Mastery Grading for Equity in a Chemistry for Engineers Course

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Many teachers and instructors have used the traditional grading system since they began teaching and I am no exception. Assignments and assessments are provided and students earn points on these which add up to give them a particular grade in the course based on the 0 – 100% grading scale. Earn 90% of the points and an A is earned, 80% for a B, 70% for a C, 60% for a D, and below 60% designates failure of the course. Due dates are firm and there are not retakes on assessments. If students missed a particular day or deadline, they would receive a zero. This grading system rewards the students that are able to attend class every session and learn on the timeline the instructor determines. This inherited practice skews outcomes against already underserved student populations in typical engineering education, such as students of color and first-generation college students. Traditional grading practices have an embedded hidden curriculum that rewards behaviors such as attendance, participation, and turning assignments in on time rather than assessing the understanding of the content. This system favors the students that already know how to "do school".

The good news is that there are alternative assessment methods that are more equitable. All students can benefit from more equitable grading practices. These alternative methods are often referred to as "ungrading" and are more commonly embraced in arts and humanities courses. Of the faculty in the University of Colorado Denver's Ungrading Community of Practice, only two out of nine are faculty in STEM disciplines. Translating these grading practices to the STEM fields may draw concerns from many faculty that the academic rigor will be reduced. Yet, when the focus of assessment shifts toward proficiency with the content and skills being taught, learning can actually be enhanced, not diminished. With mastery grading, rather than earning points, the students are assessed on their level of mastery on a variety of content outcomes. Mastery grading allows for learning to be student-centered and focuses on the understanding of course content on the student's timeline. Mastery grading promotes the growth mindset [1] and highlights the learning process as a continuum rather than focusing on fixed high-stakes assessments.

Making the switch to a non-traditional grading system can seem daunting. The transition I describe in this work-in-progress paper was supported by my participation in the "Designing Learner-Centered and Equitable Courses" presented by the Association of College and University Educators (ACUE) during the summer of 2022. This course made me rethink my grading methods and teaching practices. Instructors such as Earle M. Crosswait III [2] from Saginaw Chippewa Tribal College and Candice L. Freeman [3] from Fayetteville Technical Community College as well as experts such as Joe Feldman [4] from Crescendo Education Group helped me understand how and why the traditional grading practices are not equitable. My interest was piqued, and I read Joe Feldman's book, "Grading for Equity" [4]. I was convinced that I must make a drastic change to how I teach my Chemistry for Engineers course—three weeks before the semester was to begin!

Chemistry for Engineers is a 5-credit course for civil, mechanical, and electrical engineering students. This course is required, although students can take general chemistry to satisfy the

requirement. This course covers the content of General Chemistry 1 and 2, but without the lab. The majority of students enrolled in the course are incoming freshmen with very little college experience. There is also a significant international student population for which this is their first semester at a US university. There are also many first-generation college students at this urban research university. According to an analysis by the university, 50% of undergraduates are students of color and 50% of undergraduates are first-generation college students [5].

There are three main pieces to the course transformation of embracing mastery grading: the grading scale, the late work policy, and the creation and use of learning outcomes with the ability to reassess. Use of any of these alone would help a course be taught in a more equitable way, but all three were implemented in the first semester, Fall 2022. There were 98 students enrolled across two sections of the course during Fall 2022. The following discussion outlines these three mastery grading elements, including how and why each was chosen and applied to Chemistry for Engineers as well as challenges that were faced. Following this is a summary of student reactions to this "new" grading system.

Grading Scale

There are a variety of more equitable grading scales than the 0-100% scale; The 0 – 4 scale was chosen, which is similar to GPA and the one thought most relatable to students. Rather than giving assignments a points or percentage score, all work is assessed using a 0 – 4 range. A 4 means A level work, a 3 means B level work, a 2 means C level work, a D equates to D level work and a 0 means either no submission, or F level work. This change led to more efficient grading. There were fewer worries about assigning points to problems and consistently awarding partial credit. It is much easier to identify A level work vs B level work as opposed to the difference between an 89% and a 91%. A general scheme for thinking about each of the 0 – 4 values was adapted from the work by Crosswait [2]. This chart (see Table 1) is provided to students in the syllabus for the course and discussed during class time.

Evaluation Score	**Meaning**
4	EXCEEDED THE STANDARD You have demonstrated complete mastery of this element by completing assessments with no errors. Your work is exemplary and complete. Translates to a grade of A
3	MET THE STANDARD You have demonstrated proficiency in this element. Your work indicates an understanding of the skill or concept but contains minor errors (incorrect or missing units, work not shown, transcription errors) Translates to a grade of B
2	HAS KEY GAPS IN UNDERSTANDING OF THE STANDARD You have demonstrated adequate progress in this element. Your work demonstrates a basic understanding of the element, but some questions remain. You may do well on simply stated problems but make mistakes on more challenging ones. Translates to a grade of C

Evaluation Score	Meaning
1	UNABLE TO DEMONSTRATE B OR C LEVELS WITHOUT ASSISTANCE You have demonstrated insufficient mastery in this element. Your work demonstrates that you have some gaps in your understanding, and success is erratic. This indicates that more practice is needed. Return to the lessons that support this element, or visit with me or the TA for additional problems to try. Translates to a grade of D
0	LITTLE TO NO EVIDENCE TO ASSESS You have demonstrated insufficient mastery of this element. Your work demonstrates little to no understanding of the concept or skill and contains foundational errors. This indicates the need for supplemental instruction with me, the TA, or a tutor. Unsubmitted work so cannot properly evaluate content mastery. Translates to a grade of F

Table 1

Late Work Policy

The second element changed was the late work policy. In the past late work was generally not accepted other than in extenuating circumstances. Over the years this had modified to accept late work for 50% credit. However, when using the 0 – 100% scale and entering a zero for one assignment, this means that student would have to earn multiple A grades on other assignments to negate the one 0%. [2] [4]This hardly seems equitable and certainly does not foster the growth mindset. Now a flexible due date policy is used. Students must still take quizzes and exams at the appointed time, but classwork, problem sets, etc., can be submitted at any time without penalty. With the mastery grading framework there is not room for grade penalties as the student is purely assessed on their mastery of the content, regardless of when it is submitted. Due dates are strongly suggested. Student feedback from Fall 2022 suggested that a subset of students preferred having some accountability to due dates and would have appreciated a bit of time management assistance. In response to this feedback, for this current iteration (Spring 2023) students are required to submit something by the due date to have late work accepted.

Learning Outcomes Creation

The third element addressed was the learning outcomes. The whole premise of this transformation is to grade students on what they are able to do or have learned in the course, rather than behaviors such as attendance, participation, and turning assignments in on time. This was the most challenging piece to create. However, the process did allow deep thinking about the most important aspects of the content and the greater purpose of the course in the context of engineering education. For Fall 2022 and Spring 2023, four main categories of outcomes were used (Modules, Big Ideas, Chemistry Challenge (CC), and Skills).

Module Outcomes

The Modules outcomes are comprised of smaller outcomes specific to each module (or chapter). Three to five outcomes were written for each module. For instance, one outcome from Module 2 is: *Identify numbers of protons, neutrons, and electrons in isotopes and ions.* An outcome from Module 6 reads: *Calculate Energy from frequency and wavelength. Convert between frequency and wavelength.* Notice that these outcomes are written in a way such that they can be easily assessed. Outcomes should be brief statements that include verbs that can then translate to questions or activities to be used as the assessment tool. Students can refer to the outcomes text through the learning management system for the university.

Big Ideas Outcomes

The Big Ideas outcomes are comprised of concepts that cross modules and are embedded in the whole course. Examples of Big Idea outcomes in the course relate to significant figures, dimensional analysis, stoichiometry, and complex problem solving. The stoichiometry Big Idea outcome reads: *Use stoichiometry to determine amounts of reactants and products in chemical reactions. Full mastery includes mass to mass calculations, using molarity in solution stoichiometry reactions, using both the Ideal Gas Law and stoichiometry to calculate quantities in reactions involving gases, and stoichiometry in thermochemistry equations.* There are multiple points to this outcome, as you may expect in a Big Idea. This particular category of outcomes is assessed using a decaying average to allow for multiple assessments covering different topics. The most recent score is weighted more heavily than the older scores. This promotes the growth mindset and the idea of continuous improvement and helps motivate the students to continue their work on the content rather than giving up after one or more low marks.

Chemistry Challenge Outcomes

The Chemistry Challenge (CC) is a team project that the students work on throughout the semester. Students select a topic they want to dive more deeply into and develop a procedure, perform experiments, collect and analyze data, and present their results in a poster session. These outcomes are specific to this project and include aspects of teamwork. CC outcomes include experimental design, data analysis, and teamwork. For example: *Analyze numerical data correctly and arrive at a logical conclusion based on the data.* An outcome from ABET's criteria for accrediting engineering programs was also included in this category: *Shows an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives*.

Skills Outcomes

The Skills outcomes include general college skills that are important to work on in any course, particularly for new-to-college, first generation and traditionally underserved populations of students. This category includes outcomes such as being able to properly cite sources, being able to layout calculation work and explain process, and being able to use scientific vocabulary appropriately in writing. For instance: *Uses scientific vocabulary correctly when discussing concepts. Shows understanding of "engineering vocabulary" in written work.*
These skills can be demonstrated in a variety of assessments at any time during the semester.

Overall Grade Calculation

Each category has several outcomes in it and are weighted differently in the overall grade calculation. The final course grade is determined by averaging each of the outcomes in a category together and then applying this equation to the category averages:

$$Course\ Grade = Modules\ (0.60) + Big\ Ideas\ (0.20) + CC\ (0.10) + Skills\ (0.10)$$

The grade results in a number somewhere along the 0 – 4 scale and equates as it would to the GPA. The scale used in this course is shown in Table 2.

Table 1

Grade Minimums
A = 3.7
A- = 3.5
B+ = 3.3
B = 3.0
B- = 2.7
C+ = 2.3
C = 2.0
C- = 1.7
D+ = 1.3
D = 1.0
D- = 0.6
F = < 0.7

Outcomes Reassessment

The final element to think about is the reassessment of outcomes. Amongst the many goals in adopting this style of course assessment promoting the growth mindset and allowing students to learn at their own pace (within the constraints of the university semester) is central. It is essential to put the learning back in the students' hands with focus on the understanding of content rather than the high-stakes, high-stress assessments and points accumulation. Every outcome is assessed at least 2 times. The course is broken down into 3 units with 4 -5 modules per unit. Generally, each outcome is assessed on a module quiz, a multi-module application set (such as a project, problem set, etc) and a unit exam (all the modules in that unit). The quiz is the first opportunity for an outcome to be assessed, then the application set, and then the exam. Ideally, the student receives the quiz feedback and is then aware of what specific outcomes they need to work on and then are improving their level of understanding with the application set and then the exam. After the exam, module outcomes will not be assessed again in class. However, this does not mean that students no longer have the opportunity to show mastery of an outcome. Students can attend office hours or a specific reassessment period to reassess on outcomes of their choosing.

Determining how to do this reassessment was rather challenging. Since mastery levels are naturally being reassessed within a unit, no outcomes reassessment was allowed until after the unit exam. Additionally, students could not reassess on outcomes unless they had submitted all the relevant application sets. It was hoped that students would reassess throughout the term, but as you can imagine, the vast majority of students chose to reassess the last week of the term, which presented a myriad of scheduling challenges. Unit Exam 3 was given on the last day of the term and after grading overall grades were posted. The final exam period was dedicated to reassessment. If students were happy with their grade after Exam 3, they did not need to attend the final exam. If students wanted to improve their grade, they were allowed to do so during the final exam period. The final exam consisted of a question for every single outcome and the students decided for themselves which ones they wanted to answer. Students were assured that taking the final exam would not lower their grade and were encouraged to try and improve their grade.

Iterations

Due to the overwhelming request in the last week of the term, reassessment has been modified for Spring 2023. Reassessment for Units 1 and 2 can be done 2 weeks after the respective exams during a special reassessment session outside of class time. If students do not reassess at that point, they can reassess during the final exam period. In addition to the aforementioned reason for this change, this is in the best interest of the student as the content covered in Unit 1 is needed for understanding Units 2 and 3. As in many courses, content is connected and success depends on understanding of the content presented in the beginning of the term. I'm hopeful that this method will be more successful and provide motivation for students to review content in which they are not yet proficient sooner rather than later.

Student Response

Fifty-six percent of students did take advantage of reassessing opportunities in Fall 2022. In past semesters after each exam we just moved on. Students didn't have an opportunity to improve their grade, nor was there incentive to actually go back and review previously not well understood content. There have been more students this year attending both my and the TAs office hours to better understand content than in years past.

Student response to this grading style has been positive. Students have shared their thoughts through Faculty Course Questionnaires (FCQ) (from the University) as well as a survey I created in the learning management system. 35 students completed the LMS survey 63 students completed the FCQ from the university. Demographics information was not collected and I do not have access to which student wrote which response in the university FCQ as this is meant to be anonymous.

The open-ended prompt on the FCQ from which exemplar comments are drawn was: *please offer constructive comments to your instructor on the most effective aspects of this course.* The question on the LMS survey relating to outcomes based grading was as follows:

As you know, I switched the grading in this course from a traditionally graded course (points based) to a Learning Mastery (outcomes based) grading system. I am committed to this switch as it is more equitable and promotes a growth mindset, but I know I need to iterate some more on it!

What did you think? (I know this is a broad question, but I honestly don't know how to ask this and I don't want to put ideas in your head as I want your general comments and feedback). I guess I'd like to know things like--Did this style of grading work for you? Did you feel like you had more control over your learning and your grade? Did I give you enough tools to know where you stood on your grade and level of understanding? Did I provide enough opportunity for you to increase your mastery level?

Compare this style of grading to the traditional style in terms of motivation, stress level, another way you think of . .

Do you have any ideas of how I could better support students?

Student comments fall into four main categories: quality of learning, retention of information, stress level, and understanding where to focus their studying. Suggestions for improvement were mainly centered around providing more explanation of the grading system.

Exemplar Student Comments Fall 2022

"This was the first time I have ever had this type of grading and it was a relief. I was currently taking 18 credits this semester with hard classes like physics and calculus but I was never worried about my grade in this class. I knew that I could always makeup my grade if I was failing and it was a relief that I wasn't rushing to study or pull all-nighters to raise my grade."

"I think the new grading system is better for determining where you need to put effort in to study. Overall better than the "normal" grading system."

"It allowed for more time spent on actually understanding a topic instead of just trying to get a good grade for the test and then forgetting about it."

"I had a lot more control over my grade."

"It allowed me to understand the content at my own pace rather than having to learn the content at the professor's pace, which in turn helped me learn the content better all together."

"I have taken chemistry 3 times and failed three times. This system of outcomes and mastery has not only allowed me to succeed in my most hated subject but to also actually enjoy it."

"While scoring well is a nice ego boost, it's meaningless if the retention of the material is shallow. Mastery-based outcomes force you to be evaluated on the same things if you haven't demonstrated proficiency, which is necessary given that engineers have a pretty important responsibility to know what they're doing in the field."

"Mastery grade is supported by peripheral assignments that aren't graded, which emphasized the importance that putting in additional work had on the class. This is something I never really gave thought to before, opting for the bare minimum."

Conclusions

When thinking about teaching in a more equitable manner there are many things to consider. Mastery grading is one way that can address a myriad of inequitable practices embedded in the traditional grading system and instruction of college and university courses. Converting a course over to mastery grading can seem daunting at first, but is achievable as presented here, even in the STEM fields. As evidenced by the positive response from students, this grading system is certainly worth pursuing. The outcomes-based grading system allows the learning to be managed by the student and is aligned with the growth mindset.

It is too early to discern the impact specifically on underserved populations. Future work could include collecting data on demographics such as race/ethnicity and whether or not the student is a first-generation college student. This could be done through the LMS, but probably not through the university FCQ as those are meant to be anonymous feedback. I would like to be able to compare student final grades between mastery and traditionally graded sections, but am unsure of how to "control all the variables". Anecdotally I have noticed that there are fewer "A" grades than in the points accumulation grading model. This makes sense in that now I am evaluating only their understanding of the material and not including "participation points" that tend to skew outcomes against those already underserved populations. I have also noticed fewer "F" grades, again anecdotally, from students that are genuinely trying and stay in the course until the end of the term.

The course transformation can be done in steps or all at once. But one thing is for certain—the need for us to recognize that for most students, college is not their only priority. This does not mean they don't want to succeed, but rather, that we need to adapt to help them succeed. In the mastery grading framework there is not room for grade penalties as the student is purely assessed on their mastery of the content, regardless of when it is submitted. Students are allowed the freedom to learn on their timeline rather than ours. The practices presented here help ALL students, not just those from privileged backgrounds. As people review their courses and methods of instruction through the lens of equity and inclusion, they must recognize that grading practices contribute to inequity. Mastery grading is one approach to promoting equity and refocusing education on student learning and growth.

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