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Ungrading in Unit Operations Laboratory: Implementing Alternative Assessment in a Laboratory-Based Intensive-Writing Course

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Abstract
Alternative assessment approaches, such as ungrading, have been increasingly implemented over the past several years. These approaches emphasize student learning and mastery rather than defining achievement and success through grades. Broader adoption has resulted from the many observed benefits for both students and instructors, including lower student stress, higher student productivity, maintained high standards of academic integrity, reduced student-instructor conflict, and other factors. Alternative assessment in STEM courses has tended to be implemented in standard classroom-based courses; however, despite many non-STEM examples emphasizing its potential in writing-intensive instruction. At Northeastern University, as part of a curriculum redesign, the required undergraduate Unit Operations Laboratory course in chemical engineering was developed with an intentional ungrading approach for assessment. The course utilized four modules of experimentation – discovery, heat exchangers, fluid mechanics, and separations/mass transfer, with all students getting hands-on experience with eight different experimental devices. Students completed multiple written assignments, including laboratory proposals, memos, executive summaries, and reports, as well as oral presentations, both individually and in teams. Assessment was fully implemented with ungrading: the final course grade was based on established student mastery at the end of the semester across ten course outcomes, allowing for student growth and development based on feedback received during the semester. Students and instructors both responded positively to the implementation, with student motivation as assessed by the MUSIC model being extremely high, particularly with respect to motivation resulting from believing the course design enabled success and from instructor caring. . The results of multiple iterations of implementation will be discussed in this paper. (IRB approval #24-03-17).

Motivation
The growth of alternative assessment has been well documented in recent years, with instructors at all levels of education becoming more open to implementing some form of it in their instruction.[1-6] Developed in response to concerns about traditional grading techniques, including the potential arbitrary nature of traditional grading and the emphasis on numerical performance over student learning,[7-11] alternative assessment has been described by many names and includes a range of potential approaches to evaluating student performance. These approaches include:

- Specifications-based grading,[12] in which grades assigned are designed to reflect students' completion of work to specified levels of achievement, with specific tiers for each learning outcome;
- Standards-based grading,[13] in which student mastery is defined by different tiers and grades are reflections of student proficiency in the learning objectives;
- Ungrading,[14] in which the greatest emphasis is placed on mastery and proficiency as opposed to grades.

Ungrading is used as a frequent catch-all term often in place of alternative assessment, despite it being one specific form of alternative assessment. A range of assessment approaches can be included within alternative assessment, such as contract-based grading, self-assessment, peer-assessment, and portfolios.[15] Within ungrading, these approaches are specifically used within centering the emphasis of instruction and assessment on learning, in contrast to a de-emphasis on the grade itself that is delivered. One core component of alternative assessment is the need for clear objectives that students can strive toward and consistent, timely feedback on their performance, so they understand how their mastery is evolving and where further development is necessary.

The benefits of implementing alternative assessment have been found to include several positive outcomes for both students and instructors. Student-focused conclusions have included reducing student stress, providing more accurate and authentic assessments, increasing students' motivation to learn, and separating grades from students' identity and sense of self-worth (meaning students do not define themselves by their assessed grade). Instructor-focused reasons have included upholding higher academic standards and discouraging cheating, and reducing conflicts between instructors and students because of the potential for student growth.[2,16]

In most documented efforts to implement alternative assessment techniques, instructors have focused on standard classroom-based instruction, in no small part because many earlier examples were in non-STEM courses.[14] As more STEM instructors have utilized alternative assessment to different degrees of success, the obvious room for further potential is in broader implementation of alternative assessment in laboratory-based courses. Laboratory courses offer a particularly useful setting in STEM for alternative assessment, given:

- Many of the student deliverables are often written reports or data analysis, like those of non-STEM based courses;
- The objectives for each experiment or module need to be clearly defined for the work to be done safely and thoroughly;
- Students usually conduct a series of experiments over the course of the semester, with similar deliverables, allowing for regular feedback that students can use in future deliverables to support growth and improvement.

Evaluating the effectiveness of implementing alternative assessment techniques in laboratory courses is thus a necessary next step in expanding the approach. In consideration of both the success of alternative assessment in classroom-based courses and the untapped potential for laboratory environments, in conjunction with a curriculum redesign at Northeastern University and based on previous experience in successful implementations of ungrading techniques,[17,18] an ungrading approach was implemented and refined by a team of instructors of the main chemical engineering unit operations laboratory course.

Methods

Course Structure

As part of a curriculum redesign, the chemical engineering laboratory course at Northeastern was converted from two 4-credit courses in sequence to a single 4-credit course. The previous format involved a Lab I course focusing on:

- Introduction to experimental design through fluid properties module (2 weeks)
- Bench-scale fluid mechanics module (2 weeks)
- Pilot-scale fluid mechanics module (4 weeks, students working with 2 of 4 experiments)
- Experimental design project (4 weeks, design and proposal of a theoretical experiment)

The Lab II course that followed focused on:

- Introduction to analytical design through transport properties module (2 weeks)
- Pilot-scale and industrial-scale heat exchanger module (2-3 weeks, students working with 1 of 4 experiments)
- Pilot-scale and industrial-scale separations and mass-transfer module (3-4 weeks, students working with 1 of 4 experiments)
- An open-ended water remediation project (4 weeks, hands-on design experience)[19]

Upon conducting a curriculum review and determining several areas of overlap, in addition to shifting priorities in what skills and experiences students required for success upon graduation, several modules were consolidated to produce a single laboratory course:

- Introduction to experimental design through transport properties (2 weeks)
- Pilot-scale and industrial-scale heat exchanger module (2-3 weeks, students working with 1 of 4 experiments)
- Pilot-scale fluid mechanics module (4 weeks, students designing for and operating with 3 or 4 experiments)
- Pilot-scale and industrial-scale separations and mass-transfer module (3-4 weeks, students working with 1 of 4 experiments)

The course redesign focused on several operational features. First, students were now able to rotate through several fluid mechanics and separations equipment, as opposed to primarily focusing on one device during that module. This design helped address repeated concerns from students about limited laboratory experience. From an instructional perspective, the new configuration also helped ensure that students used a larger range of transport theory in their analysis. Students did not rotate through heat exchanger equipment, as the experimental theory was viewed to be relatively consistent from device to device.

Second, with the rotation system established for certain modules, teamwork could also be restructured to provide all students with opportunities at building leadership and communication. In the fluid mechanics and mass transfer modules, students would be assigned to develop an experimental plan for a specific piece of equipment and serve as the ‘leader’ for their experimental group. In developing this plan, students would work with other representative ‘leaders’ from the other experimental teams that would rotate through the equipment. Leaders would then guide their experimental team through the equipment for their part of the overall experimental plan and contribute as regular team members when rotating through the other pieces of equipment. Thus, all students would have opportunities to learn to operate different pieces of equipment, design and contribute to a multi-week experimental plan, and develop teamwork and communication skills as both leaders and contributors.

In addition to the 3.5-hour in-laboratory class each week, students attended a 100-minute recitation earlier in the week. This recitation period provided an opportunity for instructors to present technical content related to the experimental work, address proper safety procedures, and connect it to broader practical applications. Additionally, students were able to present to their individual sections during this period, as needed, or prepare with their experimental teams to be ready to begin experimentation when the laboratory class period began.

Individual sections for the laboratory period were intended for a maximum capacity of 16 students, with the potential to increase to 20 as needed based on enrollment each semester. Student experimental groups would thus be teams of four in the standard case, and expansion to five as needed. Recitation periods were held with all sections present, taught by some combination of the laboratory period instructors.

Course Assessment

The new laboratory course was designed with 10 course outcomes by which students would be assessed at the end of the semester:

- Three outcomes were focused on experimental design, analytical design, and computational tools (in-line with ABET outcome #6);
- One outcome focused on communication, both written and orally (ABET outcome #3);
- One outcome focused on the multiple aspects of teamwork (ABET outcome #5);
- Three outcomes focused on the transport theory and operation as related to the momentum, heat, and mass transfer modules (ABET outcomes #1, 2, and 7);
- One outcome addressed safety and safe practices (ABET outcome #2);
- And one outcome addressed broader impacts and applications of related experiments (ABET outcomes #2 and 4)

Student performance in the overall course would then depend on how well students performed across these 10 outcomes.

With the ungrading structure in place, student performance was not based on the average quality of work submitted or completed for each course outcome, but instead on student achievement by the end of the course. Students could thus improve within each outcome as opportunity provided and were assessed based on their final level of mastery. For example, students can grow and improve their technical writing skills through multiple written assignments, learn from mistakes and poor approaches, and develop more advanced written communication skills by the end of the semester, with their final ability level assessed.

Each module provided multiple deliverables. After being introduced to the expectations and equipment, along with any potential problem statement suggesting an objective for the module, student teams developed proposals before the next laboratory session describing their planned experiment, operating procedures, data to be collected, and a safety analysis. For the modules on fluid mechanics and mass transfer that featured rotation over multiple pieces of equipment, teams also delivered presentations to their section describing the planned experiment. After the intermediate weeks in the rotation-based modules, experimental teams wrote memos to the rest of the section, providing their collected data, observations, concerns, and recommendations. At the overall end of each module, different technical writing deliverables were required, with students building their written communication to more complete reports over the course of the semester:

- For the introductory module, students developed individual 2-page analyses of their data, limited to three illustrative figures, to practice data presentation and communicate their technical analysis.
- For the heat exchanger module, students developed individual 1-page executive summaries of their full experiments, aimed at communicating technical content concisely and supported by analytical data.

- For the fluid mechanics module, students developed individual 5-page journal articles, with data presented in no more than 3 figures and 1 table. Students should now be able to produce full technical reports using the specific journal style designed for this type of report.
- For the mass transfer module, students developed 10-page formal team reports covering the experiment in full, with no additional specific limitations.

Students were also usually assigned short deliverables for each recitation; these might include a response to the topic discussed that week or a demonstration of their computational analysis using JMP.

Students received frequent feedback from instructors throughout the semester on their writing, oral communication, analysis, experimental design, and all other submitted content. This steady supply of feedback, as well as communication from teaching assistants during class, helped ensure that students understood where they were exceeding or meeting expectations and where they had further room for improvement.

At the end of the semester, students would complete a final self-assessment, considering their ability with respect to each course outcome (rating themselves on a 1–4-point scale for each of the 10 course outcomes) and the mastery they had demonstrated. Students were given the opportunity to propose a final course grade based on their self-assessed performance, with each instructor meeting individually with their section's students to discuss their (the instructor's) perception of the student performance, including improvement and final mastery attained. These meetings depended on the instructor but were usually no longer than 10 minutes per student. With feedback being provided throughout the semester, this meeting often served to help summarize the instructor's assessment, as opposed to an oral exam or means of collecting more data for evaluation; effectively, these meetings were conducted after final determinations had been made and to help students reflect on their mastery achieved and where further room for growth remained. These meetings could add an additional 2-3 hours of instructor time at the end of the semester; however. University regulations required some form of in-person contact between the instructor and the student during the semester's exam week, even if no final exam was being held in the course. As a result, this instructor's time effectively served the same need and required the same time commitment as would have been required of the instructor. In any case, each instructor was allowed flexibility in how student performance was considered in full for their respective sections by the end of the semester, based on the accumulated deliverables.

In the final self-assessment form, students also answered a series of survey questions to help the instructor in their determination of the final course grade. These questions included:

- "What do you feel you have learned in this course?"
- "Was this course what you expected in terms of content? Why or why not?"
- "Do you feel that you were able to focus more on learning in this course this semester than you have in other courses? Why or why not?"
- "Did you achieve the level of learning that you wanted to this semester? Did you get everything out of this course that you wanted to?"
- "Was anything detrimental to your learning in the course this semester?"

- "Do you feel you have completed sufficient evidence that an external observer would agree you have understood and mastered the course content?"

Additional survey questions included 19 questions from the MUSIC model of student motivation[20] to help quantify student perspective of the course design. Overall, these survey questions helped to provide more insight into student personal perspectives.

Through this approach, students did not receive grades to determine their performance or achievement through the semester; the overall goal was using the provided feedback to develop towards mastery in all course outcomes by the end of the semester. Some instructors would provide strictly written and oral feedback; others would provide scales of 1-10 with feedback to help numerically describe the level of achievement and room for improvement remaining.

Data Collection

For the purposes of describing data for assessment within this paper, data includes (1) student performance on course deliverables and (2) student responses on end-of-semester self-assessment surveys. The surveys include the questions and content as previously described.

Results

In the first year of implementation, involving seven sections of the course over two semesters, the courses were considered for both the effectiveness of the structure and the implementation of the alternative assessment format. Balancing a major curriculum overhaul, even when using established laboratory modules from previous courses, often became a priority in determining what improvements were necessary and how effectively the course was delivered. With this in mind, the discussion will focus more on results from delivering the course in the second year and onward.

Instructor perspective

With the course structure universally established across sections and instructors, leeway remained in how each instructor implemented the alternative assessment approach. This was in part to allow for differences in instructors' teaching styles, which would directly affect the forms of student-instructor relationships and communication techniques that could develop. The largest difference in how instructors deviated across sections was in how feedback was delivered to students, which itself changed across multiple iterations of instruction for each instructor.

In the first semester of implementation, some instructors attempted to deliver the course without any numeric or letter grading until the end of the semester. Emphasis was placed on written comments and feedback delivered to students on their proposals, reports, and presentations. This feedback was provided regularly within a week or less of each assignment submission; however, some instructors noted:

- "… without context, a student doesn't know if the comment means 'you totally missed the boat' or 'you did the expected so well that I want to teach you how to take this to the next level.' "
- "There was some discomfort from students in the earliest, loosest iterations of ungrading that they didn't know where they stood (feedback on my too loose initial attempt). Since we're focused on mastery-based grading, giving students concrete feedback on how we perceive their current level of mastery throughout the semester, coupled with the security

of knowing that improvements to that mastery level will be rewarded, promotes continued engagement and students working hard to incorporate the feedback and improve."

The initial feedback in this 'loosest' form of implementation led instructors to provide mastery- or numeric-based rubrics in addition to continuing the previous feedback, effectively summarizing the written comments. Instructors continued to take different approaches to the rubric form; for example, one instructor utilized a mastery-based table as in Table 1, breaking down student mastery and learning into four categories of achievement. No scores are provided with this form of summary feedback, but students can have a direct-sense of where their abilities have met achievement goals or have further room for development.

Table 1. Rubric form provided by one instructor on student reports, with feedback established on a mastery-based scale of 'Beginning', 'Developing', 'Practicing', and 'Achieving'.

	Beginning	**Developing**	**Practicing**	**Achieving**
Motivation	Background is brief, vague, and incomplete.	Background introduces Chemical Engineering theory, but links to experiment are clear.	Minor flaws in links of theory and references.	Background is properly presented, clear, and supported with appropriate references. Appropriate depth of Chemical Engineering theory.
Experimental Design	Narrow or poor comprehension of parameter min/max. Lack of required testing parameters. Poor choice of measurement.	Many pitfalls in experimental design. Poor accounting for time or operational constraints.	Minor gaps in the design; data sets are not properly replicated where needed.	Full parameter space is clearly outlined. Independent and dependent variables are clearly defined. Tools/methods of measurement and resolution are identified. Redundancy: effects are measured more than one way. Theory and hypothesis driven. Measurements are properly replicated.
Clarity & Technical Writing	Spelling and grammatical errors. Vague and superfluous text. Inappropriate formatting.	Proper format. Misleading or unclear language/descriptions.	Minor flaws in technical language or grammar.	Proper format. Clear and succinct. Appropriate technical detail for replication.
Application of ChemE Theory	No link to Chemical Engineering theory. Data is presented in raw or untransformed units.	ChemE fundamentals noted in background, but plots fit with random regression fits (linear or non-linear) without regard to the form of the theoretical equations.	Minor flaws in data analysis and application of chemical engineering theory.	Theory is properly introduced, referenced, and utilized in data analysis.
Data Visualization and Analysis	Raw data tables; excel bar plots.	Data selection and/or presentation is underbaked; e.g., using category x-axes for numerical data; using Excel default plots (grid lines, too small markers and axis titles, no tick marks, poor labeling); single markers and no error bars for replicated data or error bars with context)	Appropriate data presented with some improvements needed in plot styling or caption descriptions.	Figures are clear and properly captioned. Data is properly replicated. Variability is properly displayed. Parameter/Setting differences are justified with appropriate Statistical Analysis.

Other instructors utilized a numeric form of feedback, evaluating the different components being evaluated in each submission on a scale of 1-10, as in Figure 1. Students were informed that the scores did not add up to any meaningful overall total, to reassure them that no calculation was done behind-the-scenes to determine some final grade. However, students could use the 1-10 scale as a means of considering their achievement in each category.

Name ______________________________ **Module Experiment**___________________

First Page Summary

_____ Concise and complete
_____ Experiment objective and method included
_____ Results and conclusions (quantitative) included
_____ Appropriate formatting

Introduction

_____ Explanation of purpose
_____ Summary of theory (if applicable) with key equations included
_____ Objectives: scope of experiment (specificity and range)
_____ Appropriate formatting

Experiment, Results, and Analysis

_____ Experimental method and measurement techniques
_____ Coincides with objectives
_____ Presentation of results
_____ Quantitative analysis
_____ Contribution to area of study or needs of problem statement
_____ Appropriate accounting for error
_____ Appropriate formatting

Conclusions and Recommendations

_____ Clear quantitative and logical conclusions from experimental results
_____ Appropriate recommendations based on analysis and error

Appendices

_____ Presentation of additional data and information
_____ Appropriate and reasonable amount of additional information

Safety Analysis

_____ Assessment of personal, material, equipment and system safety hazards
_____ Prevention and mitigation planning

Quality of Writing

_____ Clarity and quality of communication
_____ Organization of information
_____ Formatting
_____ Technical Voice
_____ Spelling
_____ Reasonable quality and quantity of work

Participation

_____ Attendance
_____ Raw Data
_____ Safety Sheet
_____ Team Charter

Figure 1. Some instructors provided a numeric rubric to summarize feedback on submitted work.

One instructor in the first semester provided "check plus, check, check minus" overall scores with a significant amount of specific written comments; in the following semester of their instruction, they utilized a more detailed rubric, as shown in Figure 1, but on a 1–4-point scale correlating to the mastery levels. Overall, with the transition to clearer rubrics, instructors felt that students were better able to understand and utilize the feedback being provided. A key aspect of the alternative assessment approach is students being able to revise and resubmit the major written deliverables in later assignments so that they iterate on a single body of work and actively incorporate the feedback, thus reinforcing the learning; revising the rubric so the student clearly knows if the resubmission demonstrated mastery or not was critical to the assessment approach:

- "Adding the numeric scoring per skill gives them the context to understand 'you have to fix this' vs 'yes, and'."

All instructors had delivered instruction in a previous iteration of the laboratory course before the new course curriculum and assessment structure were implemented, with most having 3-4 iterations of experience (some as many as 20). As such, expectations regarding student achievement on each assignment, the quality of student writing and presentation, and analytical ability were well established before the new course was developed. Discussions between instructors at the end of each semester noted relative consistency in final grades. With the new assessment format, the instructors met between semesters to discuss the effectiveness of its implementation, how it was applied in their section, and whether modifications to their approach were necessary to better balance or normalize instruction and assessment across sections. Differences between sections were partly attributable to students on different paths (4-year vs. 5-year, varying numbers of external co-op/internship experiences, fall vs. spring semester instruction), but, on average, course assessment was comparable across iterations.

Student Perspective

The MUSIC model of student motivation was used to examine how students approached the ungrading structure. Based on several theories of motivation, the MUSIC model emphasizes five components of the curricular and instructional approach that are directly related to student motivation and, thus, in theory, to student learning.[20-24] These five components include:

- empowerment (the M of MUSIC model), based on the amount of control students believe they have on their learning;
- usefulness (the U), based on students' understanding that their learning is valuable;
- success (the S), based on students believing they can succeed in the course if they put in effort;
- interest (the I), based on students finding the concepts and the course enjoyable;
- and caring (the C), based on students' believing the instructor cares about their learning.

The MUSIC model has previously been useful in educational studies with engineering students.[25,26] In an ungrading system in a laboratory course, it might be expected that students would indicate high levels of perceived opportunities for success, given that performance is evaluated by final achievement, allowing room for improvement to a higher level. Other components may be more dependent on the student-instructor relationship and the student's connection to the course content. All components of the MUSIC model are evaluated on a scale of 1 to 6 based on student survey responses, with 6 indicating the strongest agreement. Effectively, any score of 4 or above would be considered a positive outcome.

In assessing student motivation, one semester is highlighted in Figure 2, as it shows the greatest consistency in class sizes (~16 in each section). The average responses for four sections delivered by three instructors (sections 1 and 2 taught by the same instructor) are presented, as well as the overall course average for that semester.

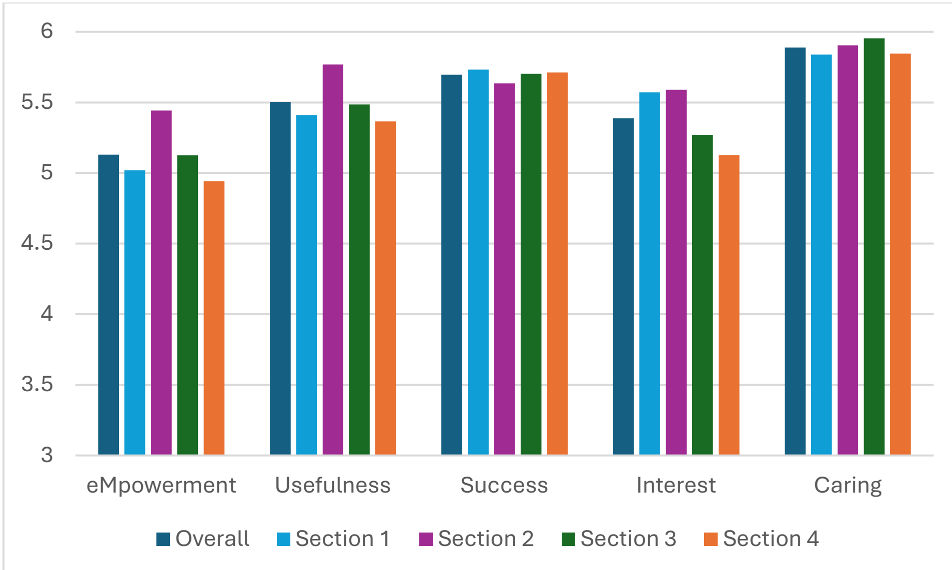

Figure 2. MUSIC model analysis of student performance in Spring 2025 semester.

Students demonstrated high levels of motivation across all categories, with strong overall course design; even in the lowest category, the average score was still above 5. Notably, the lowest average was for empowerment; even though students were able to design their own experiments and investigate a number of parameters over a range of values, the structured nature of the rotation and teams may have kept students from feeling completely empowered in the decisions they could make towards their own learning and success in the course. Usefulness, success, and caring all received average scores of 5.5 or higher, suggesting that students saw the utility of the course material and skills learned, felt the course design enabled them to succeed in their learning, and felt the instructors cared about their success.

In a few studies using the MUSIC model to evaluate course design with alternative assessment, the authors of this paper have frequently observed a similar pattern to student evaluations of instructor caring.[27,28] In these studies evaluating alternative assessment in non-laboratory, classroom-based courses, students again indicated average caring scores of 5.75 or greater. It is consistently observed that students clearly connect the benefits of alternative assessment to their personal perceptions, with the instructor enabling this through the course approach.

Student performance

Student performance was reflected in final course grades in addition to the feedback received from the students' perspective on their experience in the course. For a clearer comparison, the results for one instructor who taught several previous iterations of the course are shown in Figure 3, highlighting a pre-pandemic semester, a semester with hybrid laboratory instruction, and the new course design.

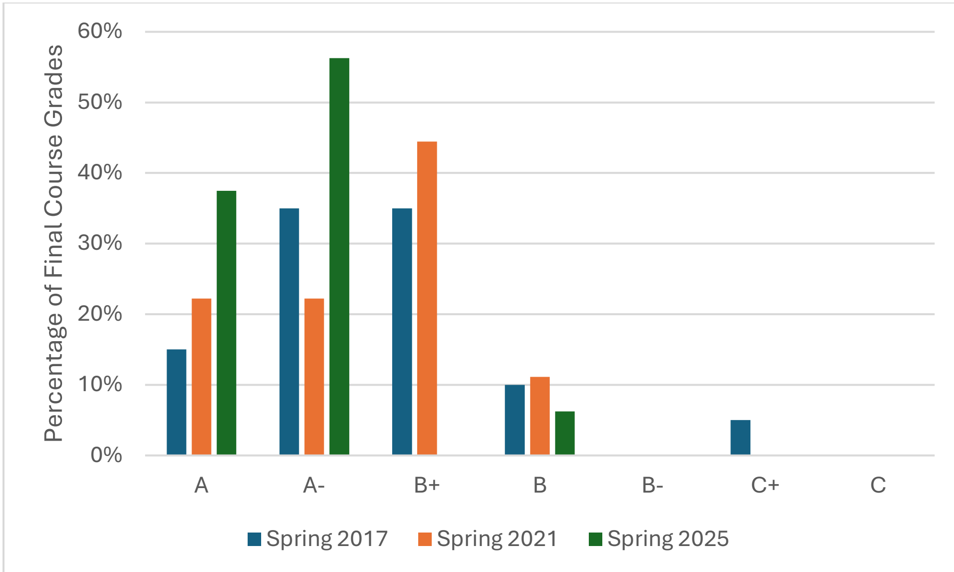

Figure 3. Final course grades were distributed by one instructor in three iterations of the laboratory course. The spring 2017 semester (in-person) and the spring 2021 semester (hybrid instruction) were previous iterations of the course, while the spring 2025 semester is the new, alternative-assessment course.

It should be noted that these final grades were from an instructor who used the detailed rubric presented in Figure 1, which evaluated student performance on a 1-10 scale across categories for each assignment. The main difference between assessment iterations as shown in Figure 3 is that a formula had been used in the pre-alternative assessment iterations to determine a numerical assignment grade for each assignment, based on those 1-10 scores which was mathematically factored into the final course grade, as opposed to using the feedback to motivate student improvement and assessing final student mastery at the end of the semester. Comparing the 1-10 scores across iterations of the course is difficult, as written reports for the different assignments were completed at different times in the semester. However, the comparison indicated that, while students demonstrated similar performance at the beginning of each semester, students achieved higher levels of mastery more quickly in the alternative assessment, with stronger performance in the third experimental module than in the final experimental module report.

Notably, most students can earn final grades in the A/A- range under the alternative assessment design, because their ability and mastery are assessed based on demonstrated and communicated work at the end of the semester, rather than an average of touchpoints along the way. Students may have previously reached the same level of learning and achievement in the traditional assessment approach but were limited by their ability and performance at the beginning of the course. Given that the same technical communication skills were repeatedly evaluated and the primary means of assessment in both forms, focusing the evaluation on student performance at the end of the semester is an effective way to support growth and improvement from feedback and previous mistakes, while still providing an overall assessment of student ability. This stands in contrast to a classroom-based course, where certain topics may be covered early in the semester and not addressed again in later evaluations, so exams assess different content. In a writing-intensive laboratory course focused on experimental and analytical design, an alternative assessment approach that emphasizes final mastery level may provide a more accurate and meaningful measure of student performance and achievement.

Differences between students' self-assessed final course grades and instructor-assessed final grades fell into two categories: students who overestimated their achievement and proposed a higher grade than their mastery warranted, and students who proposed a lower course grade than was appropriate given their demonstrated mastery. The latter category is what the authors have observed just as frequently in their alternative assessment implementation in classroom-based courses, particularly among women and underrepresented minority students.[27,28] The former category is usually one of the major expectations, as expressed by instructors who have not implemented alternative assessment, that students will propose higher grades for themselves despite a lack of evidence supporting their case. In Figure 3, 7 of the 16 students in the Spring 2025 semester proposed higher grades for themselves than the instructor assigned. However, the differences in these proposed grades were borderline, such as A to A-, rather than whole-letter grade differences. The end-of-semester meetings allow students to understand the instructor's assessment; these have rarely been contentious and usually do not require the entire allotted time, even when the instructor disagrees with the student's proposed grade.

Student survey responses were mostly positive with respect to the course and assessment design:

- "I feel that the ungrading structure did help me to focus on learning - this is the first class I've taken in this format, and it was nice to focus on exploring areas of interest in addition to meeting objectives, as opposed to worrying about a grade. It also relieved the stress of quickly determining the course expectations and being 'perfect' at the very beginning of the semester, which created a better environment and adjustment period."
- "I think the structure of the course and lack of formal assessments other than the writing allowed me to learn more in the lab and reflect on my own time on what I have learned. I enjoyed the structure, and the recitation was also good for allowing me to connect outside chem engineering classes to what we were doing, which enhanced my ability to learn."
- "This course (definitely) allowed for so much organic growth throughout the course of the semester. I found it very challenging, especially with the data analysis software; however, I find myself struggling because I was taking on exceedingly difficult tasks. When I look back on the beginning of the semester, I am now confident and effective in doing the tasks I was taking on then. Therefore, I have worked hard toward mastery."
- "I absolutely think I was able to focus more on learning in this course primarily because it was ungraded. Rather than constant stress and anxiety about if my submissions were technically correct in every way I instead focused on applying the feedback and critiques from previous submissions. This was a great mindset change and I truly believed it enhanced my learning."

It is helpful to note student perception of the benefits of alternative assessment, as described in their responses to the survey questions, often aligned with the previously described benefits observed in previous studies, including reduced pressure or student stress (usually directly cited by 25-40 percent of students in each section), and more motivation to learn given the opportunity for mistakes and growth.

Students also noted that the course was still rigorous, even with the alternative assessment approach.

- "It wasn't simply following a procedure and writing the specific results that were obtained. I think setting up the experiments required more knowledge of background information which promoted learning."
- "Since most work was team based, I had to make sure I was available to work on projects, as well as I had to make sure I was prepared to talk about the data/equipment beforehand so I didn't feel lost/behind during team meetings."

Negative responses from students often focused on factors present in laboratory experiences at most institutions, rather than on issues with the alternative assessment format itself. Examples from student self-assessment survey responses include students having difficulty with their team's organization and interpersonal dynamics, wanting more time for experimentation beyond what was provided, or requesting even more detailed feedback on the assignments.

Reflections

After several iterations of course instruction using the new curriculum and alternative assessment approach, the course has shifted from a broader "ungrading" approach to a clearer "mastery-based grading" approach. Effectively, while assessment had provided significant opportunities for feedback and for students to develop and improve over the duration of each semester, more structure was introduced with each iteration of instruction. The addition of rubrics and mastery scores per course outcome helped clarify for students where their mastery stood as the semester went along, while also giving context to the feedback so it could be better utilized in later assignments. Multiple opportunities across the experimental modules allowed students to demonstrate mastery of various course outcomes, such as connecting theory and experiment, which enabled student growth. However, emphasizing those opportunities to students was important to ensure they recognized what improvements to make and how to implement them.

Conclusions

While instructors continue to experiment with different forms of alternative assessment to determine the best approach for their instructional style and learning outcomes, a laboratory-based course may be an optimal environment for implementation. If the nature of assessment is based on broader skills that are repeatedly demonstrated over the entire course, such as technical writing, oral communication, experimental design, analytical design, and teamwork, then alternative assessment provides a means to allow for student growth, provide regular feedback to promote such improvement, and determine a more holistic evaluation of student performance based on final levels of mastery. Further work will continue to refine the nature and depth of the feedback provided to ensure students better understand how and where they can improve.

Recommendations to Other Institutions

For other institutions that would be interested in adopting an alternative assessment approach in their laboratory courses, the instructor team would recommend a system with:

- regular, detailed feedback on all deliverables submitted, delivered in a timely manner
- clear expectations not only on assignments but for the overall course outcomes

- detailed rubrics or evaluation forms that guide students on a mastery-based level, so that the feedback can be taken in by students, learned from, and utilized in future work in the course
- structuring deliverables so that students have the opportunity (which they are consciously aware of) to build on their skills and improve their mastery
- making sure that student feedback can be collected through surveys or other means that will allow for iterative improvement on the instructor side of the course

The instructors would generally recommend a system in which students propose their own grade, with the final grade determined by the instructor, to enable students to directly associate their empowerment over grades with their empowerment to develop and improve their mastery, while remaining aware that there may be institutional restrictions on doing so. A contract-based grading system in which meeting certain mastery levels in each outcome, or a total number of high mastery levels across all outcomes, may be a viable alternative. Similarly, a truly open and loose ungrading approach may not allow students to fully benefit from the feedback provided on the timescale of a semester-long course, so a mastery-based grading system or a combination with ungrading may be preferable (not only to instructors but also to the program and institution).

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