Developing an Alternative Grading Scheme for Engineering Classes

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Choosing and Developing an Alternative Grading Scheme for Engineering Classes

Abstract

Traditional grading has long been proven to have several negative effects, including increasing student anxiety and providing no actionable feedback. Ideally, a grading scheme will encourage intrinsic motivation for students, increase the value of time spent grading, and be clearly linked to the desired course and student learning outcomes. However, navigating the landscape of alternative grading can be confusing, especially for faculty who haven't had time to experiment. This paper seeks to explain the most used alternative grading schemes, explore instructor feedback from several implemented schemes, and provide a process for selecting and developing a grading scheme for engineering classes.

Introduction

Alternative grading schemes (e.g. ungrading [1], standards-based grading [2], and specifications grading [3]) are pedagogical tools that can provide great benefits to both instructors and students. A well-designed grading scheme can motivate students, reduce grading load, and even provide a framework for success in the class. However, navigating the landscape of alternative grading can be challenging. In some cases, advice is contradictory. In others, it can be difficult to understand the distinction between methods. In almost all cases, papers and books focus on a single grading scheme, with comparisons only to traditional grading methods.

This paper provides an overview of the most popular grading schemes, examples of grading schemes developed for engineering courses, and a framework for choosing and developing an alternative grading scheme. Advantages and disadvantages of each scheme are listed, as well as situations where they should be most applicable. Three case studies are provided as examples. Dr. Brown has taught Fluid Mechanics with a specifications grading framework for many years, while Dr. Ehrke has experimented with mastery grading for Calculus. Drs. Marshall and Kennedy plan on switching Senior Clinic to an ungrading-flavored scheme next year.

While similar work has been done for general audiences (e.g. Grading for Growth [4], UNgrading [1]), this work focuses on the application of these schemes specifically in engineering education. The goals of an engineering classroom are substantially different than the average college classroom, with the additional needs of ABET accreditation and professional licensure (i.e. the FE exam). Thus, the authors' key assumption is that most engineering courses will have some number of outcomes that are summative in nature. That is, the goal is not "growth" or "engagement", but rather that students at the end of a course will be able to perform some number of measurable tasks.

Learning Outcomes

The question that any grading scheme should answer is "Did the student get what they should have out of the class?" In other words, every class should have some number of learning outcomes, and every grading scheme should be outcome-oriented. If you describe the outcomes of the class, even in broad strokes, you can start to narrow down how to grade the class. There has already been a great deal of discussion on this topic, including both debates on the merits and discussion of practical implementations. For that reason, the authors will defer to [5] and [6] for an overview.

Outcomes can vary wildly depending on discipline, type of class, and position in the curriculum. Bloom's taxonomy [7] is the default method for developing and organizing learning outcomes. However, it fails to provide guidance on the type of assessment we should apply. Instead, we will categorize outcomes as follows:

a) Technical skills-based
    - "Students should be able to resolve vector forces." (Statics)
    - "Students should be able to apply conservation to pipe flow." (Fluid Mechanics)
    - "Students should have the prerequisite skills for the next class in the curricular sequence."
b) Professional skills-based
    - "Students should apply aspects of engineering design, including meeting requirements, defining specifications, and iterating on solutions."
    - "Students should work effectively in teams."
    - "Students should be able to outline, draft, and revise a professional presentation."
c) Knowledge-based
    - "Students should know the jobs/careers available as an engineer."
    - "Students should know the crystal structures that commonly appear in metals." (Materials Science)
d) Improvement-based
    - "Students should better understand the subject than when they began the class."
    - "Students should be better writers than when they began the class."
e) Labor-based
    - "Students should consistently show up to labs and work diligently with their teammates until the lab is completed."
    - "Students should spend 5 hours per week, including class time, working on their group project."

Typically, lower-level engineering courses are heavily weighted toward technical skills-based outcomes. Upper-level courses, especially design electives, tend to favor project-based learning for a mix of technical and professional skills [8]. Professional skills-based outcomes are heavily represented in ABET's Student Outcomes. In some curricula, these are relegated to individual courses (e.g. SO 4 in Engineering Ethics, SO 3 in Technical Writing). In others, they are distributed throughout the curriculum, with summative assessment in a Capstone class.

Courses which have predominantly knowledge-based or labor-based outcomes are not thoroughly discussed in this paper. However, there is some literature on specifications grading and mastery grading in General Chemistry courses [9], [10], in which the structure of the course is only slightly modified from traditional grading.

The discussion now shifts to how we can best assess these various categories of outcomes.

Grading Schemes

In this section, we will give a short overview of traditional grading and four major alternative grading schemes. The notable strengths and weaknesses of each are provided, as are the types of classes where the grading scheme is most likely to be helpful.

Traditional Grading

In traditional grading, grades are given on individual assignments on a percentage or point basis, often with partial credit awarded relative to the level of competency shown. The final grade is assigned based on a weight average of the grades on each assignment.

Traditional grading is simple, and typically well understood by students. However, numerous studies have shown negative effects of traditional grading [4]. Most important for this paper is the disconnect between traditional grading and the outcomes of courses.

Instructors should use traditional grading when they feel the benefits of other grading schemes do not outweigh the additional complexity. This might be true for introductory or survey courses, where the goal is creating a foundation of knowledge without the need for specific skills.

Mastery Grading

In mastery grading, all assignments are seen as opportunities to demonstrate mastery of a specific skill or knowledge base. The entire class is subdivided into individual skills, often between 20 and 30 different components. The final grade is assigned based on either the number skills where mastery was demonstrated or demonstrated mastery of a certain subgroup of skills.

Mastery grading directly maps grades to technical skills-based outcomes. Additionally, it prioritizes repeated testing, which is shown to be an effective practice [11], likely due to the effectiveness of retrieval practice [12]. Students value feedback over traditional testing, as failed skills must be revisited prior to continuing to later assessments. However, the necessity of designing multiple test items for each outcome, then managing the testing/retesting process can be complex.

Instructors should use mastery grading when their classes primarily teach technical skills. It has been found to be effective for Calculus, Statics, Introductory Programming, and other courses [13].

Labor-based Grading

Labor-based grading is focused on completion of defined tasks, rather than on the quality or correctness of the completed work. Often, final grades are decided based on a contract between the professor and students [14].

Labor-based grading does not evaluate student skills, which is a dealbreaker for many engineering courses. However, Marriott et. al. [15] included a quality-based metric in an introductory computer science class, though they reduced the bar for a "complete" significantly below what was necessary for a perfect score in a traditional grading scheme.

Some aspects of labor-based grading have been used at our university for group-based work in large projects. Students submit time sheets in Senior Clinic, similar to what is expected in an industry environment. This provides a level of accountability for the members of each group.

Existing literature does not support purely labor-based grading for engineering courses, but it may have a place in some courses as a portion of the grading scheme. For instance, labs may benefit from a baseline requirement of "completion" of lab work, possibly with a simple reflection component.

Ungrading

In ungrading, assignments are seen solely as tools to facilitate learning, rather than artifacts used for determining a grade. Feedback may be provided on individual assignments, but the feedback itself is not tied to a grade. Implementations of ungrading in STEM varies, ranging from asking students to assign points for exams within an otherwise traditionally graded class (see Chapter 9 of [1]) to asking students to choose a grade for the entire class, provide justification, and defend their choice in a student-teacher conference [16], [17].

Ungrading benefits from encouraging introspection and self-evaluation, both of which are valuable skills. Engaging in metacognition, in turn, provides learning benefits. Adopters of ungrading say that their students come to class more curious and ready to learn, with the explanation that the extrinsic motivation of grading has been replaced with intrinsic motivation. However, even proponents cite difficulty with holding students accountable, happy instead that average engagement improves [1].

A fully ungraded approach consists of allowing students to choose their own grade with guidance by the instructor, but without opportunity for the instructor to challenge the grade. This approach has not taken hold in engineering education. However, partially ungraded classes, either with the professor reserving the right to adjust grades as needed [17], or solely applying self-grading to specific assignments [18], have found benefits related to both student stress and quality of work.

Ungrading is best for learning outcomes that benefit from qualitative feedback. This is most true for professional skills such as communication and teamwork. Indeed, the strongest proponents of ungrading are those that teach writing and other liberal arts. In engineering, this is most applicable to courses that have a significant project-based learning component.

Specifications Grading

Specifications grading, at its core, seeks to eliminate partial credit [3]. Ideally, every question or assignment can be assigned a grade on a pass/fail basis. Specifications are built on the number of successfully completed assignments, or on the completion of bundles of assignments. However, due to the pass/fail nature of the assessments, opportunities for either retakes or revise/resubmit cycles are typically provided. Because of this, many specifications grading schemes have strong overlap with mastery grading.

Strictly speaking, however, specifications grading is very broad. It can be used with any of the grading schemes described above (except, perhaps, a pure ungrading approach). It works especially well with project-based learning, as the definition of a “passing” project can also be specified, and cycles of revision and resubmission work very well with projects.

Because of the focus on pass/fail assessment, proponents of specifications grading cite reduced grading time as a large impetus for adopting the scheme. However, this is offset by the need to design additional assessments for retake opportunities, along with needing to grade resubmissions for writing assignments and projects.

A well-designed specifications grading scheme can increase clarity and better communicate expectations with students. However, these schemes tend to be complex, often requiring a checklist for students to determine a final grade. Based on Dr. Brown’s experience, students often require multiple discussions of the grading scheme throughout the year. A grade audit a week or two prior to the end of the semester reduces surprises, but is difficult to automate, as learning management systems assume traditional grading is the norm.

Case Study 1 – Fluid Mechanics (Dr. Brown)

Fluid Mechanics, as taught by Dr. Brown, has a number of technical skills-based learning outcomes, split into five modules. The full list of outcomes is provided in Appendix A.

- Module 1 - Hydrostatics
- Module 2 - Internal Flow
- Module 3 - Pumps and Systems
- Module 4M - External Flow (Mechanical Engineering students only)
- Module 4C - Channel Flow (Civil Engineering students only)
- Module 5 - Reynolds Transport Theorem

In addition, there are several professional skills-based outcomes tied to a project in Module 3:

- Students will be able to use engineering design principles to design a product that involves pipe flow and at least one pump (ABET SO 2).
- Students will be able to communicate their design effectively through a written report. (ABET SO 3)

The combination of technical skills-based outcomes and project-based learning points to a specifications grading framework which incorporates a large portion of mastery-based grading. The grading scheme used by Dr. Brown is discussed next.

Fluid Mechanics Grading Scheme – Specifications Grading with Mastery Flavor

Assessments in Fluid Mechanics consist of three online quizzes and an in-person exam for each module, a major project based on the content of Module 3, a minor project based on the content of Module 4, and a cumulative final exam.

Additionally, video quizzes are assigned to introduce topics throughout the semester and a homework set is assigned every week. However, these are not used to determine a final grade, and are instead used to earn tokens. Tokens, in turn, allow for exam retakes and project resubmissions at a rate of 10 formative assignments (video quizzes, online quizzes, and homeworks) for one retake/resubmission.

Table 1 contains the grade requirements for Fluid Mechanics. Completion of a module refers to scoring 2/2 points on all three online quizzes related to the module (unlimited retakes) and scoring 4/5 points on the module exam (retakes limited by tokens). The "add-ons" and testing criteria are provided in Tables 2 and 3.

Table 1. Grade Requirements for Fluid Mechanics

	A	B	C	D
Complete two modules	✓	✓	✓	✓
Complete modules 1-3	✓	✓	✓	
Meet expectations on Module 3 Project	✓	✓	✓	
Number of required "add-ons"	2	2	0	0
# of testing criteria completed	2	1	0	0

Table 2. "Add-ons"

Meet Expectations on Module 4 Project
Complete Module 4M or 4C, depending on major
Complete Module 5

Table 3. Testing Criteria

Pass the Final Exam
Earn 75% or more on the Final Exam
Pass two exams without using retakes
Pass four exams without using retakes

Fluid Mechanics Grading Scheme Philosophy

One of the defining aspects of specifications grading is the bundling of skills or assignments. In this case, technical skills are bundled into topical modules. Three of these are considered "core" to the class, and are therefore required for a passing grade of "C". Additional modules are considered "optional" and are used to improve grades from the baseline "C".

In addition to the technical skills, there are two professional skills that are evaluated through a design project. Once again, it is required to demonstrate those skills at a sufficient level to pass the class. The precise expectations are enumerated in a rubric, which is attached in Appendix B.

A flavor of mastery grading is applied by allowing a limited number of retakes for the high-stakes exams and an unlimited number of retakes for the low-stakes online quizzes. A standard mastery grading scheme would require demonstrating mastery of individual technical skills. Instead, this scheme bundles those skills into exams, reducing the complexity and amount of administrative overhead in managing retakes.

The limited number of retakes is imposed through a token system. Each retake attempted by a student requires 10 tokens, which can be earned through finishing homework assignments (completion graded), watching videos and taking video quizzes, and finishing the online quizzes for a module prior to the exam. All told, there are approximately 50 tokens available in the class. This is done to incentivize students to do the things that will help them learn, while also reducing grades assigned to coursework that is done outside of class (and can therefore be completed easily by ChatGPT, copying from classmates, or similar).

In short, this grading scheme implements a mastery grading system mixed with project-based learning, leaves formative work mostly ungraded, and is governed overall by a specifications grading framework.

Instructor Experience and Student Feedback

The challenge that originally led to experimenting with specifications grading was that students were neglecting or putting minimal effort into the major design project. With traditional grading, even assigning the project a grade percentage as high as 30%, some students would aim to get half of the points with minimal effort. While it may have been possible to develop a rubric which adequately encouraged students to participate, it was much simpler to enumerate the project's expectations and make those expectations required to obtain a passing grade. This has worked well, encouraging the process of feedback and revision to obtain an acceptable product.

The best part of the grading scheme, from a professor's perspective, is that students will come to office hours after an exam to correct mistakes. Students come to discuss the feedback left on exams. Because students are required to eventually earn 80% on their exams, they must eventually learn the material. For some students, the first attempt acts as a diagnostic tool, while they are able to demonstrate improvement on the retakes.

From the student's perspective, the best thing about the grading scheme is the ability to retake any high-stakes exams. Because of the grading scheme, students perceive that their learning is more important than their performance on any given assignment. They care about feedback, and the interactions we have are almost always positive.

The logistics of providing retakes is greatly simplified by the architecture of the engineering offices. Immediately outside of Dr. Brown's office is a shared space with tables for students to work in close proximity to their professors. This allows for proctored exam retakes with only minor effort, and multiple students may retake an exam at once any time Dr. Brown is present. After each exam, the number of retakes required is known, so the exams can be printed ahead of time, further streamlining the process. Without this space, an instructor seeking to implement a system of exam retakes might request an additional table and chairs for their office or find another shared space (perhaps the campus library) for designated retake times.

Dr. Brown aims for an approximately 50% pass rate for the first attempt on exams. Occasionally, the pass rate is significantly lower than expected. Rather than implementing a curve for the exam, additional tokens might be given, or a supplementary oral exam may be provided for students reaching a certain score threshold. In those situations, passing the supplemental exam has counted as passing the original for grade calculation reasons. There is a lot of flexibility when the result needs only to be boiled down to a "pass" or a "fail".

Case Study 2 - Calculus (Dr. Ehrke)

In addition to the various learning outcomes related to specific types of problems (e.g. calculating a derivative), Calculus I utilizes five course-wide learning outcomes or CLOs. These CLOs are the framework upon which all questions in the course depend. Essentially, students are asked to demonstrate their mastery of calculus in each of these areas:

- CLO-1: Students analyze graphical depictions of derivatives, limits and their applications in a variety of contexts. (GRAPHICAL ANALYSIS)
- CLO-2: Students are able to synthesize information from a variety of techniques to give complete discussions of solution behaviors in context and draw conclusions about those behaviors. (SYNTHESIS AND DISCUSSION)
- CLO-3: Students construct and justify the validity of appropriate mathematical models of a variety of physical phenomena suitably expressed through calculus. (MODELING)
- CLO-4: Students select and apply appropriate methods in obtaining analytic solutions of problems in calculus. (QUANTITATIVE SKILLS)
- CLO-5: Students use appropriate terminology and notation to classify and describe topics related to the study of calculus. (TERMINOLOGY AND DISCUSSION)

The focus of this course is on technical skills, leading to mastery grading as the basis for assessment. Similar to the course structure of Dr. Brown in Fluid Mechanics, a project is included to harness the well-known benefits of project-based learning. Specifications grading is also used to encompass assignments which do not directly relate to the five CLOs.

Calculus I Grading Scheme - Mastery Grading with Added Specifications

This approach to grading relies on assessing a student's performance on each CLO (as listed above) within each assignment. The result is a hybrid of specifications grading (pass/fail the assignment based on assignment standards) and mastery-based grading (pass/fail based on mastery of competencies tied to individual questions within the assignment). To assess each of these areas the following assessments were given:

- Vehicles for CLO assessment questions
  - Mastery Quizzes - Short quizzes over individual mastery outcomes.
  - Exams - Three exams are given throughout the semester, along with a comprehensive final exam containing a section corresponding to each of the five CLOs listed above.
  - CALC Labs - Collaborative group-based assessments, over higher-level concepts that require analysis, application, synthesis, discussion, critical thinking, and/or technology.
- Additional assessments
  - Graded Inquiries - Pre-class assignments introducing students to new material to allow class time to focus on retrieval practice and learning gaps.
  - Group Project - This applied project requires students to work in a group to integrate many of the concepts from the course, compile a report and give a presentation.

Every assessment question, whether it be on a mastery quiz, exam, or CALC Lab, is marked with a mastery code CLO-1 through CLO-5. Individual questions are graded as Excellent (E), Satisfactory (S), or Progressing (P). (S) is reserved for responses with only minor errors of formatting or simple arithmetic errors. Any error stemming from a misunderstanding or misapplication of calculus skills will result in a grade of (P). Mastery in any one CLO requires obtaining a grade of (S) or (E) on 85% or more of the assessments in that area.

Additionally, Guided Inquiries and CALC Labs are graded as a whole, with Graded Inquiries given grades of either Satisfactory (S) or Unsatisfactory (U) and CALC Labs following the standard (E), (S), (P) grading for the course.

The full list of requirements for each grade is provided in Table 4. At the instructor's discretion, students may move up one letter grade based on their performance on the final.

Table 4. Grade Requirements for Calculus I

	A	**B**	**C**	**D**
Number of CLOs Mastered (out of 5)	5	4	3	2
Guided Inquiries scored (S) (out of 10)	9	8	7	6
CALC Labs scored (S) or (E) (out of 5)	5	4	3	3
Course Project scored (S) or (E)	✓	✓	✓	

Calculus I Grading Scheme Philosophy

Calculus I is a foundational course for engineering students. Assessing a student's level of mastery in Calculus I is important for predicting success in future courses. Most traditional grading schemes do not require mastery. Rather, they base a student's competency on completion of assignments and questions with an accumulation of points as the goal. Liberal application of partial credit can result in a student receiving a passing or near passing grade on such assignments without completing a single question correctly. For instructors in subsequent courses, inheriting students that have shaky calculus foundations is cause for concern. By repeatedly "passing" such students those foundational cracks compound until their framework for succeeding in math or engineering courses crashes down. This happens somewhere around the end of year two when differential equations and multivariable calculus are encountered.

The same is true for the student who has typically gotten by through memorizing content. As the required number of basic calculations a student must master expands, students who fall back on memorizing steps as opposed to generating mastery over concepts will see their ability to pass on memorization alone become increasingly challenged. To that end, our approach to calculus instruction blends *mastery-based* grading with *retrieval practice strategies* drawing on the lessons learned in [3] and [12].

This grading system insists students show consistent excellence in *all* assignments in the course --- outstanding work on Mastery quizzes, for example, does not "bring up" poor work or non-involvement on CALC Labs and vice versa. This level of consistency can be challenging for students, so the course provides for a system of revision and reassessment on most graded tasks. The idea is that *mistakes are data*. Failure shows us where we need to improve and it does not render a final verdict on our ability to succeed.

Students may attempt reassessment of mastery quizzes during office hours or at a scheduled reassessment period. Exams (except the final) may be reassessed once within a week of the initial test date. Finally, CALC Labs may be revised and resubmitted up to one week after their due dates.

Calculus I Instructor Experience and Student Feedback

Dr. Ehrke taught Calculus I using this approach over four semesters between Spring 2018 and Fall 2019. Each semester the CLOs and grading scheme were iterated slightly based on student feedback and concluded with the one shared above. There are several immediate takeaways from this experience.

First off, the major positive points:
1. This grading scheme identifies student weaknesses and gives actionable feedback for students. As the semester progresses students can see how they are progressing in each of the 5 CLOs. If they begin to lag behind in any one area they know in which area they need improvement and how to ask for help.
2. Specifications for (E), (S), (P) are clearly outlined on assignments so grades are not subject to bartering by asking for more partial credit points or extra credit.

Now, some of the drawbacks:
1. This grading scheme requires substantial prep work. All assignments (including exams) and retakes must be prepared ahead of time so the instructor has a firm understanding of how many questions will be asked in each CLO. Then, clear specifications for what constitutes an (E), (S), or (P) must be written for each assignment and question.
2. The grading logistics can be challenging. Modern LMS gradebooks can be used but do not cater exactly to this type of grading. Dr. Ehrke found more success keeping a separate grading spreadsheet and updating CLO assignment category grades in Canvas as the course progressed. A teaching assistant can help organize and report grading data.
3. The retesting logistics can be challenging. Since students are trying to achieve mastery in the course, a fair number of students will visit office hours and reassessment sessions. Again, a teaching assistant can staff reassessment sessions.
4. Deciding a final grade can be agonizing. Our university does not have a (+/-) system for grades, so students earn A, B, C, D or F for each course. Based on the letter grade assignments outlined in the table above, a student should earn a C if they satisfactorily complete only 7/10 guided inquiry assignments. Even if that student were to perform outstandingly in the other areas their lack of consistency in that one area would bring down their overall grade. Allowing the final exam to improve the final grade by a letter provides a way to ameliorate this particular problem.

In light of the experiences outlined above you might come away hesitant to try a different grading scheme. Dr. Ehrke would argue the experience alone is worth it, even if the outcome isn't perfect. Taking some time to reflect on the experience, developing more consistent habits of gathering feedback from students, and asking yourself what is truly important in the course, and what is just filler, are all worthwhile payoffs for your efforts.

Case Study 3 - Senior Clinic/Capstone (Drs. Kennedy and Marshall)

While there are some outcomes related to successful completion of the project, most of the outcomes for Senior Clinic are professional-skills based. Of the seven ABET student outcomes, four of them are assessed through this experience (SO 2 – application of engineering design, SO 3 – communication, SO 5 – teamwork, and SO 7 – lifelong learning). The other three could also easily apply, but we have shifted the assessment burden to other classes.

In addition, Senior Clinic is largely project-based. There are two major team milestones each semester. The milestone submittals vary based upon discipline and client, but are defined through agreement between the student team, the client, and the faculty coach as would occur with a scope of work document in industry. Ideally, the student meets the expectations of the client at these milestones, but their grade should not be tied solely to client satisfaction.

The combination of professional skills and project focus points toward a specifications grading framework with some portion of the grade based on ungrading. Here is a possibility:

Senior Clinic Grading Scheme – Mixed Labor-based Grading and Ungrading

Students who fail to meet the requirements of a “D” will receive an “F” in the course.

To obtain a “D”, a student must:
- Complete 7 of 15 time sheets
- Complete 7 of 15 weekly goal worksheets
- Meet expectations on 2 of 4 professional development assignments
- Miss no more than 8 group meetings without prior notice for approved absences
- Miss no more than 2 client meetings without prior notice for approved absences
- Participate in all milestone presentations

To obtain a “C”, a student must:
- Complete 12 of 15 time sheets
- Complete 12 of 15 weekly goal worksheets
- Meet expectations on all professional development assignments
- Miss no more than 4 group meetings without prior notice for approved absences
- Miss no client meetings without prior notice for approved absences
- Participate in all milestone presentations
- Receive an average grade of “Meets Expectations” on faculty coach feedback forms

For a grade above a “C”, students must provide additional evidence of performance on their project. This will be done through an end-of-semester conference between the student and instructor of record for the course. Students will prepare by completing reflection forms for each of the milestones in the semester, as well as a cumulative semester performance reflection form. As part of the cumulative performance reflection form, students will choose a grade that they wish to defend.

To prepare students for the end-of-semester conference, students must also schedule a mid-semester conference, which will be used to provide feedback on performance and chances for improvement. The discussion in the mid-semester conference will draw on peer evaluations, faculty coach feedback forms, and course instructor assessment to provide formative feedback to the student.

Final grades will be determined by the evidence provided by the student in their end-of-semester conference. Barring sufficient evidence to the contrary in the form of peer evaluations, faculty coach feedback, or instructor assessment, the student's proposed final grade will be accepted.

Senior Clinic Grading Scheme Philosophy

The main goals behind the grading scheme listed above are to ensure participation in the work of the project and to help students engage in self-assessment of professional skills. Students must engage with the course to receive a passing grade. To graduate, students must participate in the work of their team, at least to the degree that their teammates don't see a need to fail them.

Many of the outcomes of this course are associated with professional skills, many of which are exceedingly difficult to assess in a standard fashion. An "A" student should be able to defend their performance in design, communication, teamwork, and acquiring new knowledge. In some ways, this mirrors the act of asking for a raise or promotion in the workplace, or the process of tenure/promotion in academia.

Developing a Grading Scheme

Determine Course Outcomes

While not universally accepted, it is generally agreed that every class should be designed around its learning outcomes. In short, course outcomes should be specific and measurable, using action verbs to describe student skills at the completion of a course.

Prioritize or Group Outcomes

One possible path to develop a grading scheme is to identify a subset of the learning outcomes that are "core" to the class, leaving additional learning outcomes as "optional" or "additional" outcomes. Attainment of the core outcomes should be sufficient to pass the class, while attainment of the additional outcomes can be used to justify an increase of grade from "C" to higher scores. This is the path demonstrated in both the Fluid Mechanics case study by Dr. Brown and the Senior Clinic case study by Drs. Kennedy and Marshall.

Another path, not demonstrated here, but present in Chapter 5 of "Grading for Growth" [4] is to group outcomes into several categories, then require students to demonstrate a specified number of outcomes within each category. This allows for student choice while ensuring that students are not deficient within any particular group. In this path, higher grades are tied to a larger number of outcomes in each category.

Match Outcomes to Grading Schemes

In the Fluid Mechanics and Calculus I case studies, most of the core outcomes were technical skills, which match very well with a mastery grading approach. The professional skills may have been better matched with ungrading, but ungrading fails to enforce individual outcomes, and specifications grading was also a good match for the project. Thus, specifications grading was chosen, with a strong mastery flavor.

For the Senior Clinic case study, the core outcomes were participation/labor-based, so a labor-based grading scheme was appropriate. The professional skills evaluated in the class are very difficult to assess through a labor-based contract, so another grading scheme must be chosen. These outcomes span the entire project, are very difficult to grade traditionally, and cannot realistically be revised/revisited without retaking the entire class. Mastery and specifications grading both rely on being able to retake assessments, so the only reasonable remaining choice is ungrading.

Test and Iterate

As in all good design projects, the first pass of a grading scheme will rarely meet every expectation. Ask your best and worst students what works and doesn't, try to realign student incentives with your own goals for the course, and change assessments that just aren't working.

In one of Dr. Brown's early attempts, hard deadlines were given for retakes of exams. Of course, an otherwise good student failed the exam, then missed the deadline on the retake. Grace was extended with some minor consequences, then the policy was modified in future classes to a soft deadline by increasing the token cost after the deadline passed.

Tips for a Successful Scheme

If you choose to implement a token scheme, allow students to earn enough tokens to retake all assessments required for a passing grade. This will create sufficient scarcity to encourage students to earn tokens, but will rarely result in situations where students fail due to lack of tokens.

Don't feel like you need to completely revamp a course to see benefits from a new grading scheme. It's possible to do a partial conversion, perhaps grading a single exam using mastery grading or using specifications grading for a project. A minimal implementation would have grades based on traditional grading, but with additional stipulations based on the partial conversion. For instance:

- D - at least 60% average on all class assignments
- C - at least 70% average on all class assignments
- B - at least 80% average on all class assignments, meet expectations on class project
- A - at least 90% average on all class assignments, meet expectations on class project

Conclusions

Navigating the world of alternative grading can be challenging, but it is a rewarding way to transform your classes. Being clear about learning outcomes, how we are assessing them, and how we grade them enhances communication between students and instructors, reduces student stress, and ultimately enhances student learning.

Mastery grading, ungrading, labor-based grading, and specifications grading all have a place in engineering education, though they should not be forced into every class. There are enough documented downsides to traditional grading that every instructor should be willing to investigate alternatives, even if those alternatives involve different grading schemes for different outcomes.

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Appendix A - Full List of Outcomes for Fluid Mechanics

- Module 1 - Hydrostatics - Students will be able to:
  - calculate pressure change through an incompressible fluid medium
  - determine forces and moments due to hydrostatic loads on flat surfaces
  - determine forces due to hydrostatic loads on curved surfaces
  - solve static problems involving buoyancy
- Module 2 - Internal Flow - Students will be able to:
  - solve problems neglecting friction using the Bernoulli Equation
  - solve problems involving laminar flow in pipes using Poiseuille's equation
  - solve problems involving turbulent flow using the Moody Diagram
- Module 3 - Pumps and Systems - Students will be able to:
  - develop system curves for single-inlet, single-exit pipe systems
  - read manufacturer pump curves
  - determine an operating point for a system
  - evaluate the energy requirements and efficiency of the system
- Module 4M - External Flow (MECH students only) - Students will be able to:
  - determine lift and drag forces for flat plates, blunt objects, and airfoils
  - calculate induced drag on finite wings
  - analyze horizontal and vertical axis wind turbines
- Module 4C - Channel Flow (CIVE students only) - Students will be able to:
  - determine flow for open channels
  - design open channels for specific flow parameters
  - calculate the effect of hydraulic jumps on open channel flows
- Module 5 - Reynolds Transport Theorem - Students will be able to:
  - apply the Reynolds Transport Theorem to conservation of mass, momentum, and energy for steady-state problems
  - calculate the force generated by fluid flow through pipe systems
  - calculate the energy generated by fluid flow in a Pelton turbine

Appendix B - Professional Skills Rubric for Fluid Mechanics

	Does Not Meet Expectations	Meets Expectations
	ABET SO 2 - Engineering Design	
Objective Identification	The objective of the design product is insufficiently discussed	The following questions are answered: What is the purpose of the product? How is the success of the product measured?
Multiple Design Alternatives	One or fewer design alternatives considered	At least two design alternatives considered
Design Iteration	No iteration is documented or iteration is insufficiently documented	Iteration has occurred and documented by answering: Why did the original iteration fail? What did you change? How did the change affect the result?
Design Analysis	Calculations are incorrect or cannot be determined to be correct	All calculations documented and performed correctly
Plots	One or more required plots are missing	System curves for at least two designs, pump curves for at least two pumps, and operating points for at least two designs provided
Documents Final Design	Parameters of final design are not given	All design parameters of final design are provided with justification
	ABET SO 3 - Communication	
Organization (Sections)	Document is poorly divided or not divided into sections	Document is divided into appropriate sections, with information provided generally in a logical section
Organization (Paragraphs)	Information is not organized within sections, either without paragraphs or with no logical division between paragraphs	Information is divided into paragraphs, with each paragraph generally given a single concept
Logical Flow (Sentences)	Sentence order is clumsy and distracting	Sentence order does not impair readability
Grammar	Grammatical mistakes are frequent and distracting	Grammatical mistakes may occur, but do not greatly impair readability
Spelling	Spelling mistakes are frequent and distracting	Spelling mistakes may occur, but do not greatly impair readability
Visual Aids	One or more visual aids does not benefit the document	Visual aids all provide benefit to the document
Visual Aid Reference	One or more visual aids are not referenced in the text or not captioned	All visual aids are referenced in the text and have descriptive captions
Plot Formatting	One or more plots is poorly formatted	All plots have axis titles, appropriate text sizes, legends where appropriate, and are generally easy to read
Provides Sources	One or more outside sources not cited	All outside sources cited