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A Systematic Literature Review for Mastery Learning in Undergraduate Engineering Courses*

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Implementing mastery learning in an undergraduate engineering course can be cumbersome, requiring instructors to restructure their evaluation and grading practices significantly. There is a lack of coherent evidence on the effects of mastery learning on undergraduate engineering students and a lack of understanding of instructors' perspectives on mastery learning. Therefore, the four objectives of this study were (1) to provide educators and researchers with an overview of how mastery learning has been applied in undergraduate engineering courses, (2) to understand the effect mastery learning has had on students' learning, (3) to understand students' experiences, and (4) document reflective feedback reported by instructors who implemented mastery learning. We employed a systematic literature review methodology to address these objectives. We surveyed eight databases for published articles. Our systematic literature review focused on studies that applied mastery learning in undergraduate engineering courses in the United States; 23 articles were reviewed and synthesized. Mastery learning was implemented through many approaches, but all implementations followed the core features of specifying learning objectives, using designated evaluation metrics to measure mastery, and providing multiple retake opportunities. The most common implementations were in Statics, Dynamics, and Thermodynamics courses. Students' final exam grades were not representative of the effectiveness of mastery learning. Yet, there was evidence that mastery learning positively affected student learning when cumulative course grades or homework grades were considered. Students' evaluation of their mastery learning experience was mixed. Five studies reported that many students learned better through mastery learning. A robust evaluation of students' experience in a mastery learning course could be ascertained better through standard survey questionnaires. After analyzing the instructor's reflective feedback, we identified 16 benefits and four limitations. We conclude the systematic review by providing recommendations for instructors considering implementing mastery learning in their undergraduate engineering courses.

Keywords: mastery learning; mastery grading; alternative educational approach; systematic literature review; engineering education

1. Introduction

Educating our students is a purposeful activity, and the main objective should be that students learn what we teach. If our purpose is that all students learn, then the achievement distribution should be very different from the normal distribution [1, 2]. Bloom [1, 2] believed that viewing student learning through a normal distribution was destructive to students' self-concept and declared that this approach ensures that only a minority group of students can achieve mastery of course content. Even if students entered the classroom with an aptitude that is normally distributed when the "quality of instruction and learning time allowed are made appropriate to the needs of each learner, the majority of students [can] achieve subject mastery" [2, p. 50]. Increasing time to demonstrate mastery of course content involves a course structure that allows repeated attempts on learning assessments (i.e., homework, quizzes, exams, etc.). Traditional approaches to student performance evaluation consider what the student was able to learn at the time the evaluation assessment was administered, a snap-shot of their performance. A student's final grade becomes a composite of the separate performance snap-shots rather than a measure of students' knowledge of specific learning objectives. Awarding partial points is also common when using a traditional assessment approach. In many courses, a student can earn enough partial points to receive a passing grade without solving an entire problem correctly. The implication of awarding partial credit is a lack of understanding of the learning outcomes a student has mastered or the knowledge gap that needs to be addressed for a follow-up course. Focusing on mastering specific learning objectives ensures that students have achieved some baseline knowledge of the course to be successful in future courses and shifts students' attention from a "grade-grubbing" approach to a focus on learning [3].

The mastery learning approach recognizes that mastery is not always achieved on the first attempt, and learning from mistakes and perseverance is fundamental to learning [4–6]. Students are not penalized for failed attempts but are rewarded for achieving eventual mastery. An academic environ-

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ment that promotes mastery and continuous improvement rather than inherent ability leads to better student performance, continued interest, and persistence [6, p. 13], [7, 8]. Much attention has been given to mastery learning courses in secondary education, and the approach has shown an exceptionally positive effect on student achievement [9]. Several meta-analyses of mastery learning applied in elementary and secondary education have found a strong positive impact on raising students' final grades [9–11]. In the undergraduate engineering setting, mastery learning has been shown to produce various positive results, including improvement in content mastery and a boost in students' performance [12–14]. Averill et al. [12] compared mastery learning sections of a mechanics of materials course to traditional sections of the same course. Students in the mastery learning sections scored three letter grades higher in a partial credit final exam when compared to those in the traditional course sections [12]. Ranalli and Moore [14], who implemented mastery learning in dynamics and thermodynamics engineering courses, found that students thought mastery learning was 'fairer' than the traditional partial credit system since disputes over points taken off for errors had less importance. Homework grades were higher in mastery learning sections, and students' perception of mastery learning was largely positive [14]. Hjelmstad and Baisley [13] applied the mastery learning approach in a sophomore-level mechanics course; they found that students shifted their focus to the course learning outcomes rather than the grade they needed to pass the class, thus embracing the values of mastery learning. Leonard et al. [15] documented evidence of the benefits of mastery learning for minoritized engineering students who took a series of Circuit courses. Minoritized students performed poorly in traditional course offerings compared to their counterparts. Before the mastery learning implementation, the cumulative Circuits I pass rate for minoritized students was about 65%, and their one-year completion rate for the sequence was about 55%. Data collected across the two years when mastery learning was implemented showed that minoritized students' one-year sequence completion rate increased to 90%, while the cumulative one-year sequence completion rate for all students was 77% [15]. These findings present preliminary evidence of the effects of a mastery learning approach on undergraduate engineering students and the promise this pedagogical approach can have on students' learning dispositions.

Yet, implementing mastery learning in an undergraduate course is nontrivial as it requires instructors to restructure their evaluation and grading practices significantly [16–18]. Pedagogical approaches that are time-consuming and complicated for instructors to implement run the risk of being overlooked even when they promise to improve student performance. In light of these challenges, the extent to which mastery learning has been implemented in undergraduate engineering courses is unclear. There is a need to understand the type of mastery learning implementations reported and the student outcomes from these implementations. This paper fulfills this need by conducting a systematic review of mastery learning to answer the following research questions:

(1) How has mastery learning been implemented in U.S. undergraduate engineering courses from 1990 to 2021?
(2) What student learning gains have been reported for mastery learning implementations in undergraduate engineering courses?
(3) How did students describe their experience in their mastery learning course?
(4) What feedback or recommendations have been reported by instructors who implemented mastery learning in their undergraduate engineering courses?

1.1 Describing Mastery Learning

Bloom [1, 2], through an adaptation of Carroll's [5] model of learning, formulated a comprehensive model of mastery learning. Carroll [5] declared that students could learn a task or course content if they had sufficient time. The time needed for learning required consideration of students' prior knowledge or aptitude, students' understanding of instruction, students' willingness to actively engage in learning, and, notably, the quality of instruction [1, 2, 5]. Bloom extended this model further by asserting that students can achieve mastery of course content if attention was paid to the ratio between time spent versus the time needed for each learning unit [1, 2, 19]. Bloom's systematic approach to mastery learning involves three distinguishing features: (1) defining mastery, (2) planning for mastery, (3) grading for mastery, and (4) teaching for mastery [1, 2, 20]. Bloom predicted that applying these four components would result in higher levels of achievement. As students progressed through the learning units, they would require less corrective time since mastering prior learning units would support their learning of new topics. Bloom [1, 2] and Carroll [5, 19] asserted that under appropriate learning conditions, "95 percent of students (the top 5 percent + the next 90 percent)" could achieve an A grade, i.e., an index of mastery [p. 4]. Mastery learning (ML) should be viewed as a teaching philosophy and instructional strategies [4]. Teaching for mastery is the philosophical commitment by the instructor at the outset of the semester to structure the course in such a way that allows students time to obtain mastery of each important learning outcome. The set of strategies used to teach for mastery are defined as follows:

(1) Defining mastery comprises of clearly defined learning outcomes, specifications, competencies, etc., that students are accountable for mastering. Course objectives should then be divided into smaller learning units of achievement, which should be evaluated through assessments (i.e., homework, quizzes, exams, milestones in a project, etc.). A clear definition of how students achieve mastery of each objective should be established at the onset, further discussed in grading for mastery below. Defining mastery requires that students demonstrate evidence of successfully progressing through each learning unit to achieve mastery of the corresponding outcome [1].

(2) Planning for mastery requires consideration of students' current aptitude, ability to understand instruction, and student's willingness to persevere to achieve mastery of each outcome [1, 2]. Suppose we perceive our students' aptitudes to be normally distributed. And suppose the quality of instruction and the time for learning each outcome are appropriate to each student's needs. In that case, we should expect the majority of students to achieve mastery of the subject [1]. When teaching for mastery, aptitude should be defined as the amount of time required by the learner to achieve mastery of the learning unit and, subsequently, the larger learning outcome [1, 5]. Planning the curriculum with a mastery approach requires a course structure that gives students multiple attempts to demonstrate mastery of the learning objective, specification, or competency. Increasing the time to achieve mastery recognizes that mastery is not necessarily achieved on the first attempts and that learning from mistakes and persisting is fundamental to how we learn. Formative assessments such as homework, quizzes, exams, or project milestones are used to evaluate if students are progressing toward mastery of a learning outcome, specification, or competency.

Creating a mastery learning course requires three principal characteristics: (1) the mastery learning evaluation metric used, (2) the number of retake opportunities given, and, (3) the student feedback provided by instructors. Mastery learning evaluations allow students multiple attempts to demonstrate mastery without receiving penalties for failed attempts. The mastery learning evaluation is a process that begins when a specified assignment, assessment, or exam is given to a student to evaluate mastery of specific learning objectives and ends the moment the mastery of those learning objectives is achieved. The mastery learning evaluation process allows students multiple opportunities to demonstrate mastery by retaking that assignment, assessment, or exam [21]. Mastery learning evaluation metrics can include homework, quizzes, exams, labs, projects, or in-class activities. The number of times a student is allowed to repeat the assessment, i.e., retake opportunities, depends on the particular implementation of mastery learning; in principle, students should be allowed to perform retakes as many times as necessary to achieve 'mastery.' Achieving mastery does not necessarily mean that a student completed an assessment at a 100% level but has met the established level of mastery set by the instructor (e.g., 80% or higher; [22]).

Mastery learning evaluations can be thought of as formative feedback. A course that teaches for mastery should provide students feedback on each ML evaluation to promote improvement on subsequent retakes. The level of feedback that a student receives can range from simple feedback indicating the correctness or incorrectness of an answer to more profound guiding feedback that helps the student improve a section of a learning outcome, specification, or competency.

(3) Grading for mastery is a broad umbrella term that can include different types of grading approaches, i.e., specification grading [23, 24], and competency grading [25]. Campbell et al. [24] affirmed that mastery grading is an umbrella term for a grading system that creates clear learning objectives, specifications, or competencies, removes the point system by assessing mastery demonstrated or not demonstrated, and allows multiple attempts to demonstrate mastery. Mastery grading is designed to structure the course to remove penalty on failed attempts and not abide by a standard learning pace. Traditional grading schemes encourage students to adopt a strategy of "grade-grubbing," which promotes strategies of earning enough partial credits to pass the course, requesting extra credit to obtain a specific grade, protesting "unfair" grades, etc. The "grade-grubbing" strategy does not motivate students to master the course content [3]. A hallmark feature of mastery grading is the ability for students to have multiple retake opportunities to achieve mastery of the objective. Achieving "mastery" of the material is defined by the course instructor, but fundamentally it relies on a grading system that removes partial credit and only awards credit to students who demonstrate they have reached "mastery" of specific learning outcomes, specifications, or competencies. A grading scale of "mastery demonstrated" to "no mastery demonstrated" eliminates partial credit, as research has shown partial credit does not equate to acquired proficiency in the course content [3].

1.2 Need for this Systematic Review

Implementing new assessment strategies can be a daunting task for engineering educators. Often those seeking different strategies are unsure how to apply the approach or if students will react favorably to the new approach. The lack of coherent evidence of the effectiveness of different assessment strategies can also dissuade engineering educators. Many articles have been published implementing mastery learning in undergraduate engineering courses; however, their implementations or approaches vary. The variability in determining how mastery is evaluated can confuse educators seeking to apply a mastery learning approach to their course. Moreover, educators seeking to spend significant time and effort restructuring their course to focus on mastery learning may be hesitant due to an insufficient understanding of the efficacy of the pedagogy. Therefore, this systematic review aims to provide educators with an overview of how different engineering instructors have applied mastery learning to their undergraduate courses and how this approach has affected students' performance.

2. Methods

This investigation aims to uncover how mastery learning has been implemented in undergraduate engineering courses, the student outcomes that have been reported, and the feedback faculty have shared. Before beginning a formal systematic literature review, the authors conducted a high-level literature review to ascertain the quantity and the type of articles found on mastery learning implementations in undergraduate engineering courses. The preliminary review yielded several sources that fit our scope, indicating there would be sufficient sources to warrant employing the systematic review ([26, 27]). This paper used the methodology proposed by [26] for conducting systematic literature reviews: (1) deciding to do a systematic review; (2) identifying scope and research questions; (3) defining inclusion and exclusion criteria; (4) finding and cataloging sources; and (5) synthesizing. Borrego et al. [26] introduced the method for conducting systematic literature reviews in engineering education and adapted sources on systematic literature reviews originally meant for other fields.

2.1 Framing the Research Questions

The EPPI-Centre [28], a center based in the University College of London focused on research synthesis and use, advises systematic reviewers to conceptualize research questions appropriately as they will guide the rest of the systematic review process. In this article, we crafted the research questions to guide the investigation toward discovering how mastery learning has been applied in undergraduate engineering classrooms, understanding the student outcomes measured in those classrooms, and exploring the faculty feedback delivered regarding each mastery learning implementation. The research questions were framed using the PICO framework (Population, Intervention, Comparison, Outcomes; [26]). The PICO framework helps ensure that the relevant parameters are used in the design of research questions and the later stages of the process. In our use of the framework, the *population* to be investigated were students in undergraduate engineering classes. The *intervention* studied was the application of mastery learning to undergraduate engineering courses. The *comparison* are courses equivalent to ML courses that did not employ the mastery learning approach. However, even if studies did not have or report a control group, they were still included in the analysis. The *outcomes* to be studied were the types of implementations reported, the student outcomes reported, and the faculty feedback described.

2.2 Search Strings

The titles and abstracts of a sample of papers that used a mastery-based approach were surveyed to understand the nomenclature. The nomenclature we observed were 'mastery-based testing,' 'mastery based assessment,' 'mastery grading,' and 'mastery learning.' Thus, we determined that the initial list of root search strings would be 'mastery based' and 'mastery learning.' We use eight databases to search for sources relevant to our systematic review. Specifically, we utilized three subject databases (i.e., Education Full Text (EBSCO), Engineering Village, IEEE Xplore), two journal databases (i.e., Science Direct, ASEE PEER database), and three general databases (i.e., JSTOR, Scopus, Google Scholar).

Specifications grading and competency grading are approaches to grading that focus on mastery learning. A preliminary search revealed that 'specifications grading,' 'specifications testing,' and 'specifications based' should also be included as root phrases. To complement the mastery-based search root phrases, we also included the following in our search: 'competency grading,' 'competency testing,' and 'competency based.' The final list of root phrases employed in our search for sources can be found in Table 1.

In most of the search strings employed, we used a root search phrase, and, in other cases, we attached the keywords 'STEM,' 'science,' 'engineering,' and 'math.' The words 'STEM,' 'engineering,' 'science,' and 'math' were included so that courses labeled 'STEM,' 'engineering,' 'science,' and 'math' but

Table 1. Root search strings employed

'Mastery based'*	'Competency based'*
'Mastery learning'	'Competency grading'
'Specifications based'*	'Competency testing'
'Specifications grading'	
'Specifications testing'	

* For all databases, searching strings with hyphen (e.g., 'mastery-based') and without hyphen (e.g., 'mastery based') produced equivalent results.

that focused on engineering were not accidentally omitted. We searched for articles using the root phrases in the title, abstract, and keywords. For each database, we applied the following rules: (1) if searching for the root phrases yielded less than or equal to 25 sources each, *all* sources were included in the title and abstract review, and (2) if the databases yielded more than 25 sources, additional search words (i.e., 'STEM,' 'engineering,' 'science' and 'math') were added to the search, and those resulting articles were reviewed. The search for 'mastery grading' yielded less than 22 sources in each database; therefore, all those sources were included in the title and abstract screening. The ASEE PEER and IEEE Xplore databases are engineering databases; thus, only the root phrases were needed.

In the SCOPUS and Engineering Village databases, the search strings '"specifications based" AND engineering,' '"specifications based" AND science,' '"competency based" AND engineering,' and '"competency based" AND science' each produced more than 100 sources. Therefore, it was necessary to apply other filters to reduce the number of outputted sources. In cases where the search string produced more than 100 sources, we added the word 'education' to the search string. If the output exceeded 100, we added the word "undergraduate" to the search string. In all cases, these additional filters produced less than 100 sources. After compiling all the articles, we moved to our first title and abstract screening.

2.3 Inclusion and Exclusion Criteria

The total number of articles that met the inclusion criteria in their title or abstract in the eight databases was n = 1702. In the first iteration of the screening process, we examined the title and abstract of each paper. Articles were removed from further review if they violated one of the 17 exclusion criteria. The exclusion criteria can be found in Fig. 1. For example, articles were excluded if alternative methods besides mastery learning were incorporated into the course (i.e., flipped classroom and project-based learning). An article was removed from further analysis if the study did not discuss a mastery learning implementation or student learning outcomes. If the course was a Massive Open Online Course (MOOC), had online lecture components, or was a mobile game learning system, it was eliminated from the screening. If data for the study was collected for only part of the semester, the study was eliminated from the list. If ML was applied to only a portion of a course, for example, a laboratory, the study was removed from the list. If the study was performed on non-human subjects, it was removed. The article was only accepted if the abstract or full-text could be obtained. Other criterions used to eliminate articles include: duplicate, the population of study was outside the scope of the investigation, the article was a literature review, the focus of the study was a non-STEM course, etc. Journal manuscripts, practitioner articles, and full conference papers were considered, while work-in-progress papers were excluded.

2.4 Cataloging Sources

Fig. 1 shows the screening process and the reason articles were excluded from further review. The process began when sources were obtained through the eight databases and ended with 23 articles to be synthesized. In the first title and abstract screening, 1633 sources were screened out, and 69 were left as sources that would go on to the next step in the screening process. The next step in the screening process was a secondary title and abstract screening. The inclusion and exclusion criteria followed was the same as for the first title and abstract screening step. A second title and abstract screening process was undertaken as a quality check to verify that sources that passed through the first screening process satisfied the inclusion/exclusion criteria. The secondary screening process excluded 23 sources. Forty-six sources were left to undergo the full-text appraisal. In the full-text appraisal, each article was read to ensure it met the inclusion/exclusion criteria. The exclusion criteria were similar to the criteria used in the title and abstract screening process.

An additional exclusion criterion was added to the full-text appraisal: outside of the engineering field. Eleven papers were excluded because they were unrelated to engineering classes and were related to mathematics, physics, and science classes. The study [29] passed all screening stages and was rejected in the full-text appraisal. Mirth [29] was rejected because it did not report using a list of learning units that reflected the material to be covered in the class and on which to base ML assessments. The final number of papers that passed the full-text appraisal and were synthesized was 23.

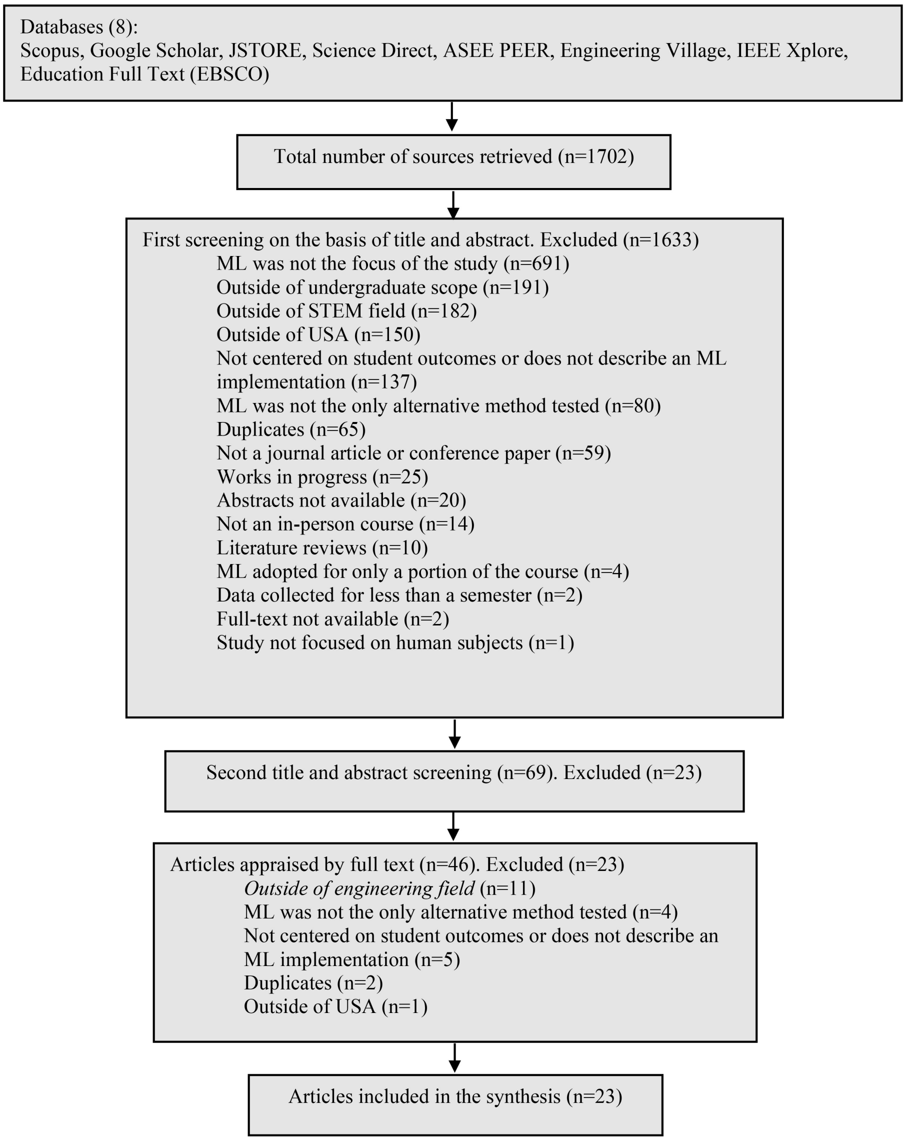

Fig. 1. Flow chart of article screening procedure.

3. Results

In several studies, we found that mastery learning was implemented across multiple courses either during the same semester or across multiple semesters but reported in one article. For example, Sanft et al.'s [30] study implemented mastery learning in five different computer science courses between Fall 2018 and Spring 2020. While in two other publications, the authors describe their mastery learning implementation of three different engineering courses, Statics, Dynamics, and Deformable Solids, together (e.g., [13, 31]).

The studies by Ranalli and Moore [14] and Moore and Ranalli [32] are thought to describe the same implementation. Moore and Ranalli [32] describe student opinions and student grades, while Ranalli and Moore [14] focus on instructor experiences. Moore's [33] implementation is very similar to Ranalli and Moore's [14] and Moore and Ranalli's [32] implementation. The difference is discussed in the Thermodynamics subsection. In Kelley [18], it was not clear how many courses or the types of courses that used mastery learning. Instead, Kelley [18] described a departmental-wide effort to implement several forms of mastery learning in their curriculum. Since the courses that employed mastery learning was unknown, we didn't add any of Kelley's [18] implementations to the count.

In the following sub-sections, we synthesize and organize the information gathered from the 23 sources based on our four research questions. First, we review how mastery learning has been implemented in undergraduate engineering courses in the US. We describe some of the main features in the implementations and group their discussion according to the course, discipline, or common themes. Second, we discuss students' learning outcomes (i.e., exam grades, course grades, etc.) that were reported. Third, and where possible, we examine data about students' experiences. Lastly, we report on the instructor's feedback and recommendations found in the final list of sources. The instructor feedback is organized into benefits and limitations of ML, and we discuss the popular benefits or limitations of ML implementations.

3.1 Implementation of Mastery Learning in Engineering Courses (RQ 1)

Twenty-three published studies applied mastery learning to their engineering courses (i.e., [13–16, 18, 30–47]). To help describe the variety of course implementations, the implementations were grouped based on salient commonalities and are presented as subsections. Studies that implemented mastery learning in the same course topic are grouped and discussed, i.e., Statics, Dynamics, and Thermodynamics. While implementations that did not have the same courses were instead grouped based on a common engineering disciplinary curriculum (i.e., mechanical engineering) or a common general course theme (i.e., programming courses, design courses, and computer-based implementations).

Across the different groupings, the implementations are further examined and discussed using three characteristics: (1) the evaluation metric used, (2) the number of retake opportunities given, and (3) the student feedback provided by instructors. These three characteristics may be thought of as the DNA of the implementation. Practitioners that plan to implement ML in their undergraduate engineering courses must choose among a set of options from each of these three characteristics. Two other important characteristics of mastery learning implementations are the difficulty of retakes and the point worth of retakes. Each instructor can gradually increase the difficulty of retake opportunities to encourage students to attain a mastery score on the first or second attempts. Additionally, each subsequent retake opportunity can decrease in value to discourage multiple retakes and encourage achieving mastery more quickly. However, these two characteristics were only discussed in a few studies. In what follows, we only mention the difficulty of retakes and points worth of retakes when a study reports them.

Table 2 provides an overview of the courses where mastery learning was implemented and the evaluation metrics used for each course. The subsections that follow are implementation descriptions and include features of each implementation that shed light on the different strategies used. In some cases, the mastery learning implementation cannot be described across all three categories since there is considerable variability in the details reported. The variation among the ML implementations discussed may be a result of the inclinations and preferences of the instructors; however, the reasons for their preferences are not described in the published studies. The following subsections provide an overview of how ML was implemented in the various courses and the characteristics of the implementations.

3.1.1 Statics Implementations

Mastery learning was implemented in four different Statics courses (i.e., [13, 31, 36, 46, 47]). Hjelmstad and Baisley [13]; Baisley and Hjelmstad [31] described their Statics ML implementation in two separate publications and therefore are referenced as a set. Mastery of course learning objectives were evaluated through exams in 3 implementations (i.e., [36, 46, 47]), and through assessments and a final exam in 1 implementation (i.e., [13, 31]).

In Hjelmstad and Baisley's [13, 31] implementation, students accumulated points by achieving passing or near-passing scores on assessments and questions in the final exam. Assessments were similar to homework or recitation problems, and each assessment evaluated students on specific learning objectives. Hjelmstad and Baisley [13, 31] provided students with 11 opportunities to achieve mastery of each objective. Students were given an assessment consisting of a simple problem every other week, and each assessment activated many if not all, objectives. Thus, students had multiple opportunities to respond to each objective in a semester. Craugh [36], implemented mastery learning in 3 sections of Statics, while in the same semester, 11 other sections of Statics were taught using a traditional format. Mastery learning was implemented in 5 exams, and each problem on the exam was graded as either "A-level," which indicated correct or almost correct, or "try again" or "R," which indicated retake. Students only retook problems for which they had not achieved a minimum level of competency. Students at Craugh's [36] institution had a free 35-minute period after their Statics class ended and the next class began. The instructors used the 35-minute period to administer the exam retakes. Sangelkar et al. [47] evaluated students' mastery of course learning objectives through 6 exams. Each exam consisted of 2 to 3 problems corresponding to a learning unit to be mastered. The retake exam opportunities were designed to test the same concepts as the first exam, with some complexity removed. Although Sangelkar et al. [47] did not state why the retake

Table 2. Mastery learning implementations and the specific mastery evaluation metrics used in each course

					Planning for Mastery: Evaluation metrics used across studies					
Source	**Courses**	**Discipline mentioned in Articles**	**Semester(s) & sections**	**Method of Delivery**	**Exam**	**Final Exam**	**Quiz/ Assessment**	**Home-work**	**Class activity**	**Project**
[13, 31]	Statics	Civil, Mechanical, and Aerospace Engineering	Fall 2019; Spring 2020; Fall 2020 (did not specify section count)			X	X			
[36]	Statics	Civil, Mechanical, and Aerospace Engineering	Fall 2015 (3 sections)		X					
[47]	Statics	Civil, Mechanical, and Aerospace Engineering	Fall 2013 (6 sections)		X					
[46]	Statics and Mechanics of Materials[1]	Mechanical, and Aerospace Engineering	Fall 2019 (1 section)		X					
[38][2]	Dynamics	Mechanical, and Aerospace Engineering	2016; 2017; semester or sections not specified		X	X				
[13, 31]	Dynamics	Mechanical, and Aerospace Engineering	Spring 2017; Fall 2017; Spring 2018; Fall 2018; Spring 2019; Fall 2019; Spring 2020; Fall 2020 (did not specify section count)			X	X			
[41]	Dynamics	Civil and Mechanical Engineering	Did not specify		X		X			
[14, 32]	Dynamics	Mechanical Engineering	Spring 2014 (2 sections at different institutions)					X		
[41]	Thermodynamics	Mechanical Engineering	Did not specify		X		X			
[44]	Thermodynamics		Spring 2019 (1 Section)				X			
[14, 32, 33]	Thermodynamics	Mechanical Engineering	Fall 2013 (1 section) Spring 2014 (2 sections at different institutions)					X		
[33]	Strength of Materials	Mechanical Engineering	Spring 2015 (1 Section)					X		
[41]	Fluid Mechanics	Mechanical Engineering	Did not specify		X		X			
[37]	Vibration Analysis	Mechanical Engineering	2019		X	X				
[13, 31]	Deformable Solids		Spring 2017; Fall 2017; Spring 2018; Fall 2018; Spring 2019; Fall 2019; Spring 2020; Fall 2020 (did not specify section count)			X	X			
[15]	Circuit Analysis I and Circuit Analysis II	Electrical and Computer Systems Engineering	Fall 2006; Fall 2007	Computer-based	X					
[16]	Signals and Systems	Electrical Engineering	Fall 1999 (did not specify section count)	Computer-based				X		
[45]	Introduction to Circuits Analysis	Electrical Engineering Technology	Fall 1998 (did not specify section count)	Computer-based				X		
[42]	Structural Design in Reinforced Concrete	Civil Engineering	2016-2017; 2017-2018 (did not specify semester or section count)	Computer-based			X			
[35]	LabVIEW Programming	Engineering- electrical systems concentration	(1 section)		X		X		X	X
[30][3]	Intro Programming for Web Application	Computer Science and Non-CS majors	Fall 2018; Spring 2019; Fall 2019; Spring 2020 (1 section each semester)					X		X
	Data Structures	Computer Science	Spring 2020 (2 sections)					X		X
	Algorithms	Computer Science	Spring 2019; Fall 2019; Spring 2020 (1 section each semester)					X		X
	Cybersecurity	Computer Science	Spring 2019; Spring 2020 (1 section each semester)					X		X
	Systems	Computer Science	Fall 2018; Fall 2019 (1 section each semester)					X		X
[18]	Engineering Graphics, Drafting, and Computer Aided Design [4]	Engineering Graphics Technology	Did not specify					X		X
[43]	Systems Analysis and Design	Computer Science and Software Engineering	Fall and Spring capstone course from 1990-1995 (did not specify section count)							X
[39]	First-Year Engineering	Biomedical Engineering	Fall 2019 (did not specify section count)					X		X
	Senior Design	Aerospace Engineering	Fall 2019; Spring 2020 (did not specify section count)							X
[35]	Environmental Engineering	Environmental Engineering	Fall 2010 (1 section)		X		X		X	X

Table 2. *Continued*

Source	Courses	Discipline mentioned in Articles	Semester(s) & sections	Method of Delivery	Planning for Mastery: Evaluation metrics used across studies					
					Exam	Final Exam	Quiz/ Assessment	Home-work	Class activity	Project
[35]	Engineering Statistics	All engineering disciplines	Fall 2010 (1 section)		X		X		X	X
[39]	Biomedical Engineering Statistics	Biomedical Engineering	Fall 2019 (did not specify section count)		X			X		
[40]	Bioelectricity	Biomedical and Electrical Engineering	Fall 2018 (1 section)		X			X		
[34]	Operations Research	Industrial Engineering	Fall 2000; Fall 2001 (1 section)		X					

[1] At this institution, Statics is taught in combination with Mechanics of Materials, while at other institutions Statics is typically a prerequisite to follow-up topics.
[2] Similar to the Hjemlstad and Baisley [13] and Baisley and Hjemlstad [31] implementation here students had to accumulate points on a number of skills. Skills were evaluated in exams.
[3] In addition, ML was also implemented to labs that included small to moderate programming tasks.
[4] Kelley [18] does not describe in what courses ML was implemented but states the courses belonged to the theme of Engineering Graphics, Drafting, and Computer Aided Design.

opportunities were simplified, it is possible that the instructors were encouraging students to attain a mastery grade. Ritz et al.'s [46] degree program combines topics from Statics and Mechanics of Solids in the same course; thus, their course learning objectives differ from the previously discussed implementations. Ritz et al. [46] evaluated students' mastery of course learning objectives through two exams. The original exams were held outside of class time in 90-minute evening sessions. For the exam retake opportunities, students were only allowed to retake portions of the exam due to time constraints. Exam retakes were held during 50-minute class times, and class times were shorter than the time allotted for the regular exam. The retake opportunities covered the same content as the original exams but with new problems. The original exams and retakes were graded on correctness or incorrectness; students received either 0% or 100% on each problem. These allowed one professor and a TA to grade over 100 exams in less than two hours. Students had the opportunity to review the graded exams, and if they determined that they had made minor mechanical errors, they could request a regrade of 80%.

In three implementations (i.e., [36, 46, 47]), students were given two retake opportunities for each exam. Providing two retake opportunities appears to be an adequate number of opportunities for students to achieve a 'mastery' grade and reduce the amount of grading. At the same time, Hjelmstad and Baisley [13, 31] had 11 opportunities to demonstrate mastery without punishing students for failed attempts. Their usage of retakes accomplished the same goal: to give opportunities to demonstrate mastery without deducting points for failed attempts.

Two studies (i.e., [46, 47]) did not change the level of difficulty for subsequent retake opportunities, whereas 1 study reported decreasing the level of difficulty for subsequent retake attempts [36]. Hjelmstad and Baisley [13, 31] did not mention changing the difficulty level of the retake opportunities. In contrast, both Craugh [36] and Sangelkar et al. [47] awarded fewer points to students who needed the retake opportunities. While they did not provide a reason for reducing points on retake opportunities, it may be that they were trying to incentivize students to reach mastery on the first attempt. Hjelmstad and Baisley [13, 31] and Ritz et al. [46] did not provide information on the point worth of retakes.

The feedback provided to students focused on the correctness or incorrectness of problems in Ritz et al.'s [46] and Sangelkar et al.'s [47] implementations. While in Craugh's [36] implementation, students had to schedule a meeting with the instructor before the 3rd retake to discuss the issues they were having with the assessment. In Hjelmstad and Baisley [13, 31] students were provided two types of formative feedback. The first type of feedback was a Mastery Assessment letter detailing the mastery objectives and how the student performed on each objective. The second type of feedback was a dashboard, a set of charts documenting a student's performance in all aspects of the course including computing projects, homework, and mastery objectives.

3.1.2 Dynamics Implementations

Four studies implemented mastery learning in Dynamics courses (i.e., [13, 14, 31, 32, 38, 41]). Ranalli and Moore [14] and Moore and Ranalli [32] describe the same Dynamics and Thermodynamics implementations and are therefore referenced as a set. Specifically, Ranalli and Moore [14] focus on the experience of faculty who implemented mastery learning, while Moore and Ranalli [32] describe student opinions and grades. Students' mastery of course learning objectives were evaluated through exams and a final exam in [38], through quizzes at the end of class or as part of traditional exams in [41], through homework assignments in [32]; [14] and in assessments and a final exam in [13]; [31].

In Hjelmstad and Baisley's [13, 31] implementation, students earned points on learning units by achieving passing or near-passing scores on assessments and questions in a final exam. The assessments were similar to homework or recitation problems, and students could earn points on multiple objectives by achieving a passing or near-passing score on an assessment. There were 11 opportunities to respond to each objective. Many opportunities to respond to each objective were available because each assessment targeted multiple if not all, learning objectives. In DeGoede's [38] implementation, students were given multiple opportunities to demonstrate mastery in a set of 11 pre-defined course skills analogous to learning units. DeGoede's [38] structure of providing students opportunities to demonstrate mastery on a predetermined set of learning units was similar to Hjelmstad and Baisley's [13, 31] implementation. DeGoede [38] allowed students to demonstrate mastery of skills in four exams and a final exam. Students demonstrated mastery of a skill by earning a score of 4.5/5.0 or 5/5.0 on a single test problem. By the end of the semester, students had 10 opportunities to demonstrate mastery of a skill. To allow 10 opportunities to demonstrate mastery of a skill, it is possible that exam problems tested more than one skill, although this was not clearly stated. Hochstein and Perry [41] implemented a mastery learning approach where students needed to pass a set of competencies. Competencies are targeted statements about what students should be able to perform (e.g., the ability to apply Newton's Second Law and solve a problem about particle kinematics) and are similar to learning objectives. Students were given 4 to 6 competency quizzes per semester. Each competency was assessed via a 10-minute quiz at the end of the class or in traditional exams. When a competency quiz appeared in a traditional exam, the competency problem was graded using partial credit as part of the traditional exam. It was also graded as a pass/no pass to satisfy the competency requirement in that topic area. Moore and Ranalli [32, 14] evaluated mastery through homework assignments. Problems from the textbook were assigned weekly; each assignment consisted of approximately 3–5 problems. The assignments would be graded and returned to the student within one week. Students were then given one week to resubmit an assignment. For problems 'not mastered,' students would rework these problems on a separate sheet of paper and staple that paper to the original assignment. The instructor would regrade the resubmissions and return them to the student. Students could repeat this process until they had 'mastered' all problems or until they had failed to resubmit by the deadline.

Regarding the maximum number of retake opportunities allowed in each study, in Hochstein and Perry [41], two retakes were given for each mastery learning assessment. In DeGoede [38], up to 10 opportunities were given to demonstrate mastery of a skill. Similarly, in Hjelmstad and Baisley's [13, 31] implementation there were 11 opportunities to master each objective. Following the spirit of unlimited attempts in mastery learning, Moore and Ranalli [14, 32] allowed for an unlimited number of retakes. Moore and Ranalli [32] reported that, in practice, students needed a maximum of two retakes to master all problems.

Moore and Ranalli [14, 32] both delivered feedback to students one week after the assignment was collected, and the feedback concerned how to correct the mistakes made on the assignments. Hjelmstad and Baisley [13, 31] provided students with two types of formative feedback: a Mastery Assessment letter and a feedback dashboard. The dashboard was a set of charts that documented a student's performance in computing projects, homework, and mastery objectives. Neither Hochstein and Perry [41] or DeGoede [38] reported the feedback style used in their implementations; however, it is likely that some feedback was delivered to students.

3.1.3 Thermodynamics Implementations

Mastery learning was implemented in Thermodynamics courses in 4 cases (i.e., [14, 32, 33, 41, 44]). Ranalli and Moore [14]; Moore and Ranalli [32] discuss the same Thermodynamics implementation, however each article focuses on different results. Moore's [33] implementation is similar to that discussed in Ranalli and Moore's [14, 32] implementation, any differences are described below. Students demonstrated mastery of the course learning objectives through homework assignments in Ranalli and Moore's [14, 32] and Moore's [33] implementations, through quizzes in Okamoto's [44] implementation, and through quizzes administered at the end of class or as part of traditional exams in Hochstein and Perry [41].

Hochstein and Perry [41] implemented mastery learning through an approach where students needed to pass a set of competencies or learning units. Competencies were learning objectives that students needed to achieve, such as apply the First Law of Thermodynamics to a problem involving a closed system or an open system. To show mastery of the specified competencies, students were given 4 to 6 quizzes per semester, administered during the last 10 minutes of the class, and traditional exams. If a competency problem appeared in a traditional exam, the problem was graded twice. The problem was graded once using partial credit and was included in the grade of the traditional exam, and it was graded a second time using a 'pass' or 'no pass' system to evaluate whether the student met the competency in that topic area. Hochstein and Perry [41] imply there were grades for the traditional exams and the competency quizzes, however, they do not explain how these grades combined to give 1 grade for the course. Okamoto [44] evaluated students' mastery using quizzes for each learning unit. Students could take two quizzes per week. A quiz was scheduled for 20–30 minutes of a 100-minute class. Students were not allowed to take quizzes from the next learning unit until they passed the quizzes from the previous learning unit with a score of 88% or more. Quiz retakes could be done in the last 20–30 minutes of class on days when no quizzes were scheduled. Moore and Ranalli [32, 14] assigned weekly problems from the textbook to evaluate mastery. Each assignment contained 3–5 problems. The assignments were graded as 'complete' or 'incomplete' and returned to the student within one week. After receiving the graded assignment, students were given one week to resubmit. Students that needed to resubmit certain problems were still required to include the original submission. All students could continue to resubmit problems until they had achieved a 'complete' score on all problems or until they had failed to resubmit by the deadline. Moore [33] made minor modifications to the implementation compared to what was discussed in Moore and Ranalli [32, 14]. In Moore's [33] implementation, assignments were graded based on the rubric: Mastered, Not Mastered, Not Attempted. It is likely that the implementation published by Moore [33] only modified the grading rubric to accommodate those who did not attempt the assignments, which is in contrast to the rubric described in Moore and Ranalli [32]; [14].

In three studies, the number of retake opportunities was unlimited (i.e., [14, 32, 33, 44]). An unlimited number of retake opportunities exemplifies the spirit of mastery learning as it assures students that they can attain a mastery grade if they keep trying to fulfill the assignments. Hochstein and Perry [41] provided 4–6 competency tests per semester where students could demonstrate their mastery over a set of competencies. Hochstein and Perry [41] did not report how many opportunities students had to demonstrate mastery for each competency, but implied they had more than one opportunity. For example, when describing their Fluid Mechanics implementation in the same publication, Hochstein and Perry [41] stated that students had two retake opportunities thus we conjecture the same number of retakes were given in the thermodynamics implementation.

Neither Hochstein and Perry [41] nor Okamoto [44] report on the feedback style of their implementations. It is possible that the authors did not consider the feedback delivered to students to be an essential component of mastery learning, or perhaps they considered it important and implemented it but did not report it. Moore and Ranalli [32, 14] simply stated that they delivered feedback to help students correct mistakes. While Moore [33] gave corrective feedback to students who received a grade of 'Not Mastered,' no further detail was provided regarding the approach used to provide student feedback.

3.1.4 Implementations in Mechanical Engineering courses

Mastery learning was implemented in 5 mechanical engineering courses: Deformable Solids [13, 31], Strength of Materials [33], Mechanics of Materials [46], Fluid Mechanics [41], and Vibration Analysis [37]. Mastery was evaluated using exams in Mechanics of Materials, through exams and the final exam in Vibration Analysis, through quizzes or traditional exams in Fluid Mechanics, through homework in Strength of Materials, and in assessments and a final exam in Deformable Solids.

In Hjelmstad and Baisley's [13, 31] Deformable Solids implementation, students had to achieve passing or near passing scores on assessments and in questions in a final exam. Students could earn points on multiple learning units by achieving a passing or near passing score on a single assessment. The assessments were similar to homework or recitation problems. There were 11 opportunities to respond to each learning unit. There were many opportunities to respond to each learning unit because each assessment engaged multiple learning units. In Moore [33], where mastery learning was applied to a Strength of Material course, students were assigned homework from the course textbook, and the homework was due on a weekly basis. After the homework was collected the instructors graded the assignment giving them one of three marks for each submitted problem: Mastered, Not Mastered, and Not attempted. The assignments were returned to students within one week after submission and they were given one week to resubmit retakes to problems graded 'Not Mastered.' The resubmissions were stapled to the original assessment, thus enabling a record of feedback and submissions. Ritz et al. [46] implementation in a Mechanics of Materials course used two exams to evaluate course learning objectives. The first exam attempt was held during a 90-minute evening session outside of class time. Exam retake opportunities were held during 50-minute class times which were shorter than the time allotted for the regular exam, thus students were only allowed to retake portions of the exam. The retakes tested the same content as the original exams but used new problems. The first exam attempt and the retakes were graded on the correctness or incorrectness of problems. Students received either 0% or 100% on each problem. However, upon reviewing the graded exams, if a student determined that they had made only minor mechanical errors they could request a regrade of 80%. In Ritz et al.'s [46] implementation, course content for Statics and Mechanics of Materials were taught in the same course. In Hochstein and Perry's [41] Fluid Mechanics mastery learning implementation, students needed to pass a set of competencies or learning units. Competency quizzes were given 4 to 6 times per semester. The quizzes were administered during the last 10 minutes of class or in traditional exams. Competency quizzes that appeared in traditional exams were graded twice: the competency quiz was graded with partial credit once as part of the traditional exam and a second time through pass/no pass grading system to fulfill the competency for that area. In their implementation, there was a grade for the traditional exams and a grade for the competency quiz, however they do not explain how they aggregated the grades to evaluate students' mastery of the learning objectives [41]. DeGoede's [37] Vibrations Analysis course used 4 exams to evaluate mastery. Each exam had a 'proficiency portion' and a 'mastery' portion. The 'proficiency' portion assessed the core competencies of the unit. The purpose of the proficiency portion of the exam was to ensure that all students had knowledge on the core competencies before moving to subsequent learning units. Students were allowed to perform retakes on the proficiency portion of the exam. The mastery portion assessed open-ended questions about analysis, synthesis and evaluation, and students could retake mastery assessments on the final exam.

In the Fluid Mechanics [41] and Mechanics of Materials courses [46], students had 2 opportunities to retake each test or exam while in the Strength of Materials course [33], students had unlimited opportunities to submit retakes for homework. In the Vibration Analysis course [37], students were given 3 retake opportunities on exam 1, 2 retake opportunities on exam 2, 1 retake opportunity on exam 3, and only 1 opportunity on the last exam. The retake opportunity system implemented in the Vibration Analysis course allowed students to reattempt proficiency portions from previous exams on upcoming exams. For example, for students who had to reattempt exam 1, there were three other exams where the retake could take place. In Hjelmstad and Baisley's [13, 31] Deformable Solids course, students had 11 opportunities to demonstrate mastery of specified learning units.

Regarding the feedback distributed by instructors, for Mechanics of Materials [46] students were given information about the correctness or incorrectness of problems, and for Strength of Materials [33] students who didn't receive a 'mastery' grade were given written feedback designed to help them correct errors and guide them to the correct solution. Hochstein and Perry [41] and DeGoede [37] did not describe their feedback style. Among all the implementations, Hjelmstad and Baisley [13, 31] provided the most detailed feedback. Specifically, students were provided a Mastery Assessment letter detailing mastery objectives and a 'dashboard' with documentation of a student's performance on computing projects, homework, and mastery achieved in each learning objective.

3.1.5 Computer-based Implementations

Four studies evaluated mastery learning using assessments delivered through computer-based software (i.e., [15, 16, 42, 45]). Green [16] implemented mastery learning in a Signals and Systems course. Paull et al.'s [45] implementation was in an Electrical Engineering Technology Circuits course. Leonard et al. [15] implemented mastery learning in a one-year sequence of Circuits I and II courses. Lastly, Lovell [42] implemented mastery learning in a Structural Design in Reinforced Concrete course. Green [16] and Paull et al. [45] evaluated mastery through homework assignments, Leonard et al. [15] used exams, and Lovell [42] evaluated mastery using quizzes.

Green [16] used the MATLAB Webserver in a Signals and Systems course to assign homework problems. Homework assignments were individualized to students, problems were given one week before the due date, and the parameters of the problems changed every time a retake was requested. This approach appears to be a more customizable, streamlined way to evaluate mastery. Paull et al. [45] also used an online homework system in their Electrical Engineering Technology Circuits course to evaluate mastery. For this course, the software used was Test Pilot, a Java-based authoring program. Homework problems were created, administered, and graded online. Students could practice solving problems related to the homework an infinite number of times. Following the practice problems, they were expected to demonstrate mastery on a recorded homework set. Students could only record answers in the recorded homework set once. Leonard et al. [15] used exams in a one-year sequence of courses, Circuits I and II, to evaluate mastery. The course material was divided into 16 modules. For each module, students were expected to take a mastery exam. Exams were administered in a monitored computer classroom on campus. Each exam contained ten questions, and a perfect score, analogous to achieving mastery, was required to pass the exam. If a student failed the exam, they were able to retake the exam with newly generated questions. Online practice modules were available, but students did not receive course credit on the practice problems. Students were encouraged to practice for two hours before making a mastery attempt. In the practice modules, after each question, students were given feedback in the form of the correct answer or sometimes deeper guiding feedback. The database for the practice modules was different from the Mastery database. Lovell [42] evaluated mastery of the learning units through quizzes in his Structural Design in Reinforced Concrete course. Quizzes were administered through a Learning Management System. Five quizzes throughout the semester were delivered to evaluate specified competencies or learning units. Students were required to take a competency quiz during class on even weeks (i.e., week 2 – quiz 1; week 4 – quiz 2, etc.). Retakes of the quizzes were offered in odd weeks of the course (i.e., week 3 – optional retake for quiz 1, week 5 – optional retake for quiz 1 or quiz 2). The quizzes consisted of multiple-choice, true/false, and calculation questions. Each student received a different quiz because each quiz utilized randomly generated numbers. All questions had to be answered correctly to obtain a 'mastery' grade on the quiz.

The maximum number of retake opportunities were consistent across the three studies in this category [15, 16, 45], that is, unlimited retakes were permitted. The instructors took full advantage of the electronic delivery system to ensure that students could achieve mastery. However, in Lovell's [42] implementation, each quiz had a different number of possible retakes due to the even and odd week structure; after each quiz, the retake opportunities decreased by one. That is, in quiz 1, students had 5 retake opportunities; in quiz 2, students had 4 retake opportunities; quiz 3 had 3 retake opportunities, and so on.

All four studies delivered feedback on the correctness or incorrectness of problems immediately after submitting a problem, thus taking advantage of the computer delivery system. In Leonard et al. [15], for the Online Practice modules, deeper guiding feedback was sometimes provided to students through the computer system in the form of common pitfalls or valuable ways of thinking about the context.

Across these implementations, the computer-based tools allowed the instructor to generate many retake problems, grade them and provide feedback immediately. Implementing ML can be time intensive for the instructor because of the need to create retake problems, grade them and provide feedback. Nevertheless, computer-based implementations can automate these tasks saving the instructor time and effort.

3.1.6 Programming or Software-related Courses

Seven mastery learning implementations took place in programming or software-related courses. Bekki et al. [35] implemented mastery learning in a LabView Programming course. Sanft et al. [30] implemented mastery learning in five programming courses such as Intro Programming for Web Application, Data Structures, Algorithms, Cybersecurity and Systems. Lastly, Kelley [18] implemented mastery learning in a series of courses on Engineering Graphics, Drafting and Computer Aided Design. The LabView Programming course assessed mastery learning through exams, quizzes, projects, and in-class activities [35]. In contrast, Sanft et al.'s [30] five programming courses evaluated students' mastery of learning objectives through homework, projects, and labs. Kelley [18] describes a department wide effort to implement mastery learning in Engineering Graphics, Drafting and Computer Aided Design courses. The exact number of courses that adopted mastery learning was not stated; Kelley [18] evaluated students' mastery course learning objectives through assignments and projects.

Bekki et al. [35] divided the course assignments into two categories: evidence assignments and competency assignments. Evidence assignments were homework or in-class activities that prepared students to complete competency assignments and were not counted toward the final grade. Competency assignments, in the form of questions in quizzes, exams, projects, and in-class activities, were based on instructional units that aligned with learning objectives or departmental outcomes. In Sanft et al. [30] implementation, mastery of course learning objectives were evaluated using a 10 or 0 binary rubric on homework, projects, and lab assignments. A score of 10 was given when students satisfied 100% of the requirements, and 0 was given if they did not meet the requirements or submit the assignment. In practice, instructors could grade the assignment as satisfactory, even if minor errors existed. Any student with a score of 0 could resubmit the assignment. Kelley [18] described three types of mastery learning approaches applied to projects and homework; however, the author does not provide specific information when they used the different grading approaches. The first mastery learning approach was called a "Sequential-Objective/Set-Grade" variant. In the "Sequential-Objective/Set-Grade," objectives were specified and charted, and students must sequentially fulfill objectives, as dictated by the instructor, without skipping objectives. There were no set number of times that a student could be evaluated on an objective. The second grading approach employed was termed the "Nonsequential-objective/Set-Grade;" here, students were allowed to fulfill objectives in any order desired. The "Nonsequential-objective/Set-Grade" approach was instituted to accommodate courses where it was unnecessary to achieve objectives in sequential order. This approach used deadlines to incentivize students to achieve all objectives. The third mastery learning approach was termed the "Non-sequential-Objective/Reducing-Grade." This approach is similar to the "Nonsequential-objective/Set-Grade" approach, where students could complete objectives in the order they desired, the difference being that the grade was reduced at each attempt to master an objective. The more attempts students took to complete an objective, the lower the grade they received. Irrespective of the grading approach, students' final grade was based on the number of objectives they achieved.

Across the studies in this category, there were variations in how retake opportunities were administered. Bekki et al. [35] allowed one retake opportunity on a competency assignment with a condition: all evidence assignments associated with the competency had to be attempted before students can take advantage of a retake. In Sanft et al. [30], for each retake, 1 point was subtracted from each assignment. However, Sanft et al. [30] does not describe the maximum number of retakes allowed. While Kelley [18] does not describe the maximum number of retakes permitted in any of the ML approach variants, he does report that the grade of the assignments were reduced as the number of retakes increased when using the Non-sequential-Objective/Reducing-Grade approach.

In this group of studies, Bekki et al. [35] is the only one that provided information on the type of feedback administered. Bekki et al. [35] delivered formative feedback and suggestions for remediation of the failed assignments. Sanft et al. [30] and Kelley [18] stated that they administered feedback but did not detail the type of feedback delivered.

3.1.7 Implementations in Design Courses

We found that mastery learning was also implemented in three design courses: Systems Analysis and Design [43], First-year Engineering [39], and Senior Design [39]. Students' mastery of the learning objectives was evaluated by examining phases of projects in the Systems Analysis and Design course [43], in projects such as documents, presentations, and a poster in the Senior Design course [39], and both homework and portions of a project in the First-year Engineering course [39].

Mukherjee and Cox [43] applied ML to a project class where learning units were defined based on project phases. After the first submission of a project phase, the instructor graded the deliverables and returned the document with feedback. Students then had the opportunity to return the document with the corrections added. This process continued until students achieved a perfect score for that phase, or 'mastery'. The grade of that phase was determined by averaging the scores of the first three submissions of that phase to discourage non-serious attempts. Fernandez et al.'s [39] implementation of mastery learning in a First-year engineering course evaluated mastery of course learning units through homework and portions of projects. In contrast, the Senior Design course evaluated mastery through documents, presentations, and a poster. In their design courses, they implemented a different version of mastery learning called specifications grading. In the specifications grading version, clearly defined specifications are written for each assignment and specifications grading rubrics are created to make a 'B' grade the threshold for 'passing.' Assignments are graded on a satisfactory/unsatisfactory basis, or pass/fail, and tokens are distributed to re-do or erase an unsatisfactory assignment. Additionally, students can earn extra tokens during the semester [39].

There was a stark contrast between the number of retake opportunities Mukherjee and Cox [43] allowed compared to Fernandez et al. [39]. Mukherjee and Cox [43] permitted infinite retake opportunities on all phases of their projects, while Fernandez et al. [39] limited the number of possible retake opportunities by assigning a set number of tokens to students. At the start of the semester, only three tokens were given to the First-year Engineering students, and two tokens were given to the Senior Design students. In the First-year Engineering course, a token could be used to re-do an unsatisfactory assignment or turn in an assignment one week after the due date. In the Senior Design course, students were given one individual token and one group token. The individual token could be used to drop one peer evaluation, an uncommunicated absence, or an individual presentation. The group token could be used to revise a document, a group presentation or the poster. Tokens could be earned through extracurricular activities; it was noted that only a few tokens were given in the First-year Engineering course and the Senior Design course. The small number of tokens given severely limited the number of retakes students could perform. While distributing fewer tokens can reduce the grading load for the instructor, it is in the spirit of mastery learning to allow the students ample opportunities to improve on their mistakes.

The content provided in project documents can vary based on the diverse approaches to a design solution. Thus, the feedback delivered to project phases is expected to be more extensive and time intensive than the feedback given to calculation-based problems. The feedback assigned by Mukherjee and Cox [43] entailed pointing out mistakes, suggesting modifications, and indicating areas where improvement was needed for each document students submitted. In the Senior Design course, Fernandez et al. [39] delivered feedback to students before the document was due. This resulted in student groups with documents that exceeded expectations. However, we could not evaluate the feedback delivery effort taken since Fernandez et al. [39] did not detail the feedback approach used in the design courses.

3.1.8 Implementations in a Potpourri of Engineering Courses

Several mastery learning implementations could not be grouped based on course commonalities. This section describes the mastery learning implementation in a potpourri of engineering courses, including Engineering Statistics and Environmental Engineering [35], Operations Research [34], Bioelectricity [40], and Biomedical Engineering Statistics [39]. In the Engineering Statistics and Environmental Engineering courses, ML was evaluated through exams, quizzes, projects, or in-class activities [35], the Operations Research course evaluated mastery through exams [34], the Bioelectricity course evaluated mastery using homework, exams, concept questions, and practice problems [40], and in Biomedical Engineering Statistics mastery was assessed through homework and exams [39].

Bekki et al.'s [35] Engineering Statistics and Environmental Engineering courses had two evaluation instruments: evidence assignments and competency assignments. Evidence assignments comprised of homework or in-class activities that prepared students to complete competency assignments. Evidence assignments were designed to provide practice on competencies and were not counted toward students' final course grade. Competency assignments were quizzes, exams, projects, or in-class activities aligned with learning objectives or departmental outcomes. In Amarcost and Pet-Armacost's [34] Operations Research course, mastery was evaluated through two exams, yet the authors do not provide further detail regarding the mastery grading approach applied. As shared from other implementations, there are variations in how instructors evaluate mastery, however, it is unclear if Amarcost and Pet-Armacost [34] used a binary pass/fail approach or some other variant. In Helmke's [40] Bioelectricity course, the mastery learning evaluation metrics were homework, exams, concept questions and practice problems using a specifications grading system. Concept questions asked for written responses based on class readings, and practice problems were short numerical problems that helped students answer homework problems or exam problems later. Helmke [40] assessed whether learning objectives were met by evaluating homework, exams, concept questions, and practice problems as bundles. If the student completed the bundle, they would earn the course letter grade related to that bundle. Each bundle was closely mapped to specific course learning objectives. Helmke's [40] publication, in the appendix section, provided a sample of the course syllabus when he describes mastery and, specifically, the specifications grading system used. In Biomedical Engineering Statistics, Fernandez et al. [39] also implemented a specifications grading version of mastery learning to achieve course objectives. Their implementation used a pass/fail grading system on sections of problems instead of problems as a whole and allowed students to redo problems for which they did not get full credit. The grading system for each problem was divided into three parts: setup, calculation, and interpretation. Students could earn 1 point on each part if the work was done correctly, adding up to 3 points per problem. Each homework or test would consist of 3 problems, worth 3 points each, and conceptual questions worth 1 point, totaling 10 points. Fernandez et al. [39] token system allowed students to resubmit assignments up to 3 times during the semester.

Amarcost and Pet-Armacost [34] do not explicitly report how many retake opportunities were given. However, they do state that retakes were scheduled to be within one week or less than the previous retake. As well, retake opportunities were designed to be increasingly more difficult; that is, the longer students waited to retake an exam, the more difficult the exam was. The retake difficulty was based on the difficulty of the last retake offered to the class, not on the difficulty of the previous retake the student completed. A student's exam grade was based on the last retake opportunity; they did not take the average of all attempted retake opportunities nor chose the highest grade. Any student wanting a retake opportunity had to complete a request form acknowledging this grading policy [34]. In Bekki et al.'s [35] Engineering Statistics and Environmental Engineering courses, students were given a second opportunity to retake assessments if they attempted all evidence assignments associated with the competency. This technique was used so that students would have greater practice with the competency before attempting their second try. Helmke [40] provided tokens to students. Each token could be redeemed for any of the following reasons (1) retake a test that was marked as incomplete, (2) retake a homework, concept question, or practice problem that was incomplete requiring students to explain the revisions and what was learned during the revision process, (3) extend a homework deadline by 48 hours, or (4) or automatically grade one concept question or practice problem as 'meets expectations.' Students could only redeem one token per assignment or exam. Additionally, students could earn up to five extra tokens by performing one of two activities, a self-evaluation of their learning or through an evaluation of the learning process through test wrappers. Test wrappers, according to the American Psychological Association, are tools students can use to evaluate their exam readiness and identify strategies to improve on their readiness. In a Biomedical Engineering Statistics [39] course, a token system was implemented that allowed students to resubmit assignments up to three times during the semester. This low number of possible resubmissions severely limited the opportunities for students to take advantage of the mastery learning approach.

Bekki et al. [35], Helmke [40], and Fernandez et al. [39] acknowledged that they provided feedback to students. However, Bekki et al. [35] was the only study, among the group, that provides some detail on the feedback delivered; explicitly stating that students were given feedback on their first competency assignment with suggestions for improvement. While Amarcost and Pet-Armacost [34] emphasized the importance of providing feedback to students in mastery learning implementations, they do not describe the type of feedback provided.

3.2 Evaluation of Students' Learning Gains (RQ 2)

Nine studies in this systematic review reported information about students' overall learning gains (i.e., [15, 32, 33, 36, 38, 40, 44–46]). Instructors used four approaches to evaluate students' learning gains: (1) comparing the mastery learning final exam course grades with equivalent traditional course offerings, (2) comparing rates of learning objectives that were awarded a mastery score against a control group (i.e., a traditional course offering), (3) comparing mastery learning homework grades against a control group, and (4) comparing overall course grades and course passing rates against a control group. Craugh [36] compared final exam grades between the mastery learning section and a control group for students with low previous GPAs. DeGoede [38] compared the percentage of the class who mastered required skills, or "learning units," with a control group, and Moore and Ranalli [32] compared mastery learning homework grades with homework grades from traditional courses. Paull et al. [45] and Leonard et al. [15], who implemented ML through a computer-based format, reported grades and course passing rates and compared them with control groups.

In Ritz et al.'s [46] university, the Statics and Mechanics of Materials topics were taught in one course. Two sections of Statics and Mechanics of Materials courses were compared; one section was taught using the traditional grading method, analogous to a control group, and the other section was taught using a mastery learning approach. The effectiveness of the mastery learning course was evaluated by comparing the grades on the final exam. However, the final exam for both sections were graded using a partial credit grading technique. Ritz et al. [46] concluded that the mastery learning implementation did not lead to significant learning gains, evidenced by the lack of statistical difference in the final exam between the two sections. However, the mastery learning course did show a higher final exam grade than the control group. Moore [33], like Ritz et al. [46], evaluated students' learning gains by comparing final exam grades in two mastery learning courses to final exam grades from two control groups (i.e., traditional courses). Among the two courses, Strength of Materials and Thermodynamics, no significant difference in final exam grades were found when compared against their corresponding control groups [33]. In Okamoto [44], two sections of a Thermodynamics course were taught in the same year; one section used traditional grading, while the other used a mastery learning approach. A traditionally graded final exam was implemented in both sections to evaluate students' performance. The final exam consisted of calculation-based and multiple-choice questions from a published Thermodynamics concept inventory; unfortunately, the author does not include a reference to the concept inventory [44]. The average final exam score for the two sections was similar: 71.9% for mastery learning and 73.5% for traditional sections. Craugh's [36] Statics course sections were conducted at the United States Naval Academy which uses a grading metric called Quality Point Rating (QPR), similar to GPA. Craugh [36] reported that students who enrolled in the mastery learning course with a lower QPR had a better score on the final exam compared to students in the traditional course that entered with similar QPR scores. Thus, students who participated in the mastery learning version of Statics and had a low QPR score benefited the most from the approach.

DeGoede [38] implemented mastery learning in Dynamics courses during the academic years 2016 and 2017. His study compared the results from mastery learning to a traditional course offered in 2014. The comparison was possible because "the exam structure and available records from the 2014 course allowed for retrieval of performance measures from seven of the eleven 2016 [learning] skills," which can be thought of as learning objectives [38, p. 7]. The author calculated a mastery ratio for each course offering. The mastery ratio was an overall percentage value for students who scored 4.5 or higher out of 5 on each required skill. A score of 4.5 or higher was selected because that was the score needed to demonstrate mastery of a skill. In the 2014 traditional offering of the course, the mastery ratio for 3 'primary and required' skills ranged from 42% to 54%, whereas in the 2016 – and 2017 – ML course offerings, the mastery ratios were all above 93%. For 'supplemental' skills, the performance was similar between 2014 and 2016. DeGoede [38] also noted an increase in students' mastery of a skill categorized as supplemental in 2016 but later changed to a required skill in 2017. Specifically, 88% of the class in 2017 obtained mastery compared to 34% in 2016. An apparent increase in the number of students obtaining mastery of primary and required skills can be seen for those enrolled in the ML course (i.e., 2016 and 2017 versus 2014).

Okamoto [44] and Helmke [40] compared the final course grades with those of a control course (i.e., traditional course). The courses differed: Helmke [40] applied a specifications grading version of mastery learning to his Bioelectricity course, while Okamoto [44] applied a competency-based approach to her mastery learning Thermodynamics course. Both instructors noticed a larger number of B-range final grades for students who participated in the mastery learning course compared to the control group. Specifically, in Okamoto's [44] course, the mastery learning section had significantly more B's, 55%, compared to 20% from the traditional grading section. Helmke's [40] final grade percentage in the B-range was approximately 35% in the mastery learning section, compared to 20% in the traditional course. Okamoto [44] found no differences in the percentage of A final grades among two sections but did notice that the mastery learning section had fewer C's, D's, and F's. Conversely, Helmke [40] found that the traditional course offering had more A's than the mastery learning course. No student in Helmke's [40] ML course received lower than a B- while some students in the control course did receive a final grade in the C-range.

Moore and Ranalli [32] evaluated students' mastery of the course learning objectives through homework assignments in their Dynamics and Thermodynamics courses. The same instructors taught these three courses over the academic year and could offer a clear homework grade comparison. They compared homework assignments from the mastery learning courses (i.e., Dynamics and Thermodynamics) against those of two traditional course offerings (i.e., Thermodynamics and Strength of Materials). When examining the homework grades between the two Thermodynamics courses, the mastery learning Thermodynamics course had higher homework grades compared to the homework grade in the traditional Thermodynamics course. The Dynamics mastery learning course also had a higher homework grade than the traditional Thermodynamics and Strength of Materials courses.

In the computer-based mastery learning implementations, two studies reported on students' learning gains (i.e., [15, 45]). Leonard et al. [15] compared grades and course passing rates between a mastery and traditional course one-year sequence of Circuits I and II. They found that 66% of students that underwent the traditional approach before the mastery approach finished the one-year sequence, whereas 77% of students that experienced mastery learning passed the sequence. The study further clarified that most of this effect can be attributed to the performance of minoritized students who, before mastery, had a one-year completion rate of 55% and, after mastery, the completion rate increased to 90%. Out of all the studies included in this systematic literature review, Leonard et al. [15] is the only author who reported learning gains specifically for minoritized students. Paull et al. [45] found that the overall grades for students who received multiple homework retake opportunities through a computerized system were nearly similar to those of a section that did not offer homework retake opportunities. Although some studies showed that mastery learning had minimal impact on students' final exam grades, the approach seemed effective in raising student learning outcomes when considering other metrics.

3.3 Students' Evaluation of their Mastery Learning Experience (RQ 3)

Thirteen studies collected information about student experiences in a mastery learning course through close-ended or open-ended questionnaires. Three studies administered a set of close-ended survey questionnaires to understand students' experience (i.e., [14, 33, 34]). Five collected responses to open-ended questions centered around what the students liked and disliked about the pedagogical approach (i.e., [13, 18, 36, 38, 44]) and five others collected both closed-ended and open-ended question responses regarding the mastery learning implementation (i.e., [30, 35, 40, 46, 47]). All computer-based mastery learning implementations collected data on students' perceptions of their learning, two studies presented results from close-ended and open-ended survey questionnaires (i.e., [42, 45]), and two others discussed students' responses to open-ended questions (i.e., [15, 16]).

3.3.1 Close-ended Survey Responses: Students' Evaluation of ML Experience

Five studies commonly reported that a large percentage of their students perceive that they learn better as a result of participating in mastery learning (i.e., [14, 30, 33, 34, 42]). Armacost and Pet-Armacost [34] reported that "the results overwhelmingly supported the use of the system;" 75% of students in Fall 2000 and 67% of students in Fall 2001 strongly agreed that they learned better through an mastery learning approach [p. 24]. In a follow-up question, Armacost and Pet-Armacost [34] asked students if the retests made it such that students "only learned how to take the [mastery learning] test better" [p. 24]. All students, except one, disagreed or strongly disagreed with that question. When students were asked, "which system do you feel you learn more with," Moore [33] reported that most students responded that they learn "more with mastery" or "a lot more with mastery" [p. 5]. In these studies, students' self-evaluation was such that repeated testing did not merely teach them tricks on test-taking; instead, they reported learning the material better. Sanft et al. [30] posed the following statement, "Compared to traditional grading of assignments, specifications grading helped me learn the material better," and students were asked to rate their level of agreement [p. 40]. None of the respondents disagreed with the statement, indicating an overwhelming endorsement of specifications grading. Lovell [42] measured students' perceptions of their learning gains through the statement, "I have a better understanding of the course material because of the grading scheme," using a five-point Likert scale [p. 10]. In the 2016–2017 course iteration, 60% of students Agreed or Strongly Agreed with the statement, while in the 2017–2018 iteration, the agreement level dropped to 35%. While Lovell [42] did not explain the drop, one explanation might be that students in 2017–2018 did not study the material at the same depth as those enrolled in the course in 2016–2017. In 2017–2018 only 46% of students 'agreed' with the statement that asked if they spent more time studying the material more using mastery learning compared to a traditional course, while the rate of agreement in 2016–2017 was 73%. Finally, Ranalli and Moore [14] reported that students "felt they learned more with the mastery grading system that they would have with a traditional grading system" [p. 6]. However, the authors do not report the quantitative response values they collected.

Three studies inquired about students' preference regarding the use of a mastery grading system over a traditional grading system (i.e., [30, 33, 34]). The results of the inquiry were mixed; however, there was a slight inclination towards preferring the mastery learning approach. Moore [33] reported that most survey respondents agreed they prefer mastery learning over the traditional system. Similarly, Armacost and Pet-Armacost [34] describe that most students would like to participate in mastery learning again. However, in Sanft et al.'s [30] implementation, four students disagreed with the statement, "Compared to traditional grading of assignments, I prefer specifications grading," while ten students agreed [p. 40].

Two studies sought to understand if mastery learning required students to spend more time working on course material than a traditional course (i.e., [14, 42]). These studies suggest that a significant percentage of students perceive that they did spend more time studying, reviewing, or working on class material. Lovell [42] asked students to rate the statement "the grading scheme forced me to review/study material more than I would in similar classes with a traditional grading scheme" using a 5-point Likert scale [p. 10]. In the 2016–2017 course iteration, 73% of students Strongly Agreed or Agreed with the statement, and in the 2017–2018 iteration, 46% percent of the students Strongly Agreed or Agreed with the statement. Ranalli and Moore [14] reported that their analysis of their data reveals that "students indicated that they spent more time on the homework" as retake opportunities were applied to the homework [p. 6]. However, the authors do not provide the raw data to corroborate their claims, they only state that an analysis was conducted.

3.3.2 Open-ended Survey Responses: Students' Evaluation of ML Experience

Ten implementations gathered information about students' mastery learning experience through open-ended questions administered at the end of the course (i.e., [13, 18, 30, 35, 36, 38, 40, 44, 46, 47]). All four computer-based ML implementations collected answers to open-ended questionnaires (i.e., [15, 16, 42, 45]). Ten studies presented positive student evaluations about their experiences with mastery learning in the form of statements summarizing comments received or as sample comments (i.e., [13, 18, 35, 36, 38, 40, 42, 44, 46, 47]). Eight studies reported negative student evaluations of mastery learning (i.e., [18, 30, 35, 36, 40, 42, 46, 47]), while the remaining studies did not report negative evaluations. In other studies, the number of positive and negative comments received from open-ended questions about mastery learning were counted to obtain an overall summary of students' experiences (i.e., [13, 18, 35, 47]). Studies where the number of positive and negative comments of mastery learning were counted may provide more robust evidence of the overall appreciation or rejection of the approach. This subsection presents summary information on the positive aspects of mastery learning reported by students, followed by negative evaluations.

We present three student responses that help explain why they perceived they learned better through an ML approach (i.e., [36, 42, 44]). Craugh [36] concluded that the mastery learning approach exerted positive pressure to focus and learn the material and shifted students' approach to learning as merely trying to pass the class with only partial understanding:

> "At first, I didn't like the test-taking setup, but then it really grew on me. I think it is a great way to evaluate students learning and it really helped having to retake certain problems. It made me focus and learn where I otherwise wouldn't have gone over it if I was just given partial [credit]" [p. 6].

Okamoto [44] also provided sample student quotes that emphasized how mastery learning helped them understand sections and lessons better. For example: "the new teaching method helps to understand each section of the course efficiently" and "the method of teach[ing] was effective as student will have a good understanding of a previous lesson before moving on" [p. 7]. Lovell's [42] mastery learning implementation required students to get all quiz questions correctly to show that mastery was achieved. Some students developed an appreciation for the mastery-based structure of the quizzes:

> "I like that it made me study better. Because of the quizzes, I would study a lot more intensely because I knew I had to get it completely right, so I had to understand everything. This helped me prepare for the exams" [p. 9]

Students' support for mastery learning was also reported in five studies (i.e., [13, 18, 35, 36, 38]). Craugh [36] reported that students "intellectually appreciated the concept" [p. 7], while Kelley [18] wrote that students liked the opportunity to improve their grades. Sample comments reported by Bekki et al. [35] show that students appreciated having multiple attempts to succeed, while DeGoede's [38] and Hjelmstad and Baisley's [13] students' evaluations validated the mastery learning approach they implemented. Bekki et al. [35], Hjelmstad and Baisley [13], and Kelley [18] reported that they received more positive comments than negative comments on their mastery learning implementation. Conversely, Sangelkar et al. [47] received more negative comments about the mastery learning implementation. Bekki et al. [35] reported that "the majority of student responses indicated that they were happy with the approach and the efforts made by the instructors in implementing the approach" [p. 5]. Kelley's [18] focus group revealed that "the consensus opinion from students was favorable toward mastery learning" [p. 10]. Sangelkar et al. [47] counted the instances a positive comment appeared in their open-ended question asking, "What do you like or dislike about the mastery learning method?" [p. 12]. The top three positive comments were: "I can retake/multiple tries," obtaining 40% positive comments, "I can solve problems correctly from the first time," receiving 18% positive comments, "Less material to study for each exam" obtaining 11% positive comments [p. 12].

From the eight studies that reported *negative evaluations* of mastery learning through open-ended questions, a few emerging themes were observed across the studies. A common negative remark in two studies is that some students thought the time it took to complete an assignment or test was too long due to the retake opportunities (i.e., [18, 36]). Another negative comment repeated across three studies was that students felt they should be allowed to get partial credit on an assignment or exam – earning partial credit on the assignment or exam would void the need to earn a 'mastery' grade (i.e., [18, 36, 42]). Lovell [42] reported that some students preferred receiving partial credit on quiz questions, specifically:

> "Even though we got quiz retakes, I still wish the quizzes would be done differently. For example, if you get the first part wrong, there is no chance (most of the time) that you can get the other parts right." [p. 9]

Some negative comments may be attributed to overly complicated mastery learning implementations. For example, Bekki et al. [35] reported negative comments on student evaluations describing confusion and dissatisfaction with the assessment process. These comments may be connected with Bekki et al.'s [35] complicated mastery learning implementation. Sangelkar et al. [47], which coded students' written comments into categories of "like" and "dislike," found that 62% of the comments were unfavorable to the mastery learning approach. In comparison, 38% of the comments favored the implementation. Although there were some patterns in the negative feedback received across studies, some negative feedback can be attributed to an overly complicated mastery learning implementation style. Among the studies gathered in this systematic review, more studies reported positive comments than negative comments about their ML experience. In the studies that report negative comments, more positive comments are reported, and the authors express a greater emphasis on the positive comments.

3.4 Instructor Feedback and Recommendations from their Mastery Learning Implementations (RQ 4)

Of the 23 papers that passed our inclusion and exclusion criteria, 19 provided information detailing instructor feedback or recommendations about their mastery learning implementations (i.e., [13–15, 30–35, 37–44, 46, 47]). We categorize and discuss the faculty feedback regarding the benefits and limitations of implementing mastery learning. We have organized the information collected into (a) benefits, (b) limitations, and (c) recommendations. In what follows, we synthesize instructor comments on each category.

3.4.1 Instructor Feedback: Benefits Identified by Instructors who Implemented Mastery Learning

After reviewing the instructor feedback documented in the 19 articles, we found 16 distinct benefits and four limitations reported in more than one source. Since the number of benefits listed is four times the number of limitations, mastery learning is primarily a net positive teaching approach in the eyes of the instructors. We found at least six common benefits across three articles or more. This subsection describes the common benefits found across three or more articles, which may be considered the most salient benefits of mastery learning implementation. Table 3 outlines the most salient benefits.

Amarcost and Pet-Armacost [34], Baisley and Hjelmstad [31], Ranalli and Moore [14], and Ritz et al. [46] reported that through the implementation of ML, assignments become valuable formative assessments. In practice, feedback on homework assignments tends to be ignored by students since they have implicitly been treated as an evaluation of a student's understanding at a specified time (i.e., deadline). Any feedback provided to students is often ignored or viewed only as a means to study for the summative evaluation (i.e., exams; [14]). Structuring homework assignments as truly formative assessments allowed students to understand the areas where they were weak and needed to improve, and through retake opportunities, students could demonstrate newly acquired knowledge.

Table 3. List of 16 benefits when implementing mastery learning reported in more than one study

Benefit	No. of Articles	Article(s)
Mastery learning turns assignments into formative assessments.	4	[14, 31, 34, 46]
Students learn they have to make sure their work is correct.	3	[30, 39, 43]
Instructors are confident in the relationship between the grade a student receives and their performance in achieving the specified learning objectives.	3	[40]–[42]
Retake opportunities help students identify errors and deficiencies in their work.	3	[30, 41, 43]
Mastery learning approach saves time on grading.	3	[30, 32, 39]
The mastery learning grading system is simple, clear, and fairer. Assignments are graded on a mastery basis; instructors spend less time deciding how to distribute partial credit.	3	[14, 39, 42]
Students demonstrate a greater ability to solve problems.	2	[38, 44]
Students learned or understood better.	2	[30, 39]
Data collected on topic or concept pass rates could be used in the program evaluation and program revision process required for ABET accreditation.	2	[41, 47]
Achieving mastery of learning objectives, helps students gain confidence in their abilities.	2	[41, 43]
Mastery learning helped ensure that every student develop the requisite level of skill and knowledge.	2	[41, 43]
Students have a better understanding of the requirements and expectations for a mastery level.	2	[39, 42]
Retake opportunities ensure that students are not penalized for learning more slowly.	2	[14, 42]
The process of implementing mastery learning can be straightforward.	2	[34, 41]
Students know they must demonstrate competency in an exam, and this motivates preparedness. Mastery learning raises standards and improves success.	2	[15, 37]
There is a focus on the process of completing the assignment, to achieve mastery of a learning objective rather than simply producing a correct final answer. Students realize the process of producing quality work.	2	[39, 43]

Another salient benefit is that students learn the value of ensuring their work is correct [30, 39, 43]. Sanft et al. [30] noted that, through mastery learning, students understood there would be time savings associated with ensuring that the work they hand in is correct. Students saved time by turning in a correct assignment and not having to go through the retake process. Going through the retake experience at least once was enough for students to realize that they would be better served by handing in assignments that showed mastery. Fernandez et al. [39] acknowledged that by encouraging students to hand in correct assignments, they are training in the professionalism required in their careers. Practicing engineers are typically asked to turn in the accurate work and are not evaluated with partial credit. Mukherjee and Cox [43], who implemented the ML process on phases of a project, observed that students learned that it was no longer sufficient to get a passing grade; instead, they have to be able to perform the skills of the profession well. Specifically, Mukherjee and Cox [43] affirmed:

> "We [instructors] find that this realization encourages them to make many adjustments in their work habits in order to complete the phases on time and within the time frame of a semester [p. 48]."

An important distinction between mastery learning and a traditional teaching approach is the ability to adequately evaluate the knowledge a C student has obtained over a B student. A conventional approach to assessing students' learning makes it difficult to determine which learning objectives one C student obtained over another. For example, one C student could have demonstrated an in-depth understanding of some learning objectives. In contrast, the other C student showed no in-depth knowledge but earned enough partial credit across multiple objectives. Even a B student could have earned their grade by fulfilling *parts* of several learning objectives but not completely mastering the entire learning objective. These concerns were explicitly expressed by Helmke [40], Hochstein and Perry [41], and Lovell [42]. By implementing mastery learning, these instructors obtained confidence in the relationship between the grade their students received and their performance in specified learning objectives. These instructors also noted increased confidence in how students progressed through the learning objectives. Specifically, Hochstein and Perry [41] stated that mastery learning could provide important feedback to both students and instructors about the progress toward learning objectives. Lovell [42] noted that the mastery learning grading scheme "create[d] a catalog of objectives that students have demonstrated perfectly at least one time" [p. 12].

The implementations by Hochstein and Perry [41], Mukherjee and Cox [43], and Sanft et al. [30] acknowledged that mastery learning allowed students to identify deficiencies in their work more promptly. Mukherjee and Cox [43] explained that through identifying weaknesses, students get to play devil's advocate on their work to find their weak spots and get into the habit of professional analysts who go over their proposals several times to find errors and deficiencies.

Instructors reported that using mastery learning saved them time when grading assignments (i.e., [30, 32, 39]). Specifically, Moore and Ranalli [32] compared the time it took to grade each problem per student for a traditionally graded thermodynamics course and a mastery learning thermodynamics course. While the courses were taught at different campuses and with other instructors, they used the same assigned problems. The mastery learning instructor spent approximately 52 seconds per problem, while the traditional grading instructor spent 101 seconds per problem. The mastery learning approach took approximately half the time per problem compared to the traditional grading class that used the same problem set. In Fernandez et al. [39], the time saved on grading was obtained by identifying the grade on an assignment due to a clear mapping of the specifications created for that assignment. When the answer matched the specifications, students received a passing grade. Sanft et al. [30] examined the time expended on grading assignments in several computer science courses; they determined that specifications grading yielded significant time savings in five out of eight assignments. The time saved was attributed to less time assigning partial credit on programming assignments. Removing students' incentive to turn in incorrect work to earn partial credit also reduced the time spent grading each assignment and debating the amount of partial points earned [30].

Lastly, three studies reported that mastery learning was a simple, transparent grading system or a fairer grading system [14, 39, 42]. Fernandez et al. [39] noted that the clarity of the grading system allowed them to provide more formative feedback. Lovell [42] reported spending less time deciding how to distribute partial credit. Ranalli and Moore [14] noted that the well-defined grading standard of mastery learning removed the need on how to assign partial credit, and disputes with students over partial credit decreased.

3.4.2 Instructor Feedback: Limitations Identified by Instructors

Thirteen of the 23 sources acknowledge the limitations of implementing mastery learning in their undergraduate courses. The limitations reported

Table 4. List of limitations when implementing mastery learning reported in multiple studies

Limitation	No. of Articles	Article(s)
Implementing a mastery learning approach can be time consuming for the instructor.	8	[14, 30, 32, 33, 35, 42–44]
When mastery learning was first introduced to a class, students resisted the new approach or reacted negatively.	3	[13, 31, 38]
Students can 'game the system.' For example, students can initially submit a low-quality document and later work on the revisions marked by the instructor.	3	[39, 43, 44]
Mastery learning can be time-consuming for students.	3	[30, 32, 43]

in more than one study and the corresponding sources are listed in Table 4. We acknowledge that instructors may have experienced many limitations but decided only to report the most salient. However, no study claimed to have more limitations than benefits or vice versa. Here we describe the limitations that were reported in multiple studies. Some limitations were singularly reported, and we suspect those limitations are specific to their implementation; however, we decided not to include them in this review.

In eight sources, instructors reported that implementing mastery learning can be a time-intensive endeavor [14, 30, 32, 33, 35, 42–44]. Mukherjee and Cox [43] explained that the increased time commitment came from grading resubmissions, explaining techniques, identifying errors, and working individually with students. For Okamoto [44], the increased time commitment came from developing and grading quizzes. In her implementation, students were allowed to take up to two weekly quizzes. The quizzes pertained to each class subtopic. Students were not allowed to take quizzes on topics in a category unless they had achieved an 88% or more in the quiz in the previous category [44]. Bekki et al. [35] noted that producing individualized corrective feedback "dramatically increased the typical workload for a faculty delivering a course" [p. 6]. Lovell [42] reported that retake opportunities applied to quizzes or exams during class time took away from in-class lectures or activities. Sanft et al. [30] acknowledged that there could be an unpredictable amount of grading for resubmitted assignments. Moore [33] conducted a small study to determine how much more time it took to grade assignments. The author measured the time it took, per student, to grade a Strength of Materials problem and a Thermodynamics problem in both a mastery learning course and a traditional course. He found that a mastery learning implementation increased the grading time per problem by 120% in the Strength of Materials course and only by 3% in the Thermodynamics course. Some instructors acknowledged that implementing mastery learning increased their workload as they needed to develop more retake problem assignments or exams, grade more problems, and deliver more meaningful feedback to students. In contrast, other instructors describe that using mastery learning saved time when grading assignments (e.g., [30, 32, 39]). Spending extra time on a mastery learning course or saving time depends on the precise implementation. Increased time expenditures result from developing new assignments above those needed for a traditional course, allowing a large number of retake opportunities, grading more due to retake opportunities, and producing and delivering feedback. However, time can be optimized by not having to assign partial credit on assignments and discouraging the submission of incorrect work. Instructors can save time by having a repertoire of assignments or assignment problems that can be given to students. Time can also be saved by using a Learning Management System (e.g., Canvas) to collect and grade assignments and deliver feedback. However, formative feedback, where instructors describe to each student what areas of the assignment need to be improved and how to improve them, may still be a source of time expenditure.

Moore and Ranalli [32] reported that mastery learning could be both time-consuming and time-saving for instructors depending on what courses are compared in their study. In the first comparison, mastery learning *saved* instructors time when comparing two thermodynamics classes: mastery learning versus the traditional approach. Each course was taught by a different instructor on different campuses but used the same problem sets. Here, mastery learning was seen to take about half as much time per problem as a traditional class. In the second comparison, mastery learning was *time-consuming* for instructors when comparing three courses with the same instructor: one Dynamics mastery learning course, one Thermodynamics traditional course, and one Strength of Materials traditional course. In contrast to the results from the first comparison, in the second comparison, the mastery learning course took twice as long as the traditional courses per problem with the same instructor across different courses with different problem sets. The authors did not report the possible reasons behind the discrepancy. The difference in grading time between the first and second comparisons may be the difference in problem difficulty level across courses in the second comparison.

Baisley and Hjelmstad [31], Hjelmstad and Baisley [13], and DeGoede [38] described that at the beginning of the semester when mastery learning was implemented, students had adverse reactions to the new approach and that it took effort to explain and 'sell' the new approach to students. Baisley and Hjelmstad [31, 13] also pointed out that students' "angst was exacerbated" because they were unable to compare the current course with previous course offerings due to many changes [p. 15]. In DeGoede's [38] implementation, students initially resisted the mastery learning approach, noting that the high-performing students were concerned about their grades. However, he described that those same students preferred the mastery learning approach by the end of the semester. In the following year, students had more trust in the system because the instructor learned to better explain mastery learning and the reasons for using the approach [38].

Three studies [39, 43, 44] described that some students gamed the system to their benefit. Gaming the system can be understood as taking advantage of the mastery learning approach in a way that goes against its pedagogical spirit. For example, in Okamoto [44], students could complete higher-level problems to achieve a higher grade. Some students never solved higher-level topics, the last topics listed sequentially in students' learning outcomes. To receive an A+ or A grade, students needed to earn a passing grade on the last two higher-level topics. However, students that were satisfied with earning a grade of A– or lower in their overall quiz score could skip the quiz on the last two learning objectives, thus gaming the system. If students were satisfied with their lower grade, the practice of skipping quizzes on the last learning objectives might be considered a valid strategy if their objectives are not to attain the highest grade. However, Okamoto [44] acknowledged that this strategy disadvantages students in higher-level courses (e.g., Thermal Engineering Lab). Mukherjee and Cox [43] described how students gamed the system by submitting an initial document that clearly lacked quality. The student's goal was to rely on the instructor to point out the deficiencies and simply work on those deficiencies. This is an example of gaming the system because students are not putting in the initial effort needed to submit a quality document and are simply hoping to correct mistakes marked by the instructor; a similar experience was reported by Fernandez et al. [39]. Submitting a poor-quality document to gain time to work on the analysis goes against the spirit of mastery learning by taking advantage of the retake opportunities. In the spirit of mastery learning, students should focus on handing in the best quality documents and using tokens to resubmit documents after fixing errors [39]. However, gaming the system is not unique to a mastery learning implementation; the traditional partial credit grading system can also be gamed. That is, students turn the partial credit grading system into a game where they try to obtain as much partial credit as possible "with the lowest possible investment of time and effort" and without ever knowing how to solve the entire problem correctly [3, p. 7].

Three studies provided instructor feedback that characterized mastery learning as time-consuming for students [30, 32, 43]. In Mukherjee and Cox's [43] implementation, mastery learning was applied to project phases, and many iterations on a document were needed before students achieved a passing grade. Since "this pedagogical approach is extremely time-consuming for students," instructors must spend time motivating students to continue resubmitting documents [43, p. 50]. Mukherjee and Cox's [43] experience is corroborated by survey feedback documented by Sanft et al. [30] and Moore and Ranalli [32]. In these studies, students perceived mastery learning to require a higher time investment than the time required for a traditional course. Moore and Ranalli [32] reported that students spent more time redoing incorrect problems. Sanft et al. [30] reported that students could become overwhelmed by the backlog of resubmissions and new assignments. If students perceive that an ML implementation requires a much higher time investment than a traditional course, obtaining student buy-in for an ML course at the beginning of the semester may be harder.

3.4.3 Instructor Recommendations for Implementing Mastery Learning

In light of some of the reported limitations, some instructors provided recommendations, specifically recommendations were provided on methods that can be used to save time. Bekki et al. [35] suggested that efforts be directed toward developing more efficient feedback delivery methods. The authors of this systematic review recommend using a system like Gradescope to save time in delivering feedback. Gradescope allows instructors to create a bank of feedback, which is accumulated from one student's assignment problem that can be used for another student's assignment problem. Ranalli and Moore [14] recommend simplifying the grading resubmission process by attaching the corrected problem to the original resubmission. They also suggest not forcing students to repeat an entire problem that was graded as "incorrect," instead allowing them to begin the correction from the point where the mistake occurred. Ranalli and Moore [14] suggested grading individual problems on a mastery basis rather than assessing whether the student achieved mastery based on the entire assignment. Grading for mastery on specific problems saves time for students, who don't have to repeat correct problems, and for faculty, who don't have to re-grade correct problems. After the semester, students commented that having to demonstrate mastery only on incorrect problems was a positive force motivating them towards completing the homework.

Introducing the mastery learning approach to students at the beginning of the semester is a delicate matter that has to be done with some finesse to elicit positive responses from students ([13], [14]). Ranalli and Moore [14] suggested focusing on the learning benefits and the mechanics of how the course will work when presenting the approach to students. Emphasizing the motivation for implementing ML and clearly describing opportunities to gain lost points was another recommended strategy. Ranalli and Moore [14] recognized that this strategy elicited an initial positive response from students. Hjelmstad and Baisley [13] suggested that instructors of mastery learning clearly articulate the rationale for the shift and discuss how mastery learning will positively affect students. They also emphasized that it is not enough to describe the benefits of mastery learning at the beginning of the semester but recommend articulating the value of the unusual features periodically throughout the semester. Hjelmstad and Baisley [13] described to their students multiple times throughout the semester how mastery learning is designed to reduce exam stress and provide several opportunities to demonstrate mastery. They noted that their students' perception of mastery learning was generally positive and that the discussion amongst students favors mastery learning over traditional methods [13]. While only four studies offered explicit recommendations for those seeking to implement mastery learning in their undergraduate engineering courses, in the next section, the author team provides recommendations based on strategies to allow for a swift implementation of mastery learning.

4. Discussion and Implications

When examining how mastery learning was implemented in undergraduate engineering courses, we observed throughout the 23 studies various implementation procedures. Yet all studies followed the core features of ML, specified learning objectives, a designated evaluation metric to evaluate mastery, and multiple retake opportunities. Among the 23 studies that were reviewed, we found that mastery learning was implemented in a total of 35 undergraduate engineering courses. Many studies implemented mastery learning in multiple courses and multiple sections of the same course. All studies in this review were published as conference proceedings, the majority from the *American Society for Engineering Education*. Some studies that implemented mastery learning had implementations across multiple institutions or instructors. Statics, Dynamics, and Thermodynamics courses were popular for implementing mastery learning. These three courses are considered fundamental in various engineering disciplines and are prerequisites for follow-up courses. Since the aim of mastery learning is to help students achieve mastery of specified learning objectives, the content mastered in these courses may significantly improve their outcomes in upper-level courses. It is also likely that it is more straightforward to implement mastery learning in mathematical problem-solving-based courses where specific steps are needed to solve for the correct answer.

There were six mastery learning evaluation metrics common across studies, i.e., exams, final exams, quizzes/assessments, homework, class activities, and projects. Most of the implementations used two forms of evaluation metrics to assess students' mastery, where the most common evaluation metrics used were exams in combination with either quizzes/assessments, homework, or the final exam. Implementations that only used one evaluation metric used exams or homework assignments. The more mastery learning evaluation metrics used in a mastery learning course, the greater the amount of grading and feedback the instructor would have to do. A mastery learning evaluation begins when the assignment is given to students and ends when the retake process for that assignment is complete. There is variability in how much practice students get when mastery is evaluated using exams versus when mastery is assessed through homework assignments. We believe the practice that comes with evaluating mastery through exams is less than when assessed through homework assignments. Typically, there are a greater number of homework sets per semester when compared to the number of exams per semester. Thus, students undergo more practice through an evaluation of mastery through homework assignments, which may subsequently benefit their understanding of the course material. Most articles did not report the feedback style used in their mastery learning implementations. It is unlikely that these mastery learning implementations did not provide feedback to their students; it is more likely that some feedback was provided, but the style of feedback was not considered significant enough to be described. From those studies that described the type of feedback given to students, the feedback was based on the correctness or incorrectness of answers. In contrast, others provided information on how to correct mistakes. Of the two styles of feedback, providing information on how to correct mistakes is more helpful to students, and it aligns with the spirit of mastery learning, where corrective instructor feedback is critical if students are to improve on errors.

In our second research question, we were interested in examining concrete evidence demonstrating how mastery learning, if at all, improved students learning, what we conceptualized as learning gains. Students' final exam grades were not representative of the effectiveness of mastery learning. Some studies showed that mastery learning had a marginal effect on students' final exam grades when compared to traditional course offerings (e.g., [33, 44, 46]). However, there is considerable evidence that mastery learning positively affected students' learning gains compared to traditional courses when alternative metrics were used. For example, DeGeode [38] demonstrated how mastery learning positively impacted students' overall learning when examining grades using a mastery ratio approach. Students in Okamoto [44] and Helmke [40] demonstrated positive learning gains when they compared final course grades. Both studies reported an increase in B grades and a decrease in grades C or lower. Craugh [36] showed the beneficial effect of mastery learning for students with low QPR scores, which were similar to GPA scores. Leonard et al. [15] demonstrated how mastery learning positively affected the passing rates in the overall course sequence. Moore and Ranalli [32] showed that mastery learning students had higher homework grades than students in a traditional course. The issue that a final exam grade in a mastery learning course does not appear to be representative of the benefits of mastery learning is exemplified by Moore [33]. In his study, mastery learning did not significantly affect students' final exam grades compared to a traditional course, yet in close-ended surveys, students reported having increased learning due to mastery learning [33]. The positive effect of mastery learning on learning is echoed by four other studies where mastery learning is seen as benefiting student understanding and learning when evaluating responses in close-ended surveys (i.e., [14, 30, 34, 42]). In addition to measuring final exam grades, future mastery learning implementations should also consider using alternative measures to evaluate students' learning gains or other outcome metrics. Why mastery learning does not appear to affect course final exam grades significantly is not yet resolved but offers an area for future research. However, evidence points to the positive effect mastery learning can have on students' learning when considering alternative metrics.

When looking across studies to understand students' experiences beyond academic performance, it was difficult to arrive at a clear consensus. There was a lack of close-and-open-ended survey question replication among the studies. As a result, there was also a lack of agreement regarding the opinion of students about mastery learning. Most studies used original survey questions, while few common questions appeared across multiple studies. The objective of systematic reviews are to provide a "'bottom-line' statement regarding what the evidence supports and what gaps remain in our current understanding" [48, p. 950]. We found it challenging to determine a bottom-line statement regarding the effectiveness of mastery learning since the data collected varied. For example, of the 23 studies discussed in this systematic review, only four studies made statements regarding students' experiences, and they were typically framed in terms of positive comments relative to negative comments received from open-ended survey questions (e.g., [13, 18, 35, 47]). Specifically, three studies reported receiving more positive comments regarding students' experience in the mastery learning course than negative comments. In comparison, only one study reported receiving more negative than positive comments. These results suggest that typically, there are more positive experiences than negative experiences in a mastery learning course environment; hence students have mostly a positive view of the approach. However, the evidence is not definitive. To strengthen the conclusion that students have a greater positive perspective of mastery learning, future studies should consider asking open-ended questions about mastery learning that elicit positive and negative comments. Being transparent about the ratio between positive and negative comments is one approach that may help strengthen the conclusions drawn here. A better understanding of engineering students' experience in a mastery learning course would benefit if future studies used standard close-ended and open-ended surveys. Future studies on mastery learning in undergraduate engineering classes should distribute surveys among its students that use similar questions as those found in the most salient studies discussed here. In this manner, future systematic reviews would be able to ascertain if there are similarities or differences in the answers students have given to the same questions across studies and draw more definitive conclusions regarding students' mastery learning experience.

In this systematic literature review, we summarized instructors' feedback and recommendations for those seeking to implement mastery learning; however, many studies did not provide a section sharing instructors' experiences thus their shared insights were limited. The reasons behind this were perhaps the page limitation or the focus centering on the actual implementation. Nevertheless, instructors did report more benefits of implementing mastery learning than drawbacks. Common benefits reported across multiple studies were: mastery learning turns assignments into formative assessments, students learn they have to make sure their work is correct, instructors can easily map a student's grade to the learning objectives they achieved, retake opportunities help students identify errors in their work and, in some cases, the mastery learning approach can save time on grading. For those seeking to implement mastery learning in an undergraduate engineering course, it is important to be aware of the drawbacks in order to aid in future planning. The limitations that were reported by more than one article were: implementing the mastery learning approach can be time intensive for both instructors and students, students will initially have negative reactions to pedagogical approaches they have not experienced, and instructors should be mindful that mastery learning can be gamed by students. The most salient limitation mentioned in 8 studies was how time intensive it was to implement mastery learning. Overall, the feedback and recommendations were minimal. If enough studies provided a section on instructors' experiences, robust conclusions could be drawn from the opinions of instructors on their mastery learning implementations. Future studies documenting their mastery learning implementation should consider adding a section or a companion paper describing instructors' experiences, feedback, and recommendations (for example, see [14]).

While few explicit recommendations for those seeking to implement mastery learning were provided, amongst the author team, we identified recommendations based on practices that could best aid future implementers. We summarize the list of author team recommendations in Table 5. We recommend utilizing the feedback dashboard described in Hjelmstad and Baisley [13] and Baisley and Hjelmstad [31] as it offers the best approach to map students' progress towards achieving specified learning objectives. The dashboard has a 'mastery assessment' section which presents each learning objective next to a completion bar. The completion bar shows how many points the student has accumulated on a learning objective in relation to the maximum number of points they could accumulate for that learning objective. Each assessment that is successfully mastered increases the length of the completion bars for each learning objective. The completion bar also shows the average achievement level of the entire class for each learning objective, which can help students understand how they compare against the average. The feedback dashboard is a graphical way to rapidly determine how far the student is from mastering a learning objective and evaluate how they compare against the class average. Overall, the dashboard provides a fast and easy way to understand the progress of each learning objective. The dashboard was developed using MATLAB programs that are read into a master spreadsheet, Hjelmstad and Baisley [13] affirmed, "the programs could be easily adapted to other courses and are available from the authors upon request" [p. 10]. We recommend that instructors who implement mastery learning in their undergraduate course keep a journal of their implementation. In Bekki et al. [35], the instructors wrote weekly reflections from observations about their respective course implementations. Keeping a journal of the implementation can be a valuable technique for collecting information about the methods and effects of the implementation. Continuous and consistent reflection on the implementation can be a source of critical awareness and a deeper understanding of the actions taken [49]. Instructors can annotate the technique(s) they used for 'selling' the implementation to students, methods of execution, strong and weak areas of the implementation, successes, failures, and student comments. Finally, at the end of the semester, their reflective journals will consist of recommendations for continuous improvement of future mastery learning implementations. In Bekki et al.'s [35] implementations, in addition to journaling, they met every two weeks to discuss their experiences and to create tactics to improve the

Table 5. Summary of recommendations identified by the author team

Recommendations	Source
Utilize the feedback dashboard in Hjelmstad and Baisley [13] and Baisley and Hjelmstad [31]. The dashboard can show how far the student has advanced in completing the learning objective.	[13, 31]
Keep a journal of the implementation. The journal can include methods for "selling" the implementation to students, methods of execution, strong and weak areas of the implementation, successes, failures, and student comments.	[35]
Join or create a community of practice. A community of practice is ideal for sharing ideas or strategies for implementing ML. An example of a community of practice is the Slack channel alternativegrading.slack.com.	[35]

actions taken in the implementations; therefore, the third recommendation we offer to those instructors interested in implementing mastery learning is to join or create a community of practice. Those seeking to implement mastery learning should consider partnering with other instructors applying mastery learning to create or join an existing community of practice. A community of practice is ideal for sharing ideas or strategies for implementing mastery learning. The community could have a dedicated team messaging software like Slack or Microsoft Teams where information can be shared, and files and images can be uploaded for members to use. The community members could also meet periodically through web-based meeting platforms like Zoom. While not referenced in any of the 23 sources, we are aware of an online conference called The Grading Conference, formerly the Mastery Grading Conference, where instructors can share grading practices that are different from traditional grading practices. This conference may be an ideal location for instructors, who are the only ones implementing ML in their courses, to build community. The author team is also aware of a Slack channel for those implementing mastery grading in their courses, i.e., alternativegrading.slack.com, another avenue to connect and build community. Joining or creating a community of practice could be an effective way to find solutions and alternatives when faced with implementation issues.

5. Conclusion

Implementing mastery learning in undergraduate courses can be cumbersome as significant course restructuring is warranted to allow students to master each learning objective. Nevertheless, some engineering instructors have implemented mastery learning in their undergraduate courses. In this systematic review, we summarized how mastery learning was implemented and how each implementation specifically affected engineering students. Lastly, we compiled feedback and recommendations reported by each author to offer strategies for those seeking to apply mastery learning to an undergraduate course. The overview presented in this systematic review may benefit those redesigning their undergraduate courses using a mastery learning approach.

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