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Mastery Learning and the School Learning Theory of J.B. Carroll

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Abstract

In this paper, we present the School Learning Theory of J. B. Caroll, which was the basis for Mastery Learning, developed by Bloom [1]. We first present Carroll's theory and Mastery Learning. We then discuss examples of Mastery Learning in engineering education, and the guidance Carroll's theory provides. We conclude with results of the author's application of Mastery Learning in two engineering classes at Oral Roberts University.

Mastery learning, developed by Bloom [1], has shown great promise in encouraging students to learn, enabling a large number of students to perform at a high level, and enabling students to truly learn the fundamentals of a subject. In mastery learning students are given multiple opportunities to demonstrate mastery of course concepts, with feedback and opportunity for improvement, which enables a large number of students to succeed. The school learning theory of J. B. Carroll presents a learning theory that undergirds mastery learning, especially flexibility concerning the time available for learning. Under Carroll's theory, learning is based on the ratio of time needed to time spent on learning, with high-aptitude students needing less time. This de-emphasizes the role of innate ability, promotes hard work, and provides guidance for retaining less prepared students in engineering without lowering standards.

In the author's approach to mastery learning, no partial credit is given on 75% of test problems, however, students are able to repeat those problems, possibly with some penalty. Students must demonstrate mastery of basic material by the end of the course to pass. Positive impacts on class GPA and percentage of students passing are seen.

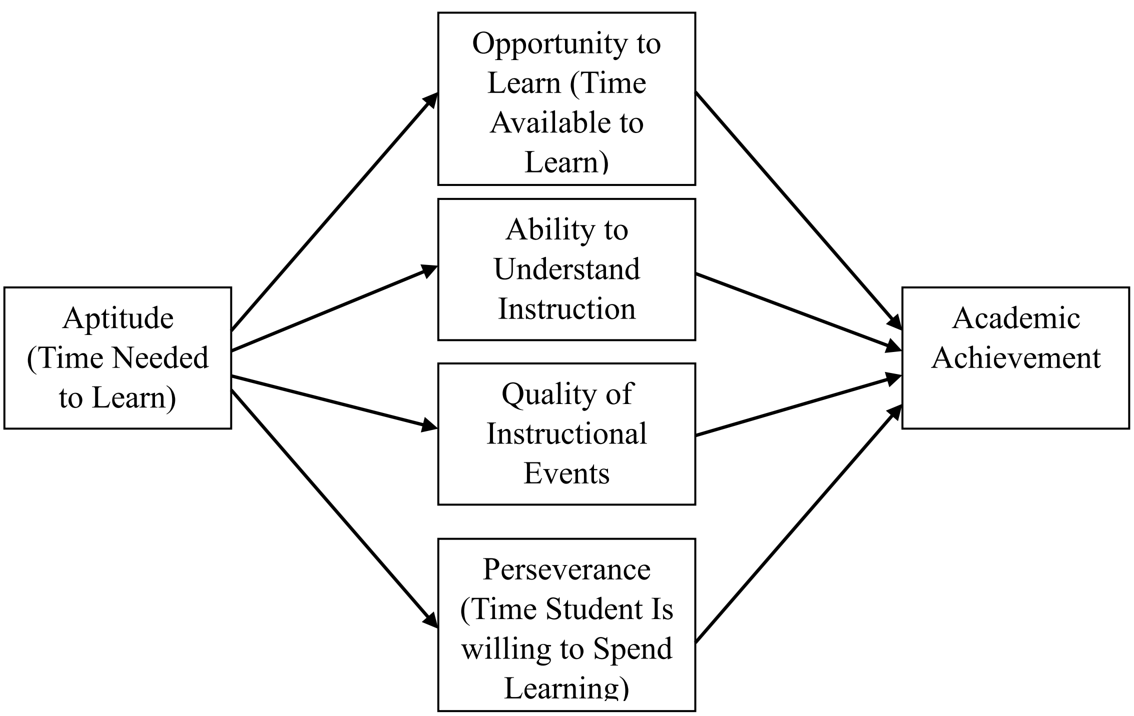

Figure 1. Carroll's Model of School Learning [4]

The School Learning Theory of J.B. Carroll

Bloom credits Carroll's School Learning Theory [2] as the basis for his mastery learning approach [1][3]. Carroll's theory has been considered as a basis for studying adaptive learning systems and web-based learning [3],[4].

Carroll's model proposes five variables to explain variations in academic achievement [5].

1. Aptitude: The amount of time a student needs to learn a concept or task assuming optimal instruction and student motivation.
2. Opportunity: The amount of time allowed for learning.
3. Perseverance: The amount of time-on-task a student is willing to spend on learning.
4. Quality of Instruction: Clearly identify what is to be learned, connect students with learning materials, carefully planned and ordered steps.
5. Ability to Understand Instruction: Language comprehension, ability of student to understand what the learning task is and how to learn it. For engineering classes, language comprehension may mean mathematics background.

One experimental test of Carroll's theory is presented in [6].

Carroll's definition of aptitude as the time required to learn, rather than the ability to learn has fundamental implications for engineering education, particularly for retention in an era of reduced math skills. The time spent learning will actually be the minimum of the time needed, the time allowed, and the time the student is willing to spend [5]. This understanding of the role of time shifts attention away from innate ability, and encourages both hard work/persistence and self-regulation as factors for academic success.

A mathematical representation for learning achievement under Carroll's model is given in [3]. The degree of learning c is a function of the time spent (influenced by Opportunity and Persistence) divided by time needed (influenced by Aptitude and Quality of Instruction)

$$c = f(\text{time spent}/\text{time needed})$$

Although Carroll himself did not view time as the only important concept in his model, researchers have studied the role of time in adaptive (computer) learning systems [3], [5]. Some online homework systems, that provide instant feedback, tutorial information and opportunities to repeat problems provide the opportunity for students who are willing to persevere and invest the time repeating problems they have missed. Students who give up, or resort to guessing may not benefit as much from these systems. Some systems have penalties for repeating problems which discourages guessing. Explicit instruction to students on how to interact with these systems might be helpful. The author is now instructing his students to avoid guessing.

Carroll's model reflects his goal to give all students the opportunity to succeed. Bloom, inspired by Carroll's work, developed mastery learning with a goal of enabling a large percentage of students to actually succeed.

Mastery Learning

Managing this mastery learning process in a way that is time efficient for the instructor and encourages students to conscientiously work to learn the material is critical.

The value of mastery learning and Carroll's framework are seen in the light of recent survey data from Inside Higher Ed's "24 Stats for 2024" [7]:

- Forty-eight percent of students doubted their ability to succeed in college when enrolling.
- Fifty-five percent of college students say their mental health is a stressor, followed by their physical health (40 percent) and finances or paying off student loan debt (32 percent). (Academics 31%)
- Sixty-one percent of students spend three or more hours per day on social media.

Bloom reports a comparison of conventional instruction, mastery learning and individual tutoring: "The variation of the students' achievement also changed under these learning conditions such that about 90% of the tutored students and 70% of the mastery learning students attained the level of summative achievement reached by only the highest 20% of the students under conventional instructional conditions" [8].

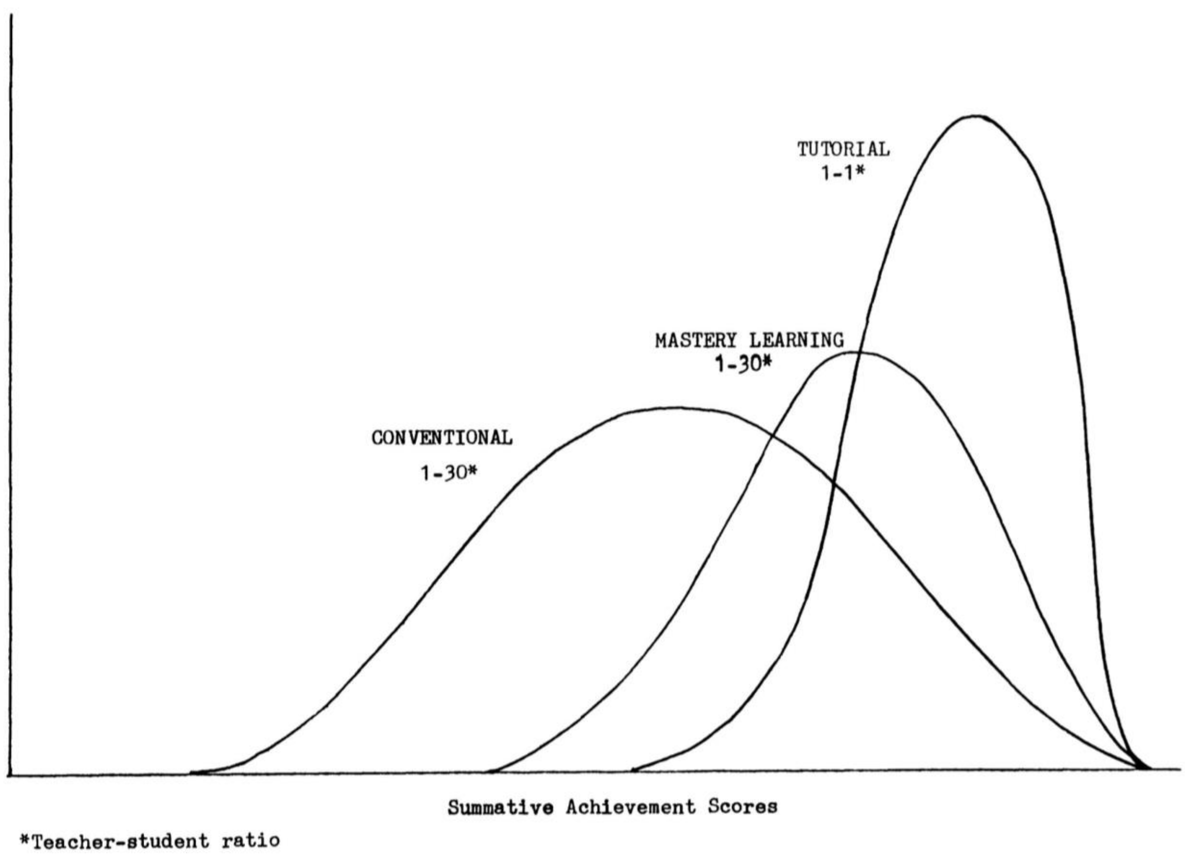

Figure 2. Achievement distribution for students under conventional, mastery learning and tutorial instruction [8].

Reflecting on Carroll's emphasis on time, for the three groups, time-on-task in the classroom was 65% for conventional instruction, 75% for Mastery learning and 90+% for tutoring. Very significantly, the correlation between aptitude and achievement was reduced for mastery learning and tutoring from .6 under conventional instruction to .35 under mastering learning and .25 under tutoring [8].

The underlying message, identified by Bloom, is that a large percentage of students have the ability to not only succeed academically, but do well, given the right instructional approach. The challenge is to deliver this instruction in a cost-effective manner [8]. Individual tutoring, for example, is not cost-effective, however mastery learning can be implemented in a standard class.

Some elements Bloom identifies as critical for mastery learning:

1. Define clearly what mastery is and how students will demonstrate it.
2. Frequent formative testing. These test are used to determine what the student still needs to learn and a clear prescription of what to do to learn it.

This formative testing is not assigned a numerical grade, but shows mastery or non-mastery, and is not part of the grading process. Other summative tests are used for grading [1].

Steps for Mastery Learning [9]:

1. Define learning objectives. All assessment will be oriented toward these objectives. Communicate these to the students.
2. Define what is meant by mastery. Is this based on a percentage achieved on an assignment or test? Communicate this to the students.
3. Establish grading protocols. Communicate these to the students.
4. Incorporate flexibility. The goal is to accommodate students who learn at different rates. Determine resubmission policies. Some possibilities:
    a. Open resubmission. Students can resubmit as often as needed.
    b. Earned resubmission. Students must meet minimum requirements, possibly submit more detailed explanations, or reflect on their first attempt.
    c. Tokens. Students have a total of resubmissions they can make during the semester on all assignments.
    d. Attempt limitations. Limit the number of times a specific assignment can be resubmitted, but have other ways for the student to demonstrate mastery of the concept.

Open resubmission can allow students to do poor quality work on their first submission, or test attempt [9]. This author has seen this.

In a study of high school business classes being taught using mastery learning, incoming students had GPA's of 2.28, but the average class GPA was 3.92. Formative tests were given that could be retaken. A grade of 70 on <u>all</u> tests was required for a C, 80 for a B and 90 for an A. In addition a final exam was given as a summative evaluation, with no retakes allowed. Some of the comments answering the question "what do you like best about mastery learning?" were telling [10]:

Why aren't all classes taught this way?
I don't have to guess what to study.
This is the first A I've ever gotten.
It's easier to learn.
I look forward to coming to class.
I don't cut this class.
It makes me feel special

These comments indicate: 1. A positive value in clearly identified educational goals, tied to appropriate assessments, and clearly communicated to the students. 2. A positive educational experience that will hopefully carry over to other classes.

Fundamentally several things are different about mastery learning. First, students have more time to master a concept, if they need it. This allows a larger number of students to succeed. Second, success is defined as demonstrating mastery of 100% of fundamental course material, rather than the 70% needed for a C. One unwritten goal is for students to develop the ability to study and learn a concept, and know if they know it.

Visually, the performance of the class under traditional and mastery grading is illustrated in Figure 3. Rather than a snapshot of performance, the instructor sees students filling in knowledge gaps.

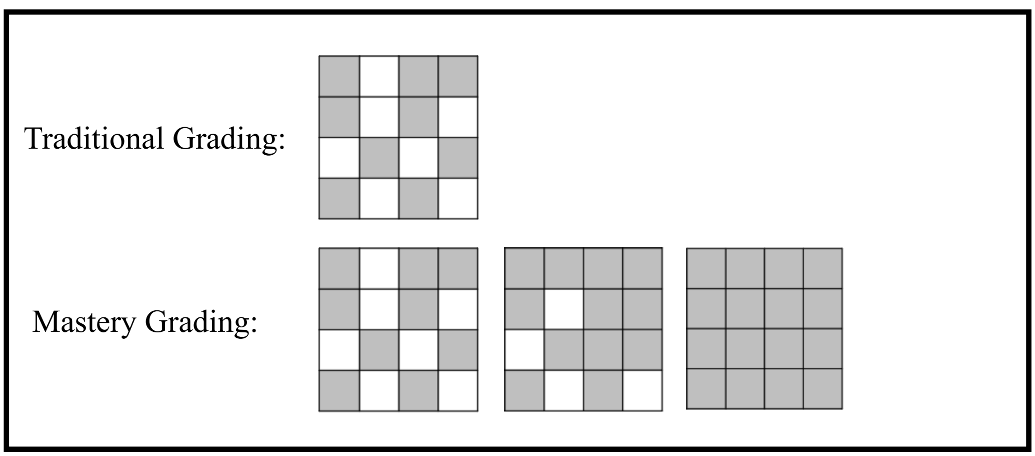

Figure 3: Student knowledge of basic concepts under traditional and mastery grading.

Review of Mastery Learning in Engineering

There are several frameworks for applying Mastery Learning in STEM. Oerther [11] adopts a framework where students must complete required assignments, based on the lower levels of Bloom's taxonomy, remember and understand. Students demonstrating mastery (100%) on these assignments, receive a grade of C for that module. Students completing all required assignments received a grade of C in the course. To receive a higher grade, students can complete additional exercises based on Bloom's Taxonomy at the higher levels of apply and analyze. Thus after mastering fundamental concepts, students can pursue higher grades. Performance at a 70% level, as required in a traditional course, will not demonstrate mastery. Oerther also reports a diversity of student opinions concerning mastery learning [12], with many comments indicating that mastery learning encouraged and enabled the life-long learning graduates need in their careers.

A self-paced approach with Mastery Learning was used in a first course in Physics (mechanics). [13]. Students were divided into two sections, one taught traditionally, and one using a self-paced mastery approach. In the mastery section, students took an oral quiz, and if they passed, could take a written test. Grading was based on identifying relevant concepts, applying appropriate solution methods, and correct answers. A score of 90% was required to pass each module. Students not passing the test would go over the results with a teaching assistant. The mastery sections required about twice as many teaching assistants as the traditional ones. Final exam results showed that the self-paced mastery group mean score was higher (Mean = 67.4, SD=15.7, N=151) than that for the traditional instruction group (Mean = 60.6, SD=17.5, N=160) [13].

How Carroll's Theory Can Guide Mastery Learning

Opportunity: Mastery learning introduced flexibility to allow some students more time to learn and demonstrate mastery. It is important that this time is being used for learning and not work in other courses or procrastination. Requiring reflection on previous test attempts or passing a pre-test before allowing a student to retake a test are ways to discourage retaking a test without learning the material.

Quality of Instruction: Clear communication of learning goals, what mastery of those goals entails, and how it will be demonstrated. This can be accomplished by a written (online) statement distributed at the beginning of each module and before each test or paper.

Perseverance: Communicate and demonstrate that hard work leads to success, not just innate ability. Students should experience this as they buckle down and study for understanding. Students may need guidance on what to do to learn, such as what textbook material to summarize, extra problems to work, etc. For example, memorizing the solutions to all homework problems is not likely to produce understanding and an ability to solve other problems.

Ability to Understand Instruction: Before retaking a test, students can be required to indicate what they need to learn for the test, and submit a plan for learning it. This might involve reading the textbook, reviewing notes, working practice problems or studying with friends. Again, guidance from the instructor may be helpful here. An adequate mathematics background, or knowledge of prerequisite material is needed to understand instruction in many engineering classes.

Results from My Classes

The framework this author has been using is to grade 75% of exam problems on a Mastery basis, give no partial credit for conceptual errors on those problems, allow retakes of those problems only, and require 100% of these mastery problems to be successfully solved to get a ‘C’ in the course.

Control Systems

EGR 330 Control Systems was taught in Fall 2023 and Fall 2024 using mastery learning. This course consists of a mix of third and fourth-year students. In the classroom, in-class exercises are used for students to learn by doing, and have a formative assessment of their knowledge. These exercises also facilitate students asking relevant questions. At the beginning of the semester, and subsequently, the students were informed the class would use mastery grading. Each of the four midterm tests consists of four problems each worth 25%. The first three problems must be completed with no conceptual errors on each exam to receive a passing grade in the course. A small number of points (1-3) is taken off for calculation errors. Each of these first three problems may be repeated multiple times. These first three questions represent fundamental concepts and design procedures. The fourth question on each test, worth 25% of the test score, is more complex and is used to determine grades of A or B. In the review for each exam, students are told what they are expected to be able to do, and they can work a practice test. In 2023, no penalty for retaking a problem was used. In Fall 2024, the first retake has no penalty. After that, a 20% penalty is assessed per retake for each problem or part of a problem that is retaken. A final exam with no retakes is also given, and a small project involving microprocessor control of a dc motor was required. Homework assignments were distributed on paper and online, and turned in online, with no repeats.

An increase in class GPA and percentage of students passing since using Mastery Learning has been seen. The penalty for retakes seemed to have little effect in discouraging students from retaking tests with inadequate preparation. This lack of effect may be due to the students not immediately ‘feeling’ the consequences of having to retake a problem.

Table 1. Student outcomes for Control Systems

Semester	**Fall 2024 Mastery**	**Fall 2023 Mastery**	**Fall 2022 Non-Mastery**	**Fall 2021 Non Mastery**
Number of Students	**19**	**22**	**30**	**24**
Percent Passing not counting withdrawals	**95%**	**90%**	**83%**	**77%**
Course GPA	**2.9**	**3.6**	**2.3**	**2.5**

Circuits and Electronics

Mastery learning was also used in EGR 225 Circuits and Electronics (electrical circuits for non-majors) generally taken by second-year students after completing Physics II. In the classroom, in-class exercises are used for students to learn by doing, and have a formative assessment of their knowledge. These exercises also facilitate students asking relevant questions. At the beginning of the semester, and subsequently, the students were informed the class would use mastery grading. Once again, four midterm exams consisted of four problems each, with the first three problems being fundamental problems that must be completed with no conceptual errors to pass the course, but can be repeated. Problem 4 was graded normally and was typically more complex. A final exam was given with no retakes allowed. In exam reviews, students were told what they would be expected to be able to do.

Homework utilized Pearson's Mastering Engineering, which allows repetition of missed problems, with some tutorial information and a small penalty, with students being given up to six attempts per problem. In general this was helpful, however a few students did take a trial-and-error approach, and sometimes came to me to request additional attempts.

The class GPA was essentially unchanged. The percent passing is increased from the average of the previous two years (93% vs 85%).

Table 2. Student outcomes for Circuits and Electronics (Electrical Circuits for Mechanical Engineering majors)

Semester	Spring 2024 Mastery	Spring 2023 Non-Mastery	Spring 2022 Non-Mastery
Number of Students	14	17	16
Percent Passing not counting withdrawals	93%	76%	94%
Course GPA	2.9	2.8	2.9

In general students have appreciated the opportunity to retake part of a test. Some students have objected to being required to successfully solve all required questions to pass the course.

Lessons Learned and Plans for the Future

As expected, stronger students generally required either no or one retake. In general, the penalties for retaking problems did not seem to have any deterrent effect in getting students to prepare for exams. In Spring 2025 students were required to reflect on the problems they missed and submit a short explanation of why their answers were wrong before retesting (Earned Resubmission). This has resulted in fewer retests than in previous semesters.

As a not-entirely-unexpected side effect, students report experiencing less fear during exams, and report feeling 'smarter' as a result. This reduction in fear, or test anxiety, may also be beneficial given the increase in mental health needs among students. [14]

Bloom's use of formative testing is being partially implemented by using practice tests for review rather than lectures. The author has found this approach especially useful in reviewing for the FE exam, especially in convincing students they need to study.

Conclusions

In the School Learning Theory, developed by J.B. Carroll [2], student aptitude is defined as the time required to learn, rather than the ability to learn. Learning depends on aptitude (time needed to learn), opportunity (time available to learn), ability to understand instruction, quality of instruction, and perseverance (time on task student invests in learning). This approach emphasizes hard work, persistence and flexibility, such as that provided by mastery grading. The amount of learning achieved is dependent on the relationship between the time needed to learn and the time available to learn. Thus a student who fails a test, works hard and learns the material, and successfully tests a week later has both learned, developed persistence, and developed the confidence needed to succeed and be retained in Engineering.

Carroll's theory suggests that there are ways to provide opportunities for the large number of underprepared students we are seeing, if they invest the time and effort, to succeed in Engineering, and improve retention. Most Engineering educators have also seen average students who are very successful in their careers. Mastery learning is a promising approach for enabling more students to succeed without lowering standards.

References

[1] B. S. Bloom, "Learning for Mastery. Instruction and Curriculum." *Regional Education Laboratory for the Carolinas and Virginia, Topical Papers and Reprints*, Number 1," Evaluation Comment Vol. 1 No. 2, May, 1968.

[2] J. B. Carroll, "A Model of School Learning," Teachers College Record, 64(8) , p. 723-733, 1963. https://doi.org/10.1177/0161468163064008

[3] A. Essa, S. Mojarad, S. "Does Time Matter in Learning? A Computer Simulation of Carroll's Model of Learning" in R.A. Sottilare, J. Schwarz, Eds. *Adaptive Instructional Systems*. HCII 2020. Lecture Notes in Computer Science, vol 12214. Springer, Cham. 2020.

[4] T. C. Reeves, "A Model of the Effective Dimensions of Interactive Learning on the World Wide Web," *Proceedings of Interaktiivinen Teknologia Koulutuksessa* (ITK'97), Hameenlinna (Finland), 1997.

[5] J. B. Caroll, "The Carroll Model: A 25-Year Retrospective and Prospective View," *Educational Researcher* Vol. 18, No. 1, Jan-Feb, 1989 pp. 26-31.

[6] J. B. Carroll, D. Spearritt, "A Study of a 'Model of School Learning'," Center for Research and Development on Educational Differences, Harvard University, Monograph 4, 1967.

[7] A. Mowreader, “24 Stats for 2024,” *Inside Higher Ed*, Dec, 2023.
[8] B.S. Bloom, “The 2 sigma problem: the search for methods of group instruction as effective as one-to-one tutoring,” *Educ. Res*. **13**(6), 4–16. 1984.
[9] M. Larson, “What is Mastery Grading” University of Nebraska-Lincoln Center for Transformative Learning, 2023.
[10] B. Whiting, G. F. Render, “Cognitive and Affective Outcomes of Mastery Learning: A Review of Sixteen Semesters.” *The Clearing House*, Vol. 60, No. 6, Feb 1987, pp. 276-280.
[11] D. B. Oerther, "Reducing Costs While Maintaining Learning Outcomes Using Blended, Flipped, and Mastery Pedagogy to Teach Introduction to Environmental Engineering," Proceedings of the 2017 ASEE Annual Conference and Exposition (2017, Columbus, OH), American Society for Engineering Education (ASEE), Jun 2017.
[12] D. B. Oerther, “Experience with Mastery Learning in Engineering Courses,” ASEE Annual Conference and Exposition, 2019.
[13] B. Masi, D. M. Watson, A. Bodek, D. A. Khaitan, E. Garcell, “Comparison of Mastery Learning and Traditional Lecture–Exam Models in a Large Enrollment Physics Course,” 2015 *ASEE Annual Conference & Exposition*, Seattle, Washington. p.23719, 2015.
[14] Center for Collegiate Mental Health. “2024 Annual Report,” Penn State University, Publication No. STA 25-489, Jan. 2025.