6-15-2019

Work in Progress: Mastery-Based Grading in an Introduction to Circuits Class

Noah Salzman
Boise State University, noahsalzman@boisestate.edu

Kurtis D. Cantley
Boise State University, kurtiscantley@boisestate.edu

Gary L. Hunt
Boise State University

Publication Information

Salzman, Noah; Cantley, Kurtis D.; and Hunt, Gary L.. (2019). "Work in Progress: Mastery-Based Grading in an Introduction to Circuits Class". *2019 ASEE Annual Conference & Exposition,* 26320-1 - 26320-13.

Board 64: Work In Progress: Mastery-Based Grading in an Introduction to Circuits Class

Dr. Noah Salzman, Boise State University

Noah Salzman is an Assistant Professor at Boise State University, where he is a member of the Electrical and Computer Engineering Department and IDoTeach, a pre-service STEM teacher preparation program. His work focuses on the transition from pre-college to university engineering programs, how exposure to engineering prior to matriculation affects the experiences of engineering students, and engineering in the K-12 classroom. He has worked as a high school science, mathematics, and engineering and technology teacher, as well as several years of electrical and mechanical engineering design experience as a practicing engineer. He received his Bachelor of Science degree in Engineering from Swarthmore College, his Master's of Education degree from the University of Massachusetts, and a Master's of Science in Mechanical Engineering and Doctorate in Engineering Education from Purdue University.

Dr. Kurtis D Cantley, Boise State University
Dr. Gary L Hunt, Boise State University

Gary Hunt a Special lecturer for the Engineering Science Department at Boise State University. Dr. Hunt received his Ph.D. in Education from the University of Idaho, his M.S. in Electrical Engineering from Colorado State University, and his B.S. in Engineering Science from Northern Arizona University. His educational research interests include freshmen STEM programs and the development of Scientific Reasoning in students.

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Introduction

Circuits is often the first required course in an electrical engineering curriculum that demands application of multiple concepts from prerequisite math and physics courses. This integration of knowledge can be a challenge for many students. Effective teaching methods can enhance the overall learning experience, increase program retention, and improve student understanding of foundational topics in electrical engineering. This paper outlines a mastery-based grading structure implemented in a sophomore-level circuits class. The focus is placed at this level because the course is a critical prerequisite for many other courses in the electrical and computer engineering (ECE) curriculum. The knowledge that students are expected to gain in circuits is paramount to successful completion of their degree. However, faculty often observe that many students pass circuits without being able to consistently apply many of the fundamental concepts therefore causing them to struggle through subsequent courses. The overall goal of this mastery-based grading scheme is to create a more positive student learning experience that also translates to improved long-term performance. It also helps to alleviate some level of test anxiety and the stress students feel in a fast-paced, rigorous course such as circuits.

Background

Mastery learning was first proposed by Bloom [1], with the idea being to allow students unlimited attempts at demonstrating complete understanding of a topic. In this serial approach, students would be required to demonstrate mastery of certain prerequisite topics before being allowed to move on to new topics. In contrast, mastery-based grading refers more generally to allowing students multiple opportunities to demonstrate mastery of a topic, though not requiring mastery before new topics are introduced [2], [3]. Prior to the introduction of mastery grading, this course would likely have one or two midterm exams and a cumulative final exam, in addition to homework and possibly a small project. Often, 50% or more of a student's grade would be determined by the exams only. Illness, lack of sleep, or loss of study time due to external factors can often be detrimental to student performance. This traditional structure also provides no motivating factors for a student to revisit the most critical topics after poor performance on an exam. They will simply move on in their studies to the current topic, without much consideration that many of the concepts build on some previously established foundation. The mastery-based grading structure forces them to eventually demonstrate understanding of the most critical concepts, with the goal of improving their long-term performance.

Mastery Grading Design

In preparation for the semester, relevant circuits faculty held a meeting to discuss potential grading structures and align on the final list of mastery topics. The challenge of this approach is that almost every topic covered in introductory circuits could be considered essential knowledge for something that comes later in the curriculum. In the end, the ten topics shown in Table 1 were chosen. Several common circuits textbooks were used as a guide [4]–[6]. During the meeting, it was decided topics that should be considered most critical are ones that students must be able to immediately apply in multiple subsequent courses without review or practice. How challenging or complex the concept may be could also play a role in determining its importance. There are certain concepts repeatedly used in circuits and beyond that students think are straightforward. Overconfidence in their own understanding often means they do not actually master the topic, which causes problems later on.

Table 1. Listing and brief description of the ten required mastery topics.

1. **Power and Energy.** Power is either absorbed or supplied by each element in a circuit. Sum of all powers must equal zero.	6. **Basic Nodal Analysis.** A fundamental technique for determining all voltages in a circuit containing only current sources or voltage sources connected to the reference node (ground).
2. **Ohm's Law.** The voltage across a resistor is given by the resistor value multiplied by the current through it: V=I*R.	7. **Basic Mesh Analysis.** A fundamental technique for determining all branch currents in a circuit containing voltage sources or current sources that belong to only one loop.
3. **Kirchhoff's Laws.** Kirchhoff's Current Law (KCL): the sum of all currents entering a node must equal zero. Kirchoff's Voltage Law (KVL): the sum of all voltages around a loop must equal zero.	8. **Ideal Op-amp Rules.** Ideal operational amplifiers have no current flowing into the input terminals, and source current from the output in order to make the two input voltages match.
4. **Equivalent Resistance.** Identify parallel and series configurations, and know how to simplify into single resistors.	9. **Standard Op-amp Configurations.** Know and apply equations for gain in standard ideal op-amp configurations, including inverting and non-inverting amplifiers.
5. **Voltage Division.** Be able to identify voltage dividers and apply appropriate equations to determine node voltages.	10. **Capacitors and Inductors.** Understand their steady-state operation, initial and final conditions when placed in a circuit.

The course was graded such that mastery of all ten topics in Table 1 had to be demonstrated over the duration of the semester in order to pass (obtain a final grade of C− or better). A detailed and labeled list of topics covered in the class, including required mastery topics and more advanced topics, was provided to the students. Every problem assigned on homework, practice tests, example problems, and actual tests was defined by one of the topics on the list. The first test on which each topic could appear was also included on the list. If mastery was not demonstrated on the first attempt, it was guaranteed that the topic would also appear on at least the next two exams. As such, there was at least three attempts to pass each mastery topic. If a student has already mastered a particular topic, they could ignore that problem on subsequent tests for no loss of points. In order to give students at least three attempts at the topics occurring later in the semester, seven total tests were administered, in addition to the final exam. Each of these tests was usually between 15-45 minutes long, and happened at the end of the designated 75-minute class period.

In addition to mastery topics, most exams also had problems for assessment of advanced topics (detailed in the topics list). These problems were graded with partial credit available for attempting them. At the beginning of the semester, a total of at least 200 points was expected to be made available in the form of advanced problems, which was how a student could obtain a grade better than C− (in addition to the points from homework and extra credit). All exams are closed book and notes, and exam dates were given up front on the schedule included in the syllabus.

A total of ten homework assignments were worth 10 points each, for a total of 100 points available. Assignments were handed out in class and available on the course's BlackBoard site and Google site. Most assignments were written and due at the beginning of class on the appropriate date. Late homework was accepted at a loss off the graded score of two points per day until reaching zero (e.g. an assignment with a score of 8.5 handed in on the afternoon of the due date will receive a 6.5, or on the afternoon of the next day will receive a 4.5, etc. It was found that almost no one took advantage of the late homework policy, and instead would just not turn in the homework at all if they knew it would be late.

Accumulation of points on tests, homework, in-class activities, and other assignments allowed students to obtain grades better than C−. The final grade breakdown based on how many points a student earned is shown in Table 2. A grade of D or F was only given if a student did not pass all ten mastery topics during the semester.

Table 2. Final letter grades based on earned points.

A+: >300	A: 270-300	A–: 240-270
B+: 210-240	B: 180-210	B–: 150-180
C+: 100-150	C: 50-100	C–: 0-50
D: 7-10 topics mastered		F: 0-6 topics mastered

Methods

A benefit to mastery-based grading and especially this hybrid approach is that the assessment can be done in much the same way as traditional grading. Homework, exam, or quiz problems can be used to provide feedback on student performance. The main difference, however, is that mastery grading is an all-or-nothing approach. On most circuit analysis problems worth a certain number of points, partial credit would likely be given if a student writes some correct equation. This scheme was a simple pass/fail grade for each mastery topic, and the problems were expected to be executed perfectly. An example of a mastery assessment problem for nodal analysis given on test 3 is shown in Figure 1a. A similar advanced nodal analysis problem from the same test but worth 20 points is shown in Figure 1b.

To track progress, the gradebook was set up with a different student in each row. One column for each mastery topic was used to indicate whether the student had passed that topic, and the number of tries they took to do it. There was also a column for the number of points scored on each test, which varied between 0 (on test 2 containing only mastery topics) and 40 points, with 75 points available on the final exam. One column for their grade on each of ten 10-point homework assignments was also added, in addition to a final column showing points earned from other sources such as in-class worksheets and hands-on activities.

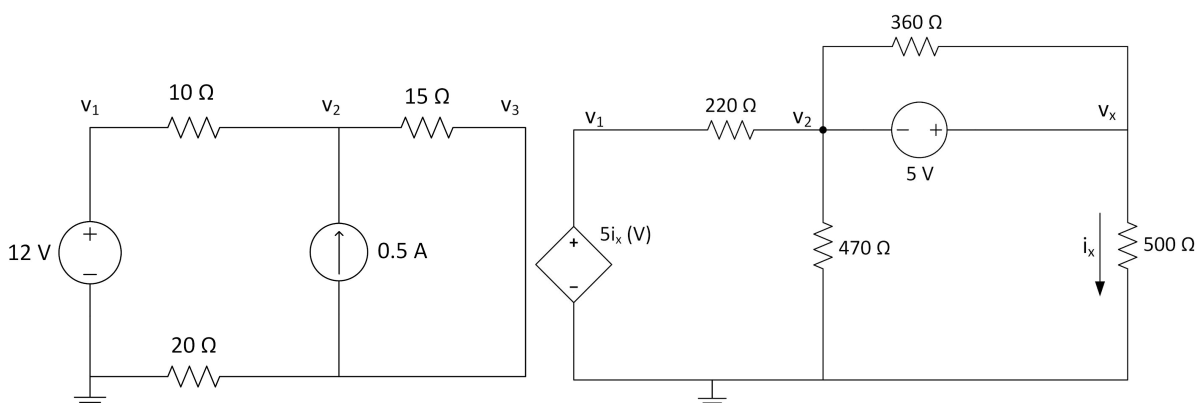

Figure 1. (a) Example mastery problem for Topic 6: Basic Nodal Analysis. Students were expected to perfectly solve problems with two unknown nodes and no dependent sources. (b) Example advanced nodal analysis problem worth 20 points.

Results

Student Performance

To determine the effect of the mastery grading system on student behavior, the count of how many tries it took students to master each topic were examined, as shown below in Figure 2. Note that there are topics of varying difficulty. Examining topic 6 (basic nodal analysis) we see that more than half of the students needed two or more tries to master the topic. This contrasts strongly with topic 4 (equivalent resistances), where only a couple of students needed more than one try to achieve mastery.

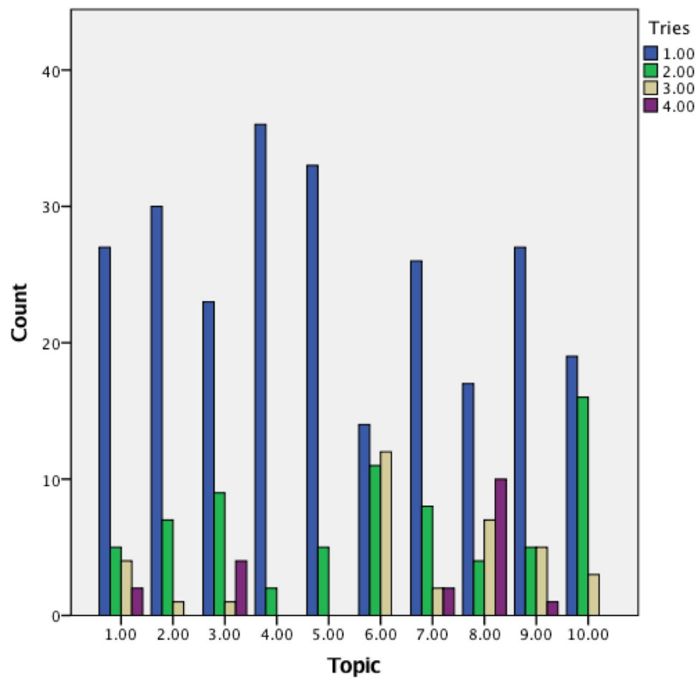

Figure 2. Distribution of number of tries by the topics given in Table 1.

Next, the relationship between student performance (their final grade) and the total number of tries used by a student was examined. This correlational analysis yielded a weak negative correlation between mastery topic tries and final overall grade, as shown in Figure 3, where $r(36)=-0.694$, $p=(.00)$.

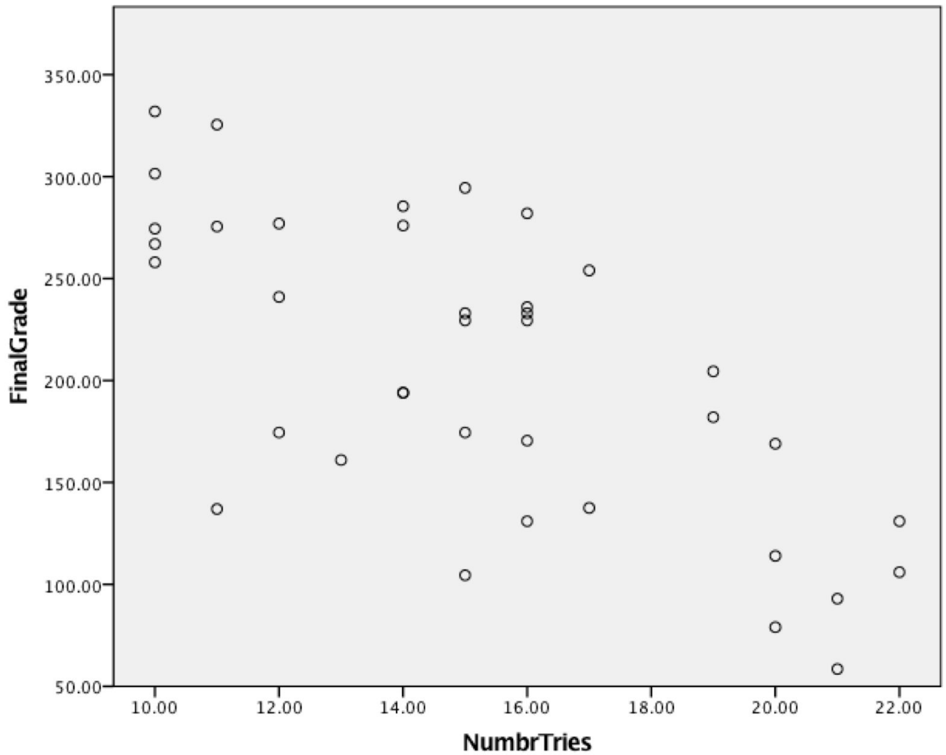

Figure 3. Scatter plot showing overall number of tries to pass all ten mastery topics versus final grade in the course, determined by number of points

This relationship suggests that higher performing students only need a few less tries than lower performing students. To better understand the significance of the total number of tries used by a student, a histogram of the total tries used was generated, as shown in Figure 4.

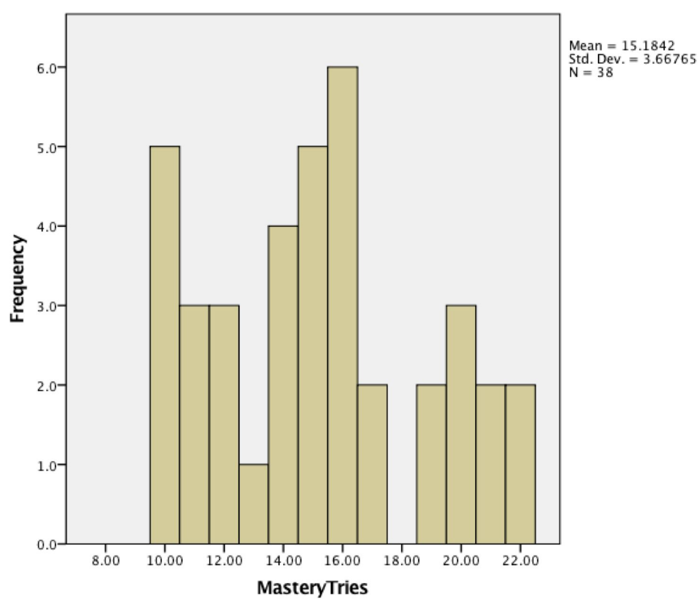

Figure 4. Frequency of total tries used by students during the master course.

Note that the tri-modal distribution shown in Figure 4 suggests breaking the students into three groups to see if the groups behaved or performed differently. The students were put into three groups as shown in the table below. Since there were 10 topics, the lowest number of tries was 10 for the student getting every mastery topic the first try.

Table 3. Student breakdown into groups by number of tries used.

Total Number of Tries	Number of Students	Total Tries Group
10-12	11	1
13-17	13	2
18-22	9	3

These groups were compared using box and whisker plots to see if they performed differently on the aspect of homework points and points earned on exams, as shown in Figures 5 and 6, respectively. Both plots suggest that students who used more mastery tries during the semester earned fewer points on exams and homework. This would tend to reinforce the idea that tries and final grade have a negative correlation.

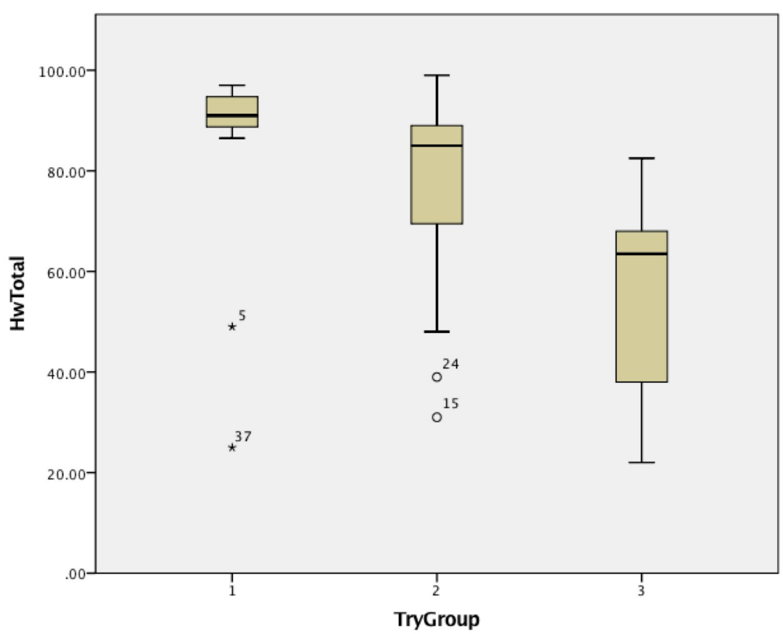

Figure 5. Homework points earned by different total tries groups.

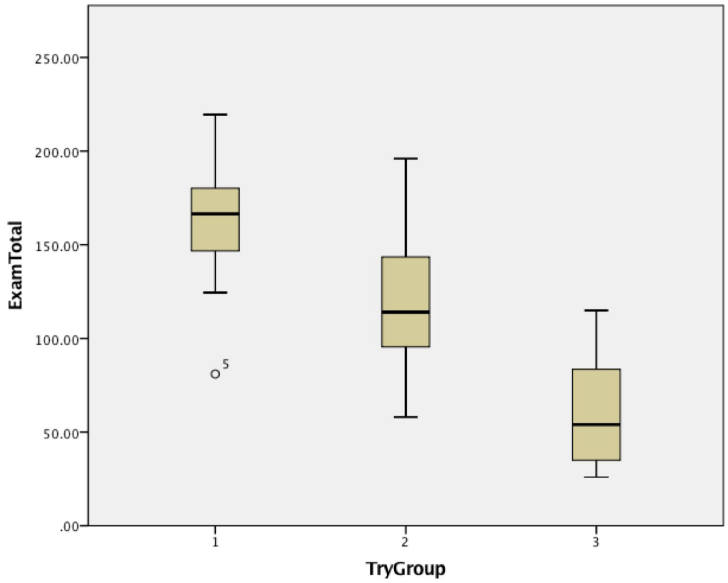

Figure 6. Test points earned by different total tries groups.

Figures 2, 5, and 6 all suggest the same result, which is that the number of tries utilized by the student is inversely related to the final grade. To put it another way, high performing students tended to use fewer tries than the lower performing students. This suggests a direction for future studies, looking to see what curricular components affect the number of tries.

Student Evaluations

Figure 7 shows a histogram of the students' overall ratings of using mastery-based grading in their Introduction to Circuits class. A majority of the respondents appreciated the approach, with 22 out of 32 students rating it as 8 out of 10 or higher. A smaller number (9 out of 32) gave a rating of between 5 and 7 out of 10, and only one student gave a poor rating to the approach.

Figure 7. Histogram of overall mastery rating from course evaluations.

Students gave several reasons for appreciating the mastery approach to assessment in the Introduction to Circuits class. Many students indicated that having multiple opportunities to complete each of the mastery topics greatly reduced test anxiety. One member of the class stated "It gives the student another chance to succeed where they failed", while another said "If there were only two midterms and a final I'm confident I wouldn't get a good grade in the course."

Increasing motivation and focus also emerged as a common theme from students' written comments on the mastery grading experience. One students wrote "This helped me focus on what the masery topics were and forced me to learn them", while another indicated that "We need to pass the mastery topics which forces us to study which is beneficial to us." Several students also valued the mastery approach as a way to understand what material in the course they needed to focus on learning, saying it "Helped me focus on what topics I needed to be professionally proficient in" and "It made me have to know the basics."

While Figure 8 shows that the majority of students thought highly of the mastery approach to assessment, students had several criticism of it as well. While they generally felt that the mastery approach reduced stress, only three tries to complete the basic mastery topics contributed to students' stress if they were on their third and final attempt to pass a particular topic. Several students also felt that the focus on mastering basic topics took away opportunities to learn more advanced topics. One student wrote "having to pass all of them to pass the class made studying the rest of the material pointless or very difficult because the mastery topics came first.", while other students stated "I focused too much on the basics and didn't spend enough time on the advanced" and "this approach really takes away from the other topics and I didn't feel as big of a need to focus or even work on them". Connecting the basic mastery topics to the advanced topics can also be a challenge, with one student writing:

> I was able to pass mastery easily every time but the advanced problems on exams were a lot more challenging and I did poorly on those. I would have liked the system to have had a strong connection between mastery topics and advanced topics. The masteries were super easy and advanced was super difficult, there was no in between.

In order for students to pass a mastery topic, they needed to complete the problem with no mistakes, which led to frustration for some students. One wrote "Having to do the mastery problems perfectly to get credit is kind of annoying. However, because we are given three tries each, it isn't that bad", while another compared this approach to a more traditional class stating "It punishes very small mistakes such as negative signs by missing the whole topic whereas in a traditional class the same work might earn a nine out of 10 or eight out of 10".

Finally, several students felt that the mastery assessment approach was logistically challenging, and stated "It's hard to understand where your grade is at in the class if you are interested in more than just passing the class. That might be because this is the first class I've had with the mastery grading structure and I"m still getting used to it." It can also be hard "just trying to remember which one you have passed/need to take". However, an anonymized list (by student ID number) that specified which topics were or were not passed was made available in each lecture prior to a test, as well as immediately before each test.

Challenges

One challenging aspect of this particular course design was keeping students motivated to push themselves and really expand their capabilities. There were students who only focused on passing the mastery topics, and had no desire to earn any additional points. They can be seen as outliers in the bottom left portion of Figure 2 or 6, having used very few tries to complete the mastery, but still earning final grades of C+. The primary cause was really the grading structure itself, since a student could pass the course without doing any additional work beyond passing mastery topics. However, another contributing and related factor was that mastery problems were probably slightly too easy. In the case where passing of all mastery topics is absolutely required, making the assessment problems too difficult is very hard to do. Otherwise, the instructor potentially finds themself telling multiple students that they have no chance of passing after only a few weeks into the 16-week semester.

Another difficult aspect of mastery grading is that it can require more effort on the part of the instructor. A much larger number of assessment problems must be created when students have multiple opportunities to pass them. In this course, mastery assessment-like problems were practiced and discussed in class using online polling system (iClicker). In addition, in-class practice tests were given in each lecture prior to an actual test. These practice tests contained similar problems, each of course labeled with their corresponding topic number, and were done in class. Allowing students the opportunity for deliberate practice was the justification for in-class practice tests. However, this resulted in an enormous portion of the lecture time being used for practice and assessment, and less for instruction. To offset this, practice problems were also provided in the two-hour discussion sections students were required to attend once per week. These sessions provided students with a significant amount of one-on-one instruction. Videos of the instructor solving numerous example problems were also created for the students to access at any time outside of class. Many students said they watched the videos on their phones, and the videos did have large numbers of views. Without these external opportunities available for supplemental learning, it would be easy to have a significant imbalance in the ratio of assessment versus instruction.

Finally, it might be anticipated that clearly communicating expectations to the students could be a challenge, but it turned out not to be. Every problem assigned on either homework or tests (both the practice and actual) was mapped to the labeled list of mastery and advanced topics. As such, students knew exactly the topics on which they needed to focus their study. A list of mastery topics they had or had not passed as well as their current point total was always available on BlackBoard. The same list was also generated in hard copy using student ID numbers as identifiers. It was passed out in each lecture before a test, and was always available immediately prior to and during the tests as well.

Conclusions and Future Work

Based on the results of the course evaluations, students were either indifferent to the mastery grading scheme that was implemented, or they were very positive about it (Figure 4). Only one student reported disliking the grading structure. From the standpoint of the instructor, the main disadvantage is the effort required for preparation, and time and grade management. On the other hand, it does not require significantly more time investment than other practices such as a flipped classroom. In fact, if a repository of assessment problems for each topic can be created by a group of instructors, the workload is much more efficiently distributed.

In the current semester, the circuits course is again using a similar mastery-based grading scheme, but with several changes to address the challenges outlined above. In particular, mastery topic 3 (Kirchhoff's Voltage and Current Laws, see Table 1) was split into two topics, resulting in 11 total mastery topics. In addition, students are now required to earn at least 70% of the total number of possible points in order to obtain a C, instead of only requiring demonstrating of mastery. This scheme will subsequently remove the outliers observed in Figure 2. It will also reduce the burden on the instructor with respect to making a strict determination of whether a student will pass or fail very early in the semester.

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