer quiz score, i.e. 68 points for an A-, 64 points for a B+, and so forth.

Under this grading scheme, a student meeting expectations (3 points) for all 20 quiz attempts would earn a B. A student meeting expectations on half of these attempts and earning 1 point on the other half would earn a D.

One challenge that arises when a student's grade is tied entirely to the mastery scores is that it offers no direct incentive for a student to complete activities such as textbook readings or homework sets. This presents a dilemma: to offer course points for such activities (which are non-proctored and intended to be low-stakes practice) reintroduces the possibility of a student being able to pass the course while demonstrating minimal topical mastery. On the other hand, to offer no incentive for these activities invites students to deprioritize them, at the expense of poorer mastery quiz performance.

To solve this, a concept borrowed from certain strategic board games was implemented. Each course activity category (homework, reading, etc.) was also mapped to a course grade, similar to the mastery quiz points. To incentivize a holistic approach to study, a student's course grade was based on the category with the *lowest* corresponding grade. This meant that a student could not ignore any category, nor would outstanding performance in one area make up for deficiency elsewhere.

However, to maintain the primacy of mastery performance in grade determination, the grade mappings for homework, reading completion, and reading quiz performance were designed so that these would not ordinarily be the factors that limited a student's grade. For instance, homework was based on a completion-resubmission model[9] and a student could easily earn full homework scores simply by maintaining on-time, complete submissions – correctness of the student's homework never factored into the grade. In other words, the mastery points were hard-earned, while the homework and reading scores were easy. This scheme also allowed the incorporation of a scaffolded course project, to be completed in stages, with the number of completed stages again mapped to a course grade. The project stages were graded on a true mastery/not yet basis, with students able to revise and resubmit their deliverables to address deficiencies raised by instructor feedback. The project involved researching and designing materials for sustainability, and is modeled after that developed by Yu [10]. More details on incorporating course projects into mastery grading can be found in our companion paper [11].

Grade	Mastery Quiz points earned	Homework score at least…	Project (deliverables completed)	eBook reading completion at least…	Reading quiz scores at least…
A	72	90%	4	95%	80%
A-	68	85%	4	95%	80%
B+	64	80%	3	85%	75%
B	60	75%	3	85%	75%
B-	56	70%	3	85%	75%
C+	52	65%	2	75%	65%
C	48	60%	2	75%	65%
C-	44	55%	2	75%	65%
D+	40	50%	1	60%	60%
D	36	0%	1	0%	0%
F	Does not meet minimum standards for a D in one or more categories				

Figure 2: Overall course grading scheme with example student grades in each category depicted by shaded cells (this student earned 56 mastery points, 85% homework, etc.). A student's final grade is determined by whichever of the categories is the lowest at the end of the semester. In this case, the student's 56 mastery points set the grade at a B-, despite higher achievement in other grading categories. Note that homework and reading completion is not required to simply pass the class (0% in the D row) as long as the student can demonstrate sufficient performance on the mastery quizzes and project

Perspective

In this section, the instructor will provide observations, student perspectives, and advice for others who are considering a mastery approach. Unfortunately, the effects of adopting mastery learning on student performance of learning outcomes are not readily assessable, as many other significant changes to the course were made at the same time (including a change in instructor). The overall grade distribution among the students in the course was in line with the previous iteration of the course, which followed a standard exam-based model, but covered fewer topics. However, the instructor (who is also the grader) anecdotally confirms that the grade earned indeed reflects the number of topics mastered, rather than the average mastery of all topics. That is, even students at the lower end of passing demonstrated real proficiency in at least some of the topics. Furthermore, students were more likely to simply leave quizzes blank when they knew that they weren't able to answer the question to mastery standards, rather than trying to earn some partial credit by writing whatever random info they thought might be relevant.

The average scores for each mastery topic for Fall 2025 are shown in Figure 3. This represents the two highest mastery quiz scores for every student. A few of the students elected not to make two attempts at all topics (typically quizzes 9 and 10), therefore the average for these topics is slightly lower. The strongest topics are those covered at the beginning of the course, especially those that ask students to identify material types, evaluate mechanical properties, and identify appropriate processing techniques. The most challenging topics are phase diagrams and polymer structures. However, even these topics average above a 2.5, suggesting that there are at least as many mastery scores as non-mastery across the whole class.

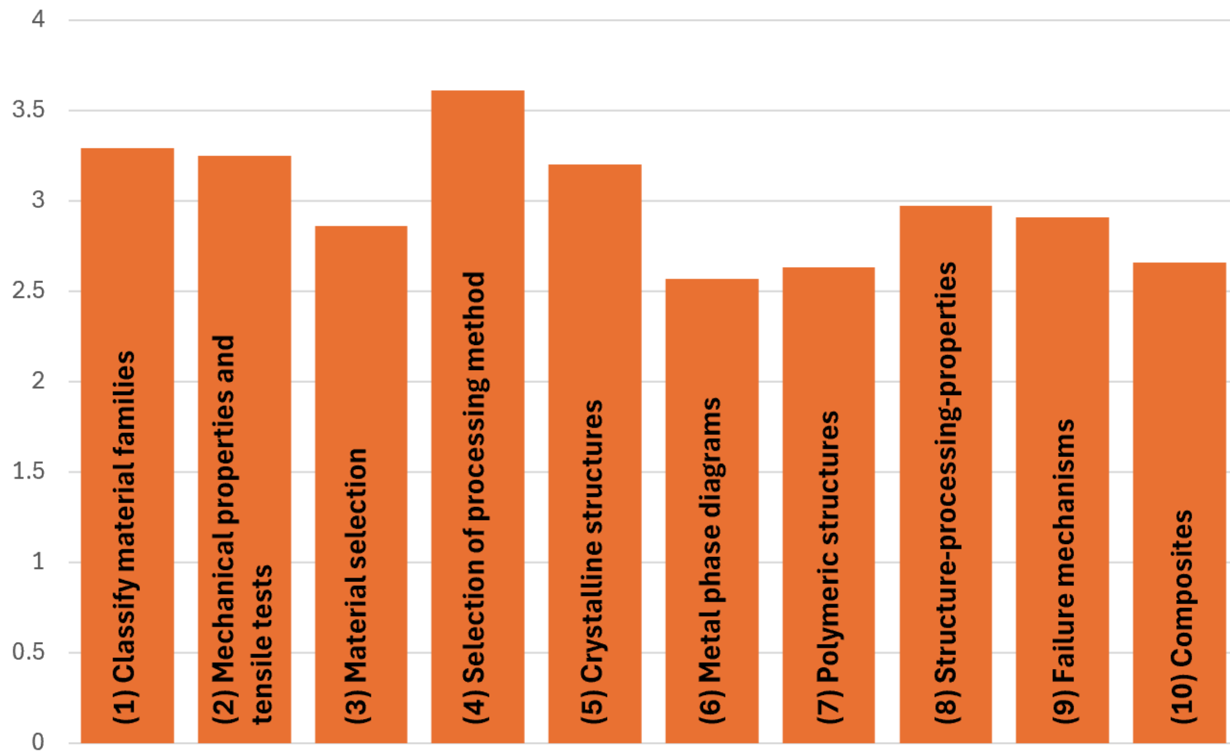


Figure 3: Average final grades for each mastery topic.

One key to success is to make sure that students are aware of the grading scheme, and the pedagogical motivations for taking a mastery approach. In the first year of this scheme, a small minority of students did not make the connection that strong homework scores could not counteract poor mastery scores, and ended up frustrated at effort they viewed as wasted. Based on this experience, extra effort was made to explain the grading scheme to students, and an Excel-based grade calculator was developed which allowed students to explore different grade possibilities (and advised them as to which area needed to improve for their grade to go up).

Relatedly, it is also evident that students need to undergo a mental adjustment to the concept of mastery grading. Students who are used to getting significant partial credit for answers that are in the ballpark definitely struggle to adjust their study approach to focus on complete mastery. What works for this may vary from student to student, but the instructor typically advises these students to focus on making flash cards for the topics that require more recall, and on physically writing out answers to practice questions for topics that require calculations, interpretations, or engineering judgment.

A survey was administered to students on a voluntary basis shortly after the Fall 2025 semester ended. The survey consisted of a series of Likert-style questions followed by a few open-ended short answer responses. Responses to the Likert-style questions are reported in Figure 4.

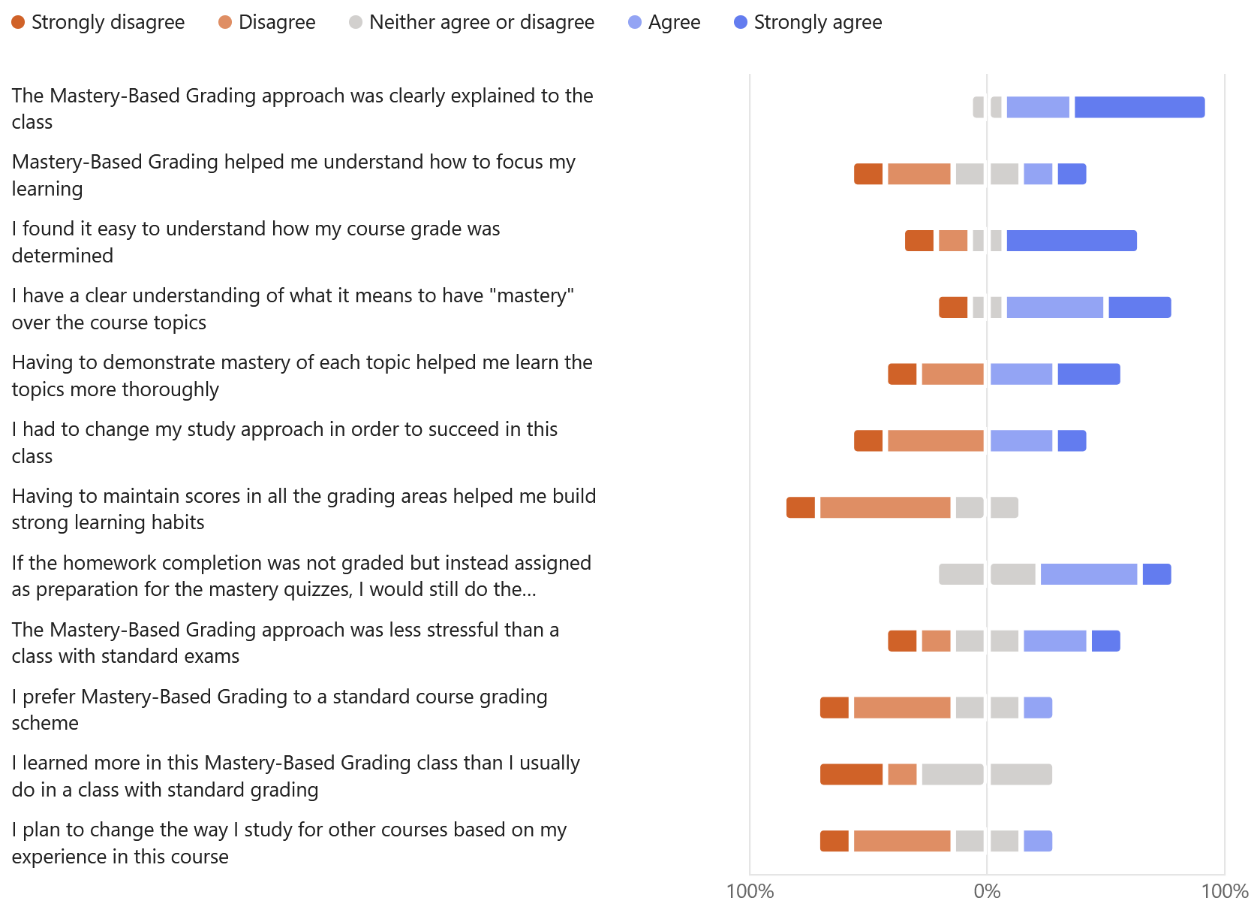


Figure 4: Summary of responses to Likert-style questions. A total of 7 anonymous responses were recorded, out of a possible 22 students.

A few observations from the survey:

- The efforts made to carefully explain the grading scheme appear to have been very successful.

- Students were split on whether they felt mastery-based learning was more effective, though the open comments addressing this area all seemed to indicate a sense of deeper learning. One student said "I felt as if I was able to learn and retain the topics from this course rather than just forgetting most of it after the course was over. The mastery-based grading scale DEFINITELY challenged me more."
- Students were also spilt on whether they felt the mastery approach reduced their stress. This result was fairly surprising and conflicted with most direct feedback the instructor had received, as well as observations of student demeanor on quiz days. The open responses also seemed to contradict this result, where one student even stated that there "needs to be some form of pressure in the class. It does not really prepare engineers for the workplace where they do not have four attempts to get the question right."
- One student was very dissatisfied with the whole concept, strongly disagreeing with nearly every statement. In their open responses, they indicated that they felt the quizzes were "opinionated (sic) based" and that the questions for the same quiz topic were not consistent from one attempt to another. This latter comment likely pertains to the fact that the quizzes are very short and cannot always cover every subtopic listed in the mastery skillset provided. In the future, greater emphasis will be provided to the students on the need to study for <u>all</u> of the mastery skills from the rubric.
- Some students perceive the bar for mastery as being too high. One student suggested adding a 2-point score as a possibility. A couple of others also expressed the idea that they felt their grade did not reflect their learning. This highlights an area that will be more of a focus in future iterations of the course.

To conclude, if an instructor is considering adopting a mastery-based approach for their own course, we can offer the following advice:

- Conducting assessments without sacrificing content delivery is the biggest logistical challenge. Consider carefully how this can be achieved in your course. For this course, the instructor devised mastery quizzes that could be answered in short time frames. Other courses move the assessments outside of the class meeting time, but this also comes with drawbacks.
- It might seem intimidating to need to grade so many assessments. However, the experience of this instructor is that the mastery approach (modified pass/fail) combined with clear rubrics makes grading go very quickly.
- Students need to adjust their mindset to properly prepare to demonstrate mastery. Some students will struggle to do this even to the end of the semester. One approach is to make mastery grading the norm for an entire program, but this requires institutional buy-in. Be prepared to discuss changes to student study habits, and for a few students to feel frustrated that their past approach isn't working as well in this new paradigm.
- Having a set weekly schedule is very beneficial for students to prepare for their mastery assessments. Students in this course knew that homework assignments were due

Mondays, resubmissions Wednesdays, and mastery quiz attempts were on Thursdays. This helped students find a study routine and led to few missed submissions or quiz attempts.

[1] T. R. Guskey, *Implementing Mastery Learning*. Thousand Oaks, California: Corwin, 2023.

[2] K. M. DeGoede, "Competency Based Assessment in Dynamics," presented at the 2018 ASEE Annual Conference & Exposition, Jun. 2018. Accessed: Jan. 21, 2026. [Online]. Available: https://peer.asee.org/competency-based-assessment-in-dynamics

[3] M. Spencer, "Implementation of Competency-Based Learning in a Laboratory-Focused Analog Design Course," presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 21, 2026. [Online]. Available: https://peer.asee.org/implementation-of-competency-based-learning-in-a-laboratory-focused-analog-design-course

[4] C. Perez and D. Verdin, "Mastery Learning in Undergraduate Engineering Courses: A Systematic Review," presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 21, 2026. [Online]. Available: https://peer.asee.org/mastery-learning-in-undergraduate-engineering-courses-a-systematic-review

[5] J. Gargac, "Failing Forward: A Mastery-based Learning Approach in a Theory of Machine Kinematics and Dynamics Course," presented at the 2024 ASEE Annual Conference & Exposition, Jun. 2024. Accessed: Jan. 21, 2026. [Online]. Available: https://peer.asee.org/failing-forward-a-mastery-based-learning-approach-in-a-theory-of-machine-kinematics-and-dynamics-course

[6] J. Gargac, S. Das, K. M. Degoede, and S. A. Atwood, "Mastery-Based Learning Inspires Persistence and Growth Through Failure," presented at the 2025 ASEE Annual Conference & Exposition, Jun. 2025. Accessed: Jan. 21, 2026. [Online]. Available: https://peer.asee.org/mastery-based-learning-inspires-persistence-and-growth-through-failure

[7] K. M. Degoede, B. Read-Daily, and R. Koh, "MBL (Mastery-Based Learning) Supports a Normalization of Failure as an Essential Part of Learning," presented at the 2024 ASEE Annual Conference & Exposition, Jun. 2024. Accessed: Jan. 21, 2026. [Online]. Available: https://peer.asee.org/mbl-mastery-based-learning-supports-a-normalization-of-failure-as-an-essential-part-of-learning

[8] M. Williams, M. Brinton, K. M. Degoede, and E. D. Dalton, "Student Anxiety and Belonging in a Mastery-Based-Learning Course," presented at the 2024 ASEE Annual Conference & Exposition, Jun. 2024. Accessed: Jan. 21, 2026. [Online]. Available: https://peer.asee.org/student-anxiety-and-belonging-in-a-mastery-based-learning-course

[9] Derek Breid, "Replacing Cheating with Metacognition – Reevaluating the Pedagogical Role of Homework in Foundational Engineering Courses," Tampa, Florida: ASEE Conferences, Jun. 2019. [Online]. Available: https://peer.asee.org/33237

[10] B. Yu, "Materials Education for Sustainability: a Design-Led Approach," presented at the American Society of Engineering Education Annual Conference, Jun. 25, 2024.

[11] D. Breid, "Integrating Course Projects into Mastery-Based Grading," presented at the 2026 ASEE North Central Section Conference, Alliance, OH, Mar. 2026.

Appendix:

Example of mastery rubric

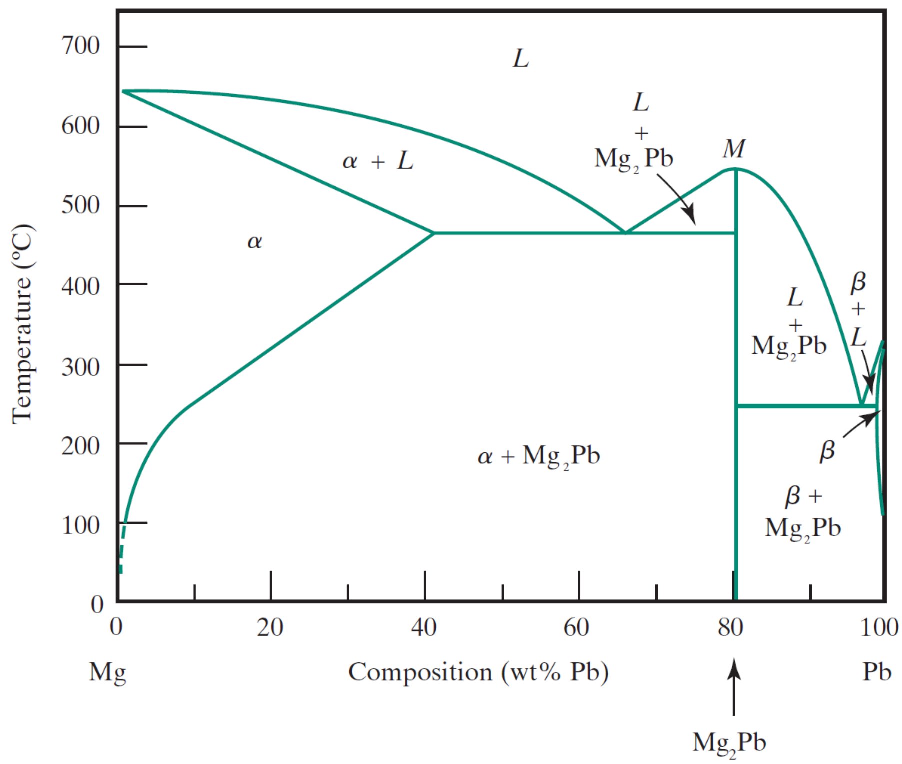
Course outcome: *Interpret metallic phase diagrams*

Students may be asked to demonstrate the following skills or knowledge:

- Identify key features of phase diagrams, including phases, phase boundaries, eutectic and eutectoid points
- Determine the compositions of phases, and the amounts of each phase that is present
- Identify or sketch microstructures that are present at different points of a phase diagram based on given information about the composition and heating history, and describe why the microstructure exists this way.

Score	**Student Performance**
4 (High Mastery)	Student demonstrates clear knowledge of metallic phase diagrams, including correct determination of the composition and amounts of each phase present. Student correctly identifies relevant microstructures and demonstrates superior understanding of their formation.
3 (Mastery)	Student demonstrates adequate knowledge of phase diagrams with at most a minor interpretation or calculation error. Student demonstrates understanding of the relationship between given information, the phase diagram, and the resulting microstructure.
1 (Developing)	Student recognizes some features of a phase diagram, but not all. Student determines compositions and amounts of phases present with at least one conceptual error. Student demonstrates partial understanding of relevant microstructures.
0 (Absent)	Student does not identify key features of a phase diagram. Determinations of phase composition and amounts contain key errors or are missing. Student identifies or sketches microstructures that are completely disconnected from provided information.

Example of mastery quiz



An alloy that is 50% lead (Pb) and 50% magnesium (Mg) is heated to 700°C, then slowly cooled to 500°C.

a) Sketch the expected microstructure and label the phases.
b) Determine the composition of each phase (by wt% Pb).
c) Determine the relative amount of each phase (by wt%)
d) The alloy is then allowed to cool completely. Sketch the expected microstructure of the alloy at this point.