A Mastery Learning Approach to Engineering Homework Assignments

1. Introduction:

In many engineering courses, homework assignments are intended to be active learning experiences, where students are asked for the first time to grapple in depth with the concepts and methods discussed in class. For this knowledge building experience, formative feedback that allows the student to test and refine their own knowledge would be ideal, but the assessment practices in many courses treat homework assignments as a summative assessment, providing only a single, final judgment that does not allow the student to refine their solutions at all.

In this paper the authors discuss a method used to help refocus the evaluation of homework assignments in core engineering theory courses as formative assessment activities, encouraging students to master the content presented in the assignments. The mastery based approach encourages students to master the content by focusing on feedback and refinement of student solutions, rather than on grades. To implement this goal, the mastery grading system used an all or nothing grading scheme for each problem, but offered instructor feedback and allowed for unlimited resubmission of assignments without penalty. This rewarded mastery of the problems, encouraging students to continue working on the problems until they had completely and correctly answered every aspect of the problem.

Because this method had not been previously implemented in the classroom, the authors sought to conduct an exploratory study examining the feasibility of such a setup in the engineering classroom. Through this study the authors sought to answer the following questions:

- How will the mastery grading setup affect student homework behaviors and student performance on homework assignments?
- What are students' opinions of the mastery grading setup?
- What time commitments are required from students and from instructors to implement the mastery grading setup?

To answer these questions, the authors discuss the literature and theory behind the method in Section 2, the methods used to implement and evaluate the mastery grading setup in Section 3, the results in Section 4, the conclusions and their implications for practice in Section 5, and finally the limitations of the work and the potential for future work in Section 6.

2. Literature Review:

2.1 Formative Assessment:

Assessment in education serves to provide feedback on student understanding to both the student and to the instructor. By providing this feedback in a timely fashion during an instructional unit, it can serve to help the student identify topics that they do and do not understand and adjust plans accordingly, and it can serve to help the instructor do the same. When assessment fills this role, it

is known as formative assessment [1]. High quality feedback provided through formative assessment has long been known to be an essential part of the learning experience [1]–[3].

Another role that assessment can also fill is to verify that at the end of an instructional unit, the student sufficiently understands the content. When assessment fills this role it is known as summative assessment [1]. Though summative assessment is also an essential part of the educational system, it is not designed to aid student learning. Table 1 highlights the common differences between formative and summative assessments.

Table 1: A comparison of formative and summative assessments

Formative Assessment	Summative Assessment
Measures student understanding in order to adjust instruction to improve student learning	Measures student understanding in order to determine the level of success in reaching the learning objectives of the course
Provided in the midst of the instructional unit	Provided at the conclusion of the instructional unit
Usually constitutes only a small portion of the students final grade if any	Usually constitutes a large portion of the student's final grade

Because homework assignments are often viewed as a way for students to learn the content in the course, rather than a final evaluation of their understanding, the feedback on homework assignments would ideally serve as a form of formative assessment. In practice though, homework assignments are often evaluated as a single measure of student understanding at a single moment in time. This more closely matches the summative assessment approach, when a formative assessment approach would be better matched to improving student learning.

To make this transition from summative to formative, the focus must be shifted from feedback that measures success versus failure (i.e. the grade on the assignment) to content based feedback that identifies how the student can improve their understanding. Though this content based feedback may be offered to the student in addition to the grade on the assignment, there is often little immediate incentive for the student to pay attention to this feedback. In many cases it may be weeks before the student is asked to demonstrate proficiency in the topic area again, even if they demonstrated major gaps in their knowledge.

2.2 Existing Mastery Based Assessment Systems:

Though no existing literature was found discussing a system that was identical to the mastery grading system discussed in this work, prior work has been done to offer high quality formative assessment in classrooms which has informed the design and implementation of the mastery grading system described in this paper. The literature that is relevant to this research generally fits into one of three categories: rapid feedback systems (often called clickers), automated homework assessment systems with resubmission, and resubmission policies with course exams.

Rapid feedback systems ask students to answer multiple choice questions posed in class. The students' responses to these questions are collected either via an electronic device or via flash cards. The instructor can then use the aggregated student responses to adapt instruction to address any common misconceptions. This method has been shown to improve student learning [4]–[6], especially if integrated with peer discussion.

Though the method has been shown to be a valuable form of formative assessment offering instant feedback to the students, the method also has its drawbacks. Because of the nature of the data collection and aggregation systems, it only works well with multiple choice questions which may limit the complexity of the questions asked. In addition, even if long and complex questions are worded as multiple choice questions, having the students successfully solve these problems will require a significant amount of in class time, as these systems are not designed to work outside of the classroom.

Another widely used form of formative assessment is an automated homework assessment system where students are allowed to resubmit. In these systems, students submit electronic homework assignments to a computer program that automatically evaluates and offers instantaneous feedback on the student submission. After receiving the feedback, students are often allowed to redo the problem or at least a similar problem and resubmit that to the program for evaluation. Only the grade for the last submission counts as part of the homework grade. When properly implemented, these systems have been shown to have a positive effect on student learning [7], [8].

As with the clicker-based approach, this method also has a few drawbacks. First, the method works best with programming assignments that can most easily be assessed via computer program. Second, the development of an intelligent tutoring system that can offer valuable feedback to the student takes significant time on the part of the instructor, or requires monetary investment to access commercial tools.

Finally, though it is less common than the previously discussed methods, some engineering educators have implemented policies that allow students to retake in class exams where new scores replace old scores [9], [10]. This system was also implemented with the intention of making assessment more formative, though the differences in perceptions between in class exams and out of class homework may make a difference for students. Though the data on student learning is limited in these studies, they did indicate that students reported giving more attention to instructor feedback [9] and that the mastery system was more "fair" [10], showing promise for the methods and echoing similar results found in this study.

Because the focus of this project was on homework assignments conducted outside of the classroom, the design of the automated assessment systems were used as a starting point, though the evaluation itself would not be automated. The authors instead focused on emulating the process of offering feedback to the students and asking students to fix any mistakes and resubmit

the assignments. Though the feedback would not be instantaneous, it was hoped that the feedback and resubmission process would still be valuable as a formative assessment practice.

3. Methods:

3.1 Study Population:

The mastery grading system was implemented in two core engineering theory courses (one engineering dynamics class and one thermodynamics class) at different college campuses with two different instructors in order to get a broad view of the implementation. Both classes were relatively small with five total students in the dynamics class and eighteen in the thermodynamics class. To have a basis for comparison, data was also collected from two other engineering science classes (with the same instructor and at the same institution as the mastery based dynamics class). Each of these classes enrolled six students.

Table 2: Overview of Research Participants

Course	HW Grading System	Campus	Instructor	Number of Consenting Participants
Thermodynamics	Mastery	Campus A	Instructor A	16
Dynamics	Mastery	Campus B	Instructor B	5
Thermodynamics	Traditional	Campus B	Instructor B	6
Strengths of Materials	Traditional	Campus B	Instructor B	5

Students in these sections were told about the purpose of the study and consent forms were distributed, asking students to either sign to consent or not consent to the study. The consent forms were collected by a student who placed them in a sealed envelope that was not opened by the instructor until after final grades were assigned. This was done to eliminate possible bias in grading of students due to consent in the study or not. Though the mastery grading arrangement was used for all students in the course as part of the instructor's regular teaching responsibilities, data for non-consenting participants was removed at the end of the semester before analysis. Of all possible participants, twenty one out of twenty three possible students (91%) consented as part of the mastery grading sections and all eleven students (100%) consented as part of the control sections. At campus B, many students were enrolled in more than one class with instructor B (a common occurrence at small campuses), and thus may have been part of both experimental and control groups. Since student performance in each class is evaluated independently, each student's performance in each class was treated as a separate measure.

3.2 Mastery Grading Implementation:

The mastery grading system was implemented in the two classes described above across the entire spring semester of 2014. The procedure was introduced on the first day of class and also explained in the course syllabus. The complete procedure used for the mastery grading system was as follows:

1. Problems from the course textbooks [11]–[13] were assigned to the class and due on a weekly basis. Most assignments consisted of 3-5 open ended problems. At the assigned due date the assignments were collected from the instructor.
2. The instructor evaluated the student assignments and provided one of the three following marks for each problem.
    a. Mastered: The problem was answered correctly and completely.
    b. Not Mastered: The problem has one or more errors, or analysis was incomplete.
    c. Not Attempted: The student made no significant effort in trying to solve the problem.

    In addition to the each of the three possible marks, students receiving the not mastered mark were also given feedback on any mistakes or gaps in their analysis, guiding them towards the correct and complete solution.
3. Within one week, these marks were recorded by the instructor, and the assignments with the marks and the feedback were given back to the student.
4. The student was then given one week to use the feedback to correct any problems marked "not mastered". Students would rework those same problems on a separate sheet of paper and turn in the resubmissions stapled to the front of the original assignment.
5. The instructor would then grade the resubmissions, giving students one of the same three marks as in the original process, as well as written feedback for any problems still marked not mastered.
6. Students were allowed to resubmit in this fashion until they had either mastered all the problems or failed to turn in a resubmission on time. In theory this would allow for unlimited resubmits, but in practice no student turned in any assignment more than three times (one original submission plus two resubmissions).
7. At the end of the semester, the student's homework grade (20% of the total grade in Dynamics and 15% of the total grade in Thermodynamics) was the number of problems that the student mastered divided by the total number of problems assigned. This meant that students received no credit for a problem until it was mastered, but there was also no penalty for mistakes, so long as the student corrected those mistakes in the resubmission process.

The overall process was designed to encourage students to work to perfect the solution to each problem, without penalizing students for the amount of time they took to master each problem.

As the semester progressed, the process was streamlined in two ways.

First, for multi-stage problems, the instructors would mark the initial sections of the problem as correct. The student was then allowed to redo the problem from the end of that section, rather than having to rewrite the initial, already correct, portion of the problem. This saved both the student and the instructor time in the resubmission process, and eliminated what many students saw as meaningless copying of previous work. Second, when a large portion of the class made a particular mistake, the instructor would address the issue in the next class, rather than writing the

same comments out on many assignments. This served to save time for the instructor and allowed for more dialogue on particularly difficult concepts. Both of these changes were implemented early in the semester in both classes, and it is not believed that either of these adaptations fundamentally changed the mastery grading system.

3.3 Mastery Grading Evaluation:

To answer the original research questions posed in Section 1, multiple types of data were collected over the course of the semester.

- First, to understand how students used the mastery grading system and to understand the effect the system had on student grades, student grades were recorded over the course of the semester, including the grades at each step of the resubmission process.
- Second, to understand student opinions of the mastery grading system, semi-structured interviews were conducted with seven of the consenting participants at the close of the semester.
- Third, Instructor A (who was new to mastery grading), kept a journal of his experiences and perceptions of the grade for mastery system to help gather instructor opinions of the system and to help inform other instructors new to mastery grading in the initial implementation of this system.
- Finally, to better understand the time commitments required for the implementation of this system, the instructors recorded the time spent grading each assignment.

Grade data was collected from all students in the sections involved in the study by the course instructors. This included data from each step in the resubmission process for homework assignments, in order to see how students progressed from one step to the next. This was done as part of the normal instructional process, though non-consenting participants were removed from the data set and all data was anonymized before analysis was conducted. The data was then aggregated so that patterns could be looked for in the data.

After final grades for the class were assigned and the consent form packets were opened, students who consented were contacted to participate in a semi-structured interview to discuss the mastery grading system. As an incentive for participating in the interview, one student was randomly chosen to receive a $25 Amazon gift card. The semi-structured interview format followed an interview guide (Appendix A), but also allowed the interviewer to follow up on topics that arose spontaneously during the interview.

Finally, the instructors in the two courses took detailed notes on how long they spent grading each assignment and each stage of the resubmission process for each assignment. This did not include the development of the problem solutions, which would be the same in both instances, but it did include any time needed to enter grades into the course management system, as this varied across approach (more time to reenter grades). This data was collected in log books by

both instructors, noting the time they spent grading and the assignment and the number of submissions they were grading. The results from these logbooks were then aggregated at the end of the semester and used to gain insight into how the instructors spent their time grading in the courses.

4. Results:

4.1 Student Opinions:

For the results we will start by discussing the student opinions of the tool, as this informs some of the other results. As reported through the interviews, student opinions of the mastery grading system were all very positive. All seven of the students who participated in the interviews said they preferred the mastery grading setup over a more traditional homework grading setup. As justification for the preference for the mastery grading setup, two common themes could be identified in the interviews.

First, the majority of the students mentioned that they liked the process of focusing on and correcting what they got wrong initially. They felt that it helped them to learn and that it helped their course grade in the end because misconceptions could not be ignored.

> *"It [mastery grading] really put more emphasis on when you didn't get something in the homework you would go back and fix it. It just kind of helped learn it more because… well normally you get your grade and either you are like well I got it or I failed it and there is nothing I can do about so all I can do is think about what I can study for the test later."*

Second, many of the students felt the mastery grading system was a more fair way to way to grade the assignments. Students felt that if they spent the time to learn the material and answer the problems then they would eventually receive full credit for the assignments. Though some students were disappointed when small mistakes resulted in a "not mastered" mark on a problem, they were still motivated to redo the assignment which would eventually get them all the points for the problem. In the end, the students felt that this system resulted in fewer disputes over homework grades.

> *"The system is really fair, it's not ripping anyone off, and it just lets you get the grade you earned just a little bit easier, but you learn more at the same time…"*

> *"It [mastery grading] worked well because it's not going to kill your grade, if you put the extra time in to redo the questions you got wrong, then you get the points, and when you do you learn what you didn't see clearly before."*

4.2 Instructor Opinions:

In addition to recording the student opinions, instructor opinions were recorded on the implementation of the mastery grading method through the use of the journal kept by Instructor A over the course of the semester. Instructor B had previously used the mastery grading system and was helping Instructor A implement the system for the first time in his classes. The journal was utilized to gather the instructor's evolving perception of the mastery grading system and to provide guidance to other instructors who may wish to implement the mastery grading system for the first time themselves.

Overall, instructor perceptions of the system were positive. The instructor felt that students generally embraced the new system and there was less tension due to grades on homework. Additionally, because of the way the mastery grading system was set up, the instructor felt less pressure to normalize the grades, making sure that the same error always resulted in the same number of points deducted. For more detailed information on instructor perceptions of the system and for guidance in implementing the mastery grading system for the first time, see the companion piece for this paper [14].

4.3 Submission Behaviors:

Next we will discuss the student submission behaviors, examining why students did and did not utilize the chance to resubmit. It was suspected that different types of students (high achievers, average students, or struggling students) would utilize the system in different ways. For the most part however, there was a common factor that many students identified through the interview. If the student received a "not mastered" mark, they would almost always redo the problem, regardless of overall performance level.

Some exceptions to this occurred. First, students with poor attendance records and poor records of turning in the original assignment would also sometimes skip turning in resubmissions. This is not viewed as a direct result of the mastery grading system, rather a reflection of general poor participation by a small percentage of students across any system. Second, some students indicated that if multiple resubmits piled up and important coursework from other classes also became time consuming, they would sometimes fail to turn in a resubmission. In these cases they gave priority to other higher stakes assignments from this course and other courses. This piling up of work was mentioned as a drawback of the system by some students, and more commonly occurred at the very end of the semester when many classes had major projects due.

4.4 Student Grades:

Students generally felt that the mastery grading system helped their homework grades, and the data from the actual student grades supports that assumption. Below are two figures showing comparisons of the homework grades in the classes. The red lines show the average homework grades with the mastery grading technique (all students across all assignments) after the original submission, the first resubmission, and the second resubmission. The blue lines show the homework averages in the classes with traditional grading techniques (across all students and all

assignments). Since there were no resubmissions with the traditional grading technique, grades are shown as a flat line across all three attempts. Figure 1 compares the homework averages across the two thermodynamics courses while Figure 2 compares the three classes in the study taught by the same instructor.

As we can see in Figures 1 and 2, the homework grades with the mastery system started lower than with the traditional grading system. This makes sense because of the all-or-nothing approach to grading used with mastery grading, as opposed to the partial credit system used for traditional grading. By the end of the third resubmission, however, the averages with the mastery

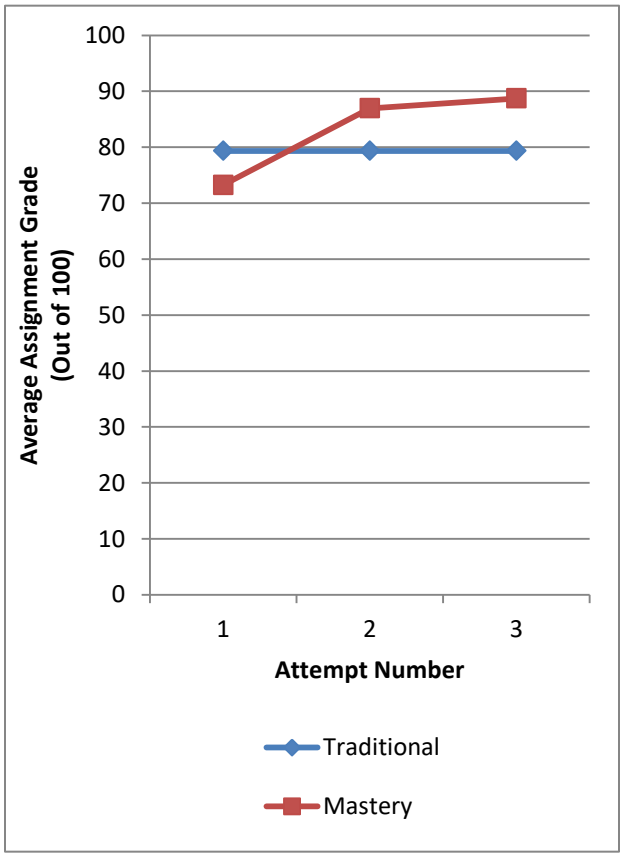

Figure 1: Comparison of homework grades with the same Class (Thermodynamics) but with two different instructors.

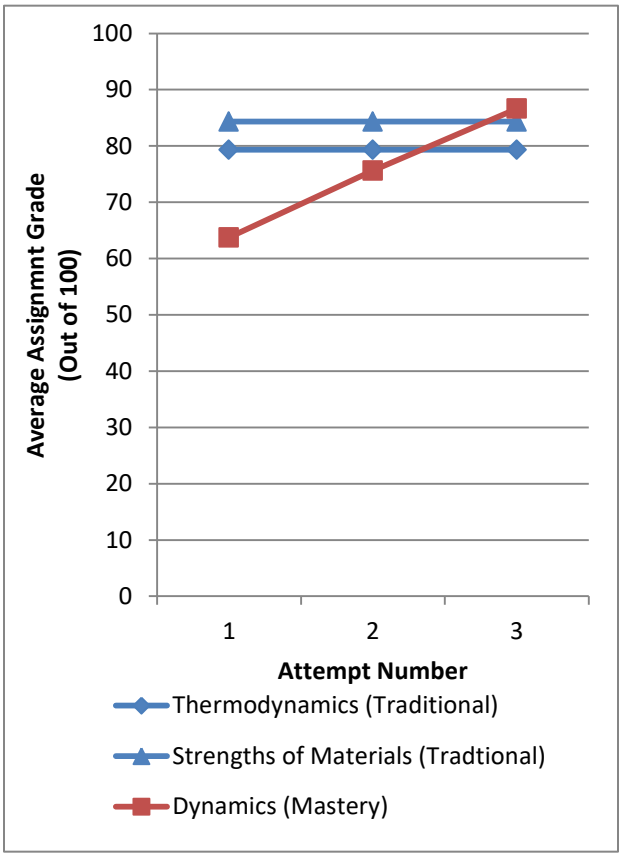

Figure 1: Comparison of homework grades with the same instructor across three different classes.

system had been raised above the traditional grading averages. Since the final grades were the only ones that matter with the mastery grading system, student homework grades were higher with the mastery grading system in both of these comparisons.

It can also be noticed that the gains seem to be higher between the two thermodynamics classes. This may point to a confounding factor with the dynamics class. Students interviewed from the dynamics class indicated that they felt the material in the dynamics class was harder to learn than the material in the thermodynamics and strengths of materials classes. This difference in

difficulty between courses may explain why the mastery curve is lower for dynamics and why there are still large gains even for the second resubmission.

4.5 Time Commitments:

Another point that is essential to the feasibility of mastery grading system is the time required of both the students and the instructors in the course. To evaluate the time commitment of the students, questions were posed during the interviews to determine if students spent more or less time on the assignments. To evaluate the time commitment of the instructors, the instructors took detailed records of the time spent grading assignments and these were compared to time records from the traditionally graded class sections.

In terms of the time that students spent on the assignments, all interviewed students agreed that they spent more time with the mastery grading system because of the time needed to redo any problems that were incorrect. Five of the seven interviewed students agreed that the time they spent on the original submission was the same as the time they would spend in a traditionally graded class but that the resubmissions meant they spent more time overall on the problems. One high achieving student said that they spent less time checking over the original assignment because they could fix any errors later, and one other student said they spent more time checking over the original assignment because they did not want to have to redo the problem later. Students also mentioned that sometimes, when multiple resubmissions piled up in addition to work from other classes, the workload could become a little hard to manage, but for the most part students said that the overall workload with the mastery grading system was manageable.

When comparing the time spent by the instructors grading the assignments, the time had to be normalized to take into account the differing number of students and the differing number of problems assigned in each class. To help in the comparison, the average time per student per problem was calculated. This was found by adding up all the time spent grading for a particular course, and then dividing by the total number of problems submitted to the instructor (including only original submissions, not resubmissions) times the number of students that submitted that problem. This gave the average amount of time that the instructor spent grading one problem for one student (including any time to regrade it). These average times were then used to compare the time spent on mastery grading to the time spent with traditional grading.

The first and most direct comparison was between the two thermodynamics classes. These classes had different instructors and were taught at different campuses, but the assigned problems were kept consistent between the two classes. In this comparison, the traditional grading instructor spent an average of 101 seconds per student per problem and the mastery grading instructor spent an average of 52 seconds per student per problem. This means that the mastery grading system actually took about half as much time per student per problem when comparing the two systems with the same problem sets but different instructors.

If we compare the three courses with the same instructor (one with mastery grading and two with traditional grading), we find the opposite of what was found in the multiple instructor comparison. The mastery grading took an average of 209 seconds per student per problem, while grading in the traditional courses took an average of 101 seconds and 92 seconds. This means that the mastery grading took about twice as long as traditional grading with the same instructor across different courses with different problem sets.

Overall the results from this analysis were inconclusive, as one comparison shows mastery grading taking significantly more time and one shows mastery grading taking significantly less time. It is suspected that student performance on problems plays a big role in the time spent grading those problems. Offering detailed feedback (done with both mastery and traditional grading here) to those students who made major errors was a time consuming process for instructors.

A second type of time analysis looked at the time spent grading original submissions versus time spent grading resubmissions in the mastery grading classes. In this comparison, it was found that the instructor using mastery grading with thermodynamics spent 86% of his grading time on original submissions and 14% of his time on resubmissions. The instructor using mastery grading in dynamics on the other hand spent 69% of his time grading original submissions and 31% of his time grading resubmissions. Though less time was spent determining how many points should be deducted with mastery grading, the time spent grading resubmissions would not have been spent with a traditional grading system. Therefore the best guess of the authors as to the time commitment of mastery grading uses the average of the two times spent grading resubmissions. It is estimated that mastery grading takes approximately 23% more time than traditional grading techniques, though again, the authors feel that more work needs to be done to better quantify the time commitment required for the instructor in the mastery grading system.

5. Conclusions:

Overall, the mastery grading system was well received by both the students and the instructors in the courses in this study. Students felt that the system better helped them learn, raised their grades, and was fairer as a grading system than the traditional one submission homework grading policy.

Generally students at all levels worked to improve their solutions until they were able to correctly and completely answer the problems within three tries. In working to redo problems that they had not completely and correctly answered, students spent more time examining and then acting on the content of the instructor feedback. This matches the original goal of the mastery grading system, trying to shift the focus in homework from grades to the content of the instructor feedback.

In terms of the time commitments, mastery grading does require more time from both the students and the instructors, though the extra time commitment from the students was generally

described as manageable and the extra time required for the instructor was tentatively estimated to be only 23% more than traditional grading.

Overall this study shows promise for the mastery grading system, and the authors believe that the extra time spent with the mastery grading system is more than worth the improvements in student learning and satisfaction.

6. Limitations and Future Work:

This work represents an exploratory experience with the mastery grading system, and although there is promise in the mastery grading system, there is still a lot of work to be done.

First and foremost, this study showed that students felt they learned more, but no direct comparison of student learning was made in this study. More work needs to be done to objectively measure the learning gains associated with the mastery grading system described in this work.

Second, with class sizes ranging from five students to eighteen students in this study, the feasibility of this system in large classes of a hundred students or more is still uncertain. In addition, the statistical power of the results of the study is limited because of the sample size. A study looking at how this system might work in larger classes would help to both increase the statistical power and determine how this system might be scaled up in larger classes.

Third, it was evident in the classes that some students had access to the solution manuals for the course textbooks. This is not uncommon for engineering students [15]. What is unknown is how access to solution manuals may impact the mastery grading process or how the mastery grading process may encourage or discourage students from using these solution manuals.

Finally, there is room to explore the social aspect of the mastery learning system. Students in the class were encouraged to work together on the homework assignments, and many students worked with friends to complete the assignments. It would be interesting to examine interactions between students who had mastered and not mastered problems, to see if any sort of peer tutoring occurs and to see how the mastery grading system would impact those relationships.

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Appendix A: Semi-Structured Interview Guide

Hello and thank you for speaking with me… (explain the purpose of the interview and **ask if they are okay having the conversation recorded**)

Background:

- Did you enjoy the course?
- How much do you feel you learned in the course?
- Do you feel that you did well in the course?

Opinions and Usage of the Grade for Mastery Technique:

- Tell me about your opinions of the mastery grading technique?
  - Tell me about your positive experiences with the setup.
  - Tell me about the negative experiences with the setup.
  - Explain how your experiences differed from your courses with a more traditional setup.
    - Do you feel that the setup helped or hindered learning?
    - Do you feel that the setup helped or hurt your course grade?
    - Do you feel you spent more or less time on your assignments because of the system?
- How often did you resubmit with this system?

What was the cutoff point for resubmitting (was there ever a point at which you felt it was not worth it to resubmit)?

Were you more or less likely to pay attention to the feedback on the assignments?

Any other comments you have about the grade for mastery setup?

How would you change the setup if you were teaching the course?