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Alternative Assessment of Lab Reports: Effects and Perceptions of Allowing Multiple Attempts to Meet Defined Standards

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Abstract
Alternative assessment, including standards-based grading (SBG) and specifications grading (often called 'specs' grading), are strategies intended to put the focus on student comprehension and skill-building by providing a more 'objective' format for determining a grade. SBG is typically employed in more 'traditional' assessments (e.g., homework or exams) and is often limited either to assessments of individual work or of team-based work where the entire team is evaluated on the same scale. Specs grading combines multiple objectives and grades them on a pass/fail system. In this study, an alternative assessment-inspired rubric was developed for assessments of technical writing in a senior-level, chemical engineering laboratory course that employs teams with defined roles for each team member. In this rubric, instructors defined standards (criteria/skills) for which proficiency could be obtained (similar to SBG grading) and could be assessed on a pass/fail basis (similar to specs grading). These standards were then allocated as either being specific to an individual team member role, or as a standard applicable to all members of the team. The number of standards met was then scaled to a traditional letter grade. Students were given the opportunity to resubmit their lab report multiple times utilizing the feedback from previous assessments. The rubric resulted in similar grades across instructors, units, and lab topics. Final submissions took less time to grade than initial submissions, although most submissions took close to an hour each to grade. Submission trends by students followed several styles; the styles indicating more proactive students showed higher final scores on average. Instructors preferred the alternative assessment method because of increased clarity of expectations, the absence of partial credit decisions, and a more distributed grading load. Students preferred the alternative assessment method because they felt it improved their writing quality, gave opportunities to improve their grade, and the flexible due dates reduced stress.

Introduction
Alternative assessment techniques, as opposed to traditional grading methods, have recently seen a surge in popularity at the collegiate level. Traditional grading, or points-based grading, possesses a number of flaws, including: (1) false positives (grades that are higher than what one would expect from a student's understanding), (2) false negatives (grades that are lower than one would expect), (3) inequities favoring students who learn quickly or reflect an instructor's implicit expectations/biases, and (4) combative student-instructor relationships from 'haggling' over partial credit [1]. Alternative assessment approaches, including mastery-based grading, specifications grading, standards-based grading, ungrading, and more, instead attempt to achieve a more objective view of a student's learning by focusing on outcome achievement [1]. Clark and Talbert propose a 'four pillar' model of alternative grading [1]:

- Clearly defined standards (description of evidence that indicate skill competency)
- Helpful feedback (that is timely and actionable)

- Marks indicate progress towards a standard (rather than arbitrary numbers)
- Reassessment without penalty (students can try again using the feedback provided)

In short, the goal of alternative assessment is to make clear to students what they should be able to accomplish and how much they have accomplished at any given time, and they are given the opportunity to learn and improve from mistakes without penalty. Although these pillars cannot always be fully achieved in a course, efforts to transition a course towards these pillars can help put the focus on learning and growth rather than grades [1].

Studies done on alternative assessment in collegiate STEM courses have found that students valued and/or preferred alternative assessment methods [2, 3, 4, 5, 6], that alternative assessment can increase students' self-efficacy [4] as well as develop expert thinking or sophisticated understanding [4, 7]. In another study, specifications grading (often call 'specs' grading) led to an increased number of systemically disadvantaged students passing general chemistry, although the achievement gap compared to systemically advantaged students was not reduced [8]. Some studies also report increased instructor satisfaction with alternative assessment (despite increased time spent grading) due to increased engagement with students and student investment in learning concepts rather than earning grades [1, 5].

While there are numerous different approaches to alternative assessment, two that have been frequently employed in STEM courses are standards-based grading (SBG) and specs grading. In SBG, students must demonstrate proficiency in defined outcomes or standards and are assessed categorically on a scale such as needs practice/proficient/advanced [1]. While SBG has been utilized in laboratory- and project-based courses [3, 7], it is more often applied in typical lecture or content-driven courses, as typical homework and exam problems can be used, but instead of points and partial credit, students are given the proficiency rating and a chance to try again if proficiency is not met. Alternatively, specifications grading typically bundles a group of expectations together, and an assignment is graded as either pass or fail as a whole [1]. This arrangement translates more readily to assessment of projects or papers [1, 5, 8], as these types of assessments often require a complex set of skills that are challenging to separate out individually.

In this study, an alternative assessment approach was applied to the major written deliverables (reports and memos) in a senior-level chemical engineering unit operations laboratory course at Washington University in St. Louis. As described in previous work [9], this course utilizes project-based learning with students in teams with multiple distinct roles: Team Leader, Experimental Engineer, and Analyst. These roles help ensure that students get practice with a variety of skills, as well as help divide up the work responsibilities. Historically, major course deliverables (lab reports and memos) have been graded with grid-style rubrics in which performance was described for each level of quality on a categorical scale of 'Unacceptable/Missing' (0%) / 'Marginal' (40%) / 'Acceptable' (60%) / 'Good' (80%) /

‘Excellent’ (100%). Different aspects of the report were worth different numbers of points based on perceived value and/or difficulty by the instructors (e.g., Discussion worth a maximum of 8 points, Conclusion worth a maximum of 3 points). Sample past rubrics are shown in Appendix C. Students were permitted to resubmit a revised version of their first lab report, and their grades for the initial and final submissions were averaged. They were not permitted to submit earlier drafts or other deliverables for feedback, although they were encouraged to discuss writing and formatting expectations with the instructors.

Unsatisfied with having to choose between difficult-to-distinguish intermediate levels of quality, and inspired by alternative assessment approaches, the instructors (the authors) developed a new rubric and grading approach to better define course expectations for writing and critical thinking skills, more objectively assess student achievement of those expectations, and better allow students to learn from their mistakes. The new rubric and grading approach is a hybrid of SBG and specs grading, in that it defines individual standards that students can achieve individually (as in SBG), but instead of using several quality levels, these standards were graded pass/fail (as in specs grading). The number of standards met was then translated to a grade (similar to SBG). Also unique to this rubric was the fact that standards were defined separately for each team role, as well as a set of shared standards for writing and formatting. As is critical to all alternative assessment approaches, students were given the chance to resubmit multiple times without penalty to improve their score.

This paper will detail the development and implementation of the new rubric and alternative assessment grading approach. Student submission timing, student grade data, time required to grade, student course evaluations, and instructor reflections will be used to evaluate the effectiveness of the method and suggest improvements.

Rubric development and implementation

Alternative standards-based rubrics were developed for both a journal-style technical report as well as a shorter business memo-style deliverable. The design process for the alternative rubrics was performed first for the full lab report, and once the full lab report rubric was finalized, the process was repeated for the memo. Final rubrics are shown in Appendix A (3-person teams) and Appendix B (2-person teams).

The instructors began by deconstructing their prior traditional grid-based rubric (Appendix C), separating rubric items assessing an entire section of a deliverable into multiple individual standards the instructors felt were critical for excellence. For example, the section for Introduction and Theory, instead of being a single rubric item, was broken down into several standards related to the expected content of the section (e.g., ‘Describes the context and motivation for the study’), as well as several related to the style/format in which it should be written (e.g., ‘Appropriate length (~2 pages)’). Rubric items related to writing style in the original rubric (e.g., 'Style'), which were shared across roles, were similarly deconstructed and clarified in the new rubric to avoid standards with multiple objectives. Each standard would then be graded on a binary scale – 'Meets Standard' or 'Not Yet'. This process was followed for all sections of the original rubric, after which the instructors tested the draft rubrics by using them to grade past student reports of low, middling, and high qualities for multiple different types of experiments.

After the first round of test grading, wording on many standards was clarified or modified to better reflect instructor expectations and priorities. The scale was also expanded to include a third category: 'Almost', which would not grant credit but would be a simple way to indicate to students whether they needed a major rework or only a simple tweak for a given standard. The test grading procedure was repeated with the new draft rubric. Once the standards were more solidified, they were divided up between student roles such that each role would be assessed both on report sections relevant to their role and on the same total number of standards (~35 per role). To evenly distribute the standards, some of the standards were slightly modified further. Because some teams would only have two students (instead of the typical three), the same standards were also divided up evenly across two roles in a similar fashion (~45 per role). While two-person teams have more standards applying to their grade, the total workload for the students was reduced for two-person groups by eliminating a task required in the lab (e.g., a scale-up analysis for a heat exchanger is not expected to incorporate an economic analysis for two-person groups, but is for three-person groups).

These finalized versions of the standards-based rubrics were then used to more formally grade other past student reports of varying qualities, and a roughly linear grading scale was developed relating the number of standards met to a grade percentage such that grades were similar between the traditional grid rubrics and the new standards-based rubrics or at least matched instructor beliefs about the overall quality of the report (Appendix A and Appendix B for three- and two-person teams, respectively). At this point, it was decided that a minimum number of standards would need to be met (~10) in order to earn a minimum grade (60%), as the instructors felt that any report that did not meet even this number would be of such poor quality that partial credit would be misrepresentative of the student effort and performance.

Study design

The new standards-based rubrics were used for assessment for the Fall 2025 cohort of the Unit Operations Laboratory course, a senior-level course at Washington University in St. Louis. The new grading method was introduced in the syllabus as well as through introductory course videos. Students were provided a Laboratory Report Manual that included writing and formatting guidelines as well as a sample report and sample memo. Eight weekly lectures were given in the first half of the semester to help introduce and summarize key points of the writing and formatting expectations in an interactive way. Meanwhile, students completed six total laboratory periods with two periods per unit, scheduled in a rotational order to allow greater instructor feedback on preliminary experimental plans and results (i.e., the students' laboratory periods were ordered Alpha-Beta-Gamma-Alpha-Beta-Gamma, where Alpha, Beta, and Gamma refer to different experimental units). Student teams rotated roles for each unit; students on 3-person teams would complete each role once, and students in 2-person teams would repeat one of the roles. They were permitted to choose the order in which they participated in each role. Once students had completed their experimental laboratory periods for three separate experiments, they were encouraged to submit their reports and memos on a regular schedule in order to maximize the time for feedback and resubmission, as well as to avoid being overwhelmed by report writing in the days leading up to the final deadline (the end of Reading Week, several study days between the end of classes and the start of the final exam period).

The instructors graded reports and memos in the order they were submitted. It was communicated to students that the instructors would target a grading time of one week or less, with the caveat that if many reports or memos were submitted at once, it might take longer. The course had 8 total student teams, and grading was divided up such that instructors graded the same number of teams' reports and memos, with each instructor specializing in the grading of two or three experiments. For each graded report or memo, instructors recorded the time it was submitted, the time it was returned, the total number of minutes needed to grade the report or memo, as well as the number of standards and grade percentage for each role. This study design was approved by IRB #202509184. Twenty-two of twenty-three total enrolled students consented to the use of their grade data.

A limitation of this study is the authors' inability to utilize grades or student feedback from the students who took the course prior to the implementation of alternative assessment. As the prior students were seniors who had graduated and largely left the university, obtaining IRB consent from these students was not feasible by the time the authors had chosen the design of this study. Additionally, two questions about perceptions of the rubric were asked as part of the end-of-course student evaluations. Unfortunately, the results were not returned to the instructors until after the initial paper submission deadline. Therefore, incorporation of these results was not reviewed and is kept to a cursory analysis (i.e., responses were not coded for quantitative analysis).

Data analysis

Grade data for each submission (N =49) were tabulated, anonymized, and students who did not volunteer their data were removed, resulting in 22 students participating in the study. Overall group average grades were calculated as the arithmetic mean of the scores of the remaining participants in the study (e.g., if a three-person group had one member that did not volunteer their data to be used, the overall group grade is reported as the arithmetic mean of the two remaining individuals). Similarly, average grades by student role (i.e., Team Leader, Experimental Engineer, and Analyst) were calculated as the arithmetic mean of the scores of the relevant population. The reported error is one standard deviation of the relevant population. The time required to grade submissions was tabulated by each individual grader (whichever instructor is responsible for grading the respective submission), who timed the total time spent grading. Error in timing is estimated at approximately 5 minutes to encompass inconsistencies in grading, e.g., grading being complete before or after the grade and feedback was uploaded to the assignment in the learning management system (2-3 minutes), minor inconsistencies in starting/stopping the timer (1-2 minutes), and minor distractions while grading. Student submission strategies were categorized qualitatively based on the total number of submissions and the grade received on the initial submission, as described in the Results.

Results

Each graded lab report represents multiple variables that differ between each submission: the unit, the type of deliverable (i.e., technical lab report or business-style memo), the lab subject (and therefore the instructor grading the deliverable), and the role the student is fulfilling on the team. Each group submits three written deliverables: Units Alpha, Beta, and Gamma. In Unit Alpha, groups submit a journal-style technical report, while in Units Beta and Gamma, groups submit a three-page emailed memo with supplemental ‘attachments’. Within each unit, group members rotate between three different roles: Team Leader, Experimental Engineer, and Analyst. Each role has a different set of responsibilities and is graded on a separate set of criteria, with a common set of criteria shared across the roles pertaining to the writing style and formatting quality. Finally, the experiment topic that each group investigates varies between units; each group completes three of five potential experiments: Heat Exchange, Pump & Piping, Distillation, Gas Absorption, and Mixing.

Average final deliverable grades were all within one standard deviation of each other for every student role regardless of the unit (Table 1). Similarly, average grades on the initial submission were all within one standard deviation of each other for each role regardless of the unit, although standard deviations on initial submissions are greater than 30% because sample sizes are relatively small (N = 6-8) such that one individual not meeting the minimum standard (i.e., receiving a zero grade on the submission) disproportionately affects the results. The average grade on initial submissions for the analyst are consistently lower than those of the Experimental Engineer or the Team Leader, although the discrepancy is well within one standard deviation. Additionally, deliverables on the Heat Exchange and Pump & Piping topics were graded by Grader A, while Grader B graded the Distillation, Gas Absorption, and Mixing topics. As shown in Table 2, average grades from Grader A were consistently slightly lower than those from Grader B, although the average grades for each role are typically within one standard deviation of each other.

Table 1. Average grade on the initial and final submissions for each role for each unit and deliverable type. Grades represent the average ± one standard deviation. Darker shades of red correspond to lower average grades on the initial deliverable submission. Darker shades of blue correspond to lower average grades on the final deliverable submission The number of grades included in each category, N, varies due to lack of permission from student(s) to include their data and the presence of a single two-person group. For the two-person group, the Team Leader/Experimental Engineer grade is included in the Team Leader category and the Analyst role is included in the Analyst category.

Submission	**Unit**	**Team Leader (%)**	**Experimental Engineer (%)**	**Analyst (%)**
Initial	Alpha Report	56.8 ± 33.9 (N = 8)	53.2 ± 38.8 (N = 6)	50.1 ± 39.2 (N = 8)
	Beta Memo	69.1 ± 26.3 (N = 8)	65.7 ± 27.2 (N = 7)	62.1 ± 26.2 (N = 7)
	Gamma Memo	70.1 ± 29.6 (N = 7)	70.3 ± 29.8 (N = 7)	70.0 ± 28.2 (N = 8)
Final	Alpha Report	88.9 ± 7.4 (N = 8)	89.0 ± 7.0 (N = 6)	87.3 ± 8.8 (N = 8)
	Beta Memo	88.6 ± 7.0 (N = 8)	86.9 ± 8.3 (N = 7)	84.4 ± 10.9 (N = 7)
	Gamma Memo	84.0 ± 7.4 (N = 7)	85.5 ± 9.0 (N = 7)	83.0 ± 9.7 (N = 8)

Table 2. Average grade for each student role based on the grader evaluating the final submission and the topic of the deliverable. Darker shades of blue correspond to lower average grades on the final submission. Grades represent the average ± one standard deviation. The number of grades included in each category, N, varies due to lack of permission from student(s) to include their data and the presence of a single two-person group. For the two-person group, the Team Leader/Experimental Engineer grade is included in the Team Leader category and the Analyst role is included in the Analyst category.

Grader	**Topic**	**Team Leader (%)**	**Experimental Engineer (%)**	**Analyst (%)**
A	Pump & Piping	83.5 ± 6.6 (N = 6)	83.8 ± 7.7 (N = 6)	82.0 ± 10.3 (N = 6)
	Heat Exchange	84.3 ± 7.0 (N = 6)	86.0 ± 6.0 (N = 5)	80.8 ± 6.3 (N = 5)
B	Distillation	88.8 ± 9.7 (N = 4)	88.3 ± 10.9 (N = 4)	84 ± 14.2 (N = 4)
	Gas Absorption	92.0 ± 3.6 (N = 3)	90.3 ± 5.7 (N = 3)	88.8 ± 5.1 (N = 4)
	Mixing	92.5 ± 2.7 (N = 4)	93.5 ± 0.5 (N = 2)	92.0 ± 2.7 (N = 4)

Throughout the semester, each lab group completed three Units: Unit Alpha, Beta, and Gamma. The final written lab deliverables for all groups were due at the end of the semester (Dec. 10); however, suggested initial submissions deadlines of each deliverable were provided (Oct. 22-23 for Unit Alpha, Nov. 5-6 for Unit Beta, and Nov. 19-20 for Unit Gamma, where the difference in dates corresponds to the different days during which lab sessions occurred) to discourage procrastination and, hopefully, distribute the submission timeline to allow for more prompt feedback. The suggested initial submission deadline corresponded to three to five weeks after their final opportunity to collect data for the lab (three for Unit Alpha, four for Unit Beta, and five weeks for Unit Gamma, respectively); it was anticipated, and broadly observed, that students would complete the lab deliverables in the order that they completed the lab units. Initial submissions for Unit Alpha ranged from 10/25 to 11/24, while initial submissions for Unit Beta and Gamma ranged from 11/9 to 12/5 and 11/28 to 12/10, respectively. Notably, no student groups submitted their initial draft on or before the recommended date. Student submissions progressively shifted to be further after the suggested deadline as the semester progressed; the median initial submission for Unit Alpha, Beta, and Gamma was on 10/27, 11/17, and 12/4, respectively (four, eleven, and fifteen days after the suggested initial submission deadline, respectively).

One result of students working on the written deliverables in the suggested order is that groups iterated more on Unit Alpha (average of 2.5 total submissions per group) than on Beta (average = 2.1) and least on Gamma (average = 1.5). Generally, students continued to submit new versions of their lab report until the deadline; only five submissions were returned prior to the final deadline without having a subsequent submission based on the returned feedback.

There is minimal correlation between the total number of iterations on a given deliverable and the average group grade for the final submission (Fig. 1). Similarly, there is no apparent correlation between the number of submissions on a deliverable and the total improvement in their score or the total number of submissions by a group and the total points achieved. The distribution of grades is approximately equivalent for deliverables where a total of one or two total submissions are made, followed by a small increase in overall grade for deliverables with three total submissions. In one instance, a group submitted a report for a fourth iteration improving their grade from 85.7% to 98.3%. This is not to say that there is no improvement across submissions; initial submissions have an average group grade of 64.4% ± 30.4% while second submissions have an average group grade of 84.0 ± 8.6% and third submissions have an average grade of 85.3% ± 7.3%.

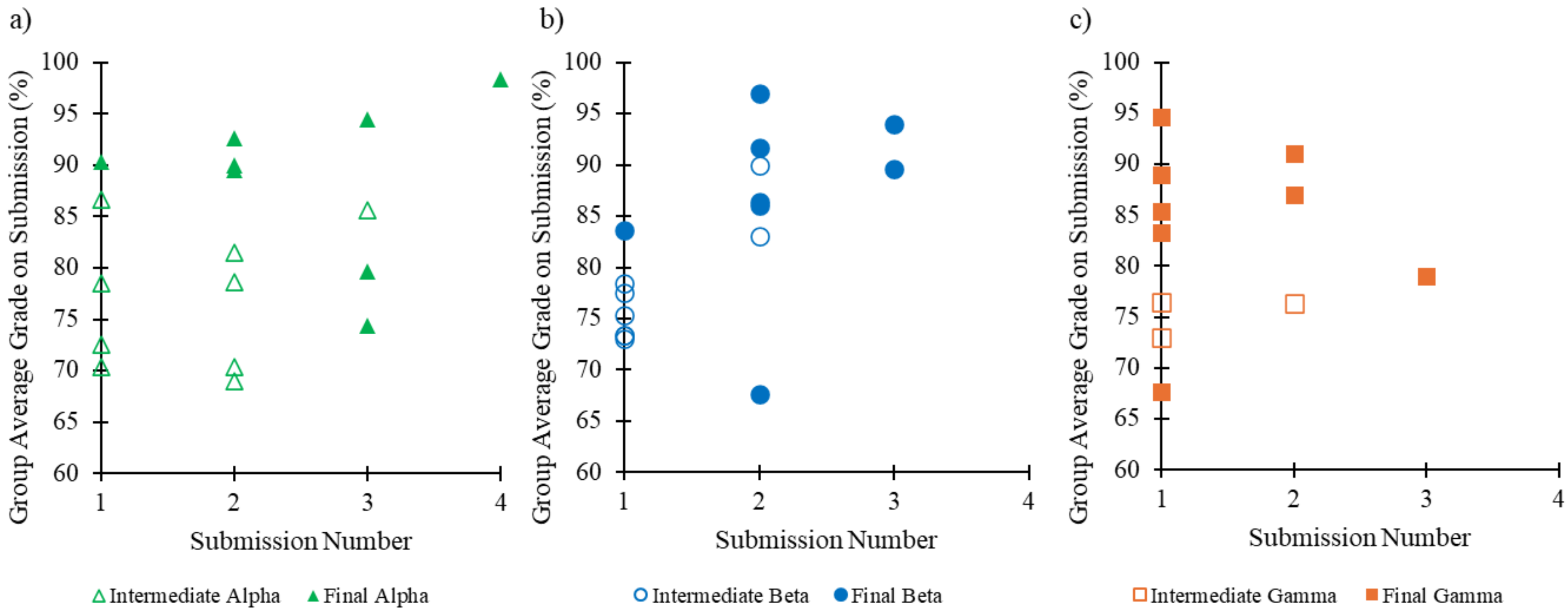

Figure 1. Average grade of group for intermediate (open) and final (closed) submissions for a) Unit Alpha (green triangles), b) Unit Beta (blue circles), and c) Unit Gamma (orange squares). Intermediate submissions are those which students received feedback on and submitted a follow up submission. Final submissions are the last submission for each deliverable. Four first submissions where at least one group member did not meet minimum requirements (i.e., at least one member receiving a grade of zero) are omitted to aid in viewing results.

A variety of student submission strategies were taken (Figs. 2, 3): the ‘standard’ ($N = 12$), the ‘rough draft’ ($N = 5$), the ‘one-and-done’ ($N = 3$), and the ‘out-of-time’ strategies ($N = 4$). In a ‘standard’ strategy, a group made two or three total submissions incorporating feedback from the first (and/or second) iterations for the final submission. Initial submissions for this strategy had an average overall group grade of 75.7% ± 4.1% and exhibited an approximately linear increase in grade to 90.8% ± 3.3% for the final submissions.

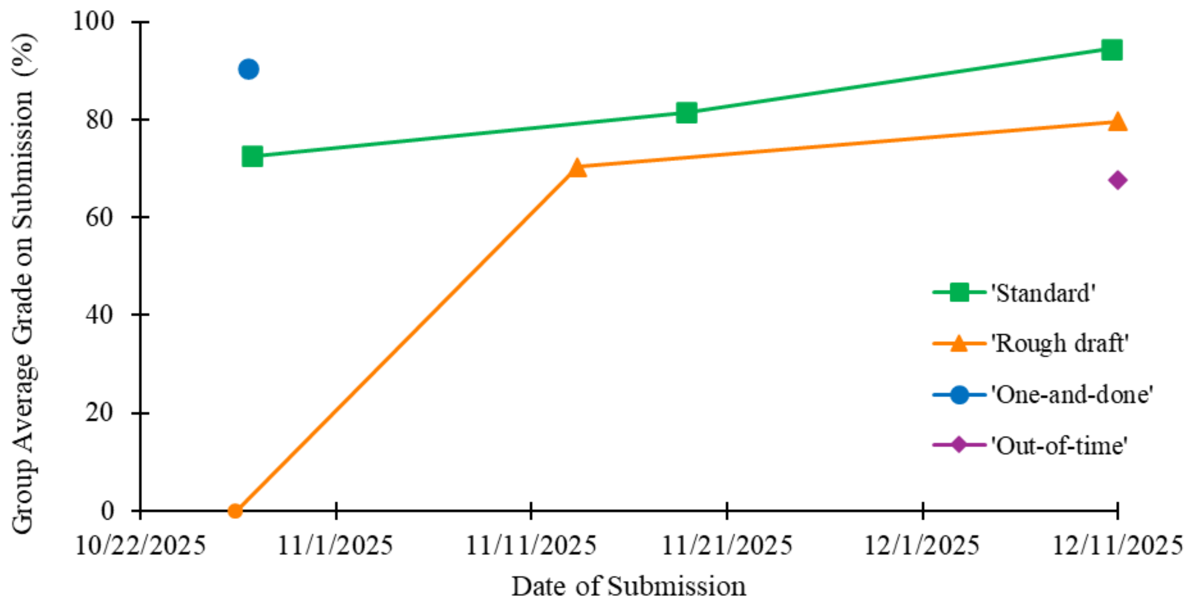

Figure 2. Representative timelines of the ‘standard’ (green square), ‘rough draft’ (orange triangle), ‘one-and-done’ (blue circle), and ‘out-of-time’ (purple diamond) submission strategies for groups. The ‘one-and-done’, ‘rough draft’, and ‘standard’ strategies are submissions from Unit Alpha, while the ‘Out-of-time’ strategy is from Unit Gamma.

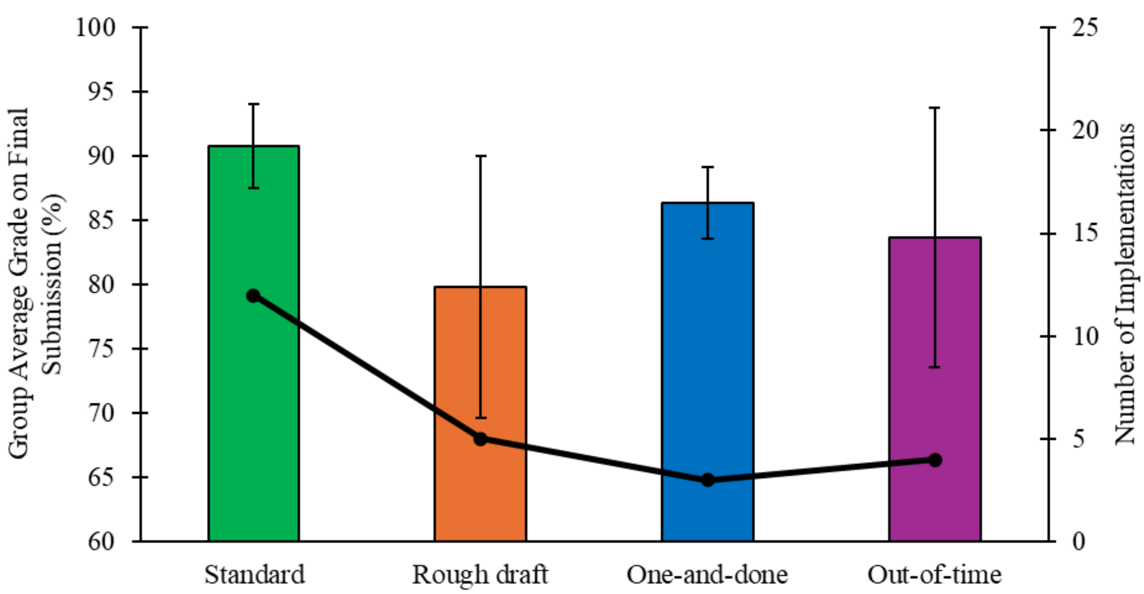

Figure 3. Group overall average final grades (bars, left axis) and number of instances of implementation (black line, right axis) for various submission strategies. Error bars represent one standard deviation of the average grade of the group.

On occasion, groups elected to take the ‘rough draft’ strategy, where they submitted a draft that did not meet minimum requirements, resulting in at least one member receiving a zero on the initial submission. When this strategy was taken, the group typically then submitted at least three submissions (two additional submissions after the initial zero-scoring draft), although in one case a group only had two total submissions and in another a group had four total submissions. Reports that did not meet minimum requirements generally were missing major components; thus, they were identified by the instructors prior to grading a significant portion of the deliverable and were returned without giving feedback. The additional iteration(s) thereby allowed the group to have at least one submission where they could act upon the feedback. Four of the five submissions in this category received a zero for every group member on the initial submission, while the one exception had one member receive a zero and the others barely meeting minimum requirements, resulting in a group average grade of a 43.3%. After iterations, the average group grades reached 83.4% ± 8.3%.

Some groups only made one total submission. In four of these submissions, the single submission was made within 5 days of the final deadline (i.e., such that the graders were unable to provide feedback prior to the submission deadline), which has been classified separately as the ‘out-of-time’ strategy. However, in three submissions (once in each unit by two separate groups across the semester), a group only made one submission despite not being near the deadline (i.e., they were likely satisfied with their original grade). This strategy has been classified as the ‘one-and-done’ strategy; these submissions had an average grade of 86.7% ± 2.8%, while the ‘out-of-time’ strategy had an average final grade of 83.67% ± 10.1%.

In addition to observing the impact of the new rubric and resubmission strategy on student grades and behaviors, the impact of the rubric on grading time is important. Written deliverables with a grade above 90% (almost exclusively final submissions) required an average of 25.8 ± 13.0 min to grade while with a grade below 90% (mostly intermediate submissions) required an average of 52.1 ± 23.3 min to grade (Fig. 4). Overall, the time required ranged from less than two minutes for a submission that clearly did not meet minimum standards up to 85 minutes. Across all lab reports, Graders A (orange) and B (purple) required an average of 46.1 ± 24.6 min and 46.3 ± 23.6 min to grade submissions. Both graders required more time to grade intermediate submissions (51.3 ± 27.0 min for Grader A and 63.5 ± 20.3 min for Grader B) on average than to grade final submissions (40.5 ± 20.2 and 29.2 ± 10.7 min for Graders A and B, respectively, Figure 5). The time required to grade submissions did not vary substantially based on the Unit or type of report being graded (journal-style report vs. emailed memo).

The time required to return submissions also varied by grader (Fig. 6). Graders A and B required 4.76 ± 3.0 days and 5.28 ± 2.2 days to return feedback on intermediate submissions, respectively. To return the final submissions, Grader A took on average 7.4 ± 1.9 days and Grader B took on average 5.1 ± 0.3 days.

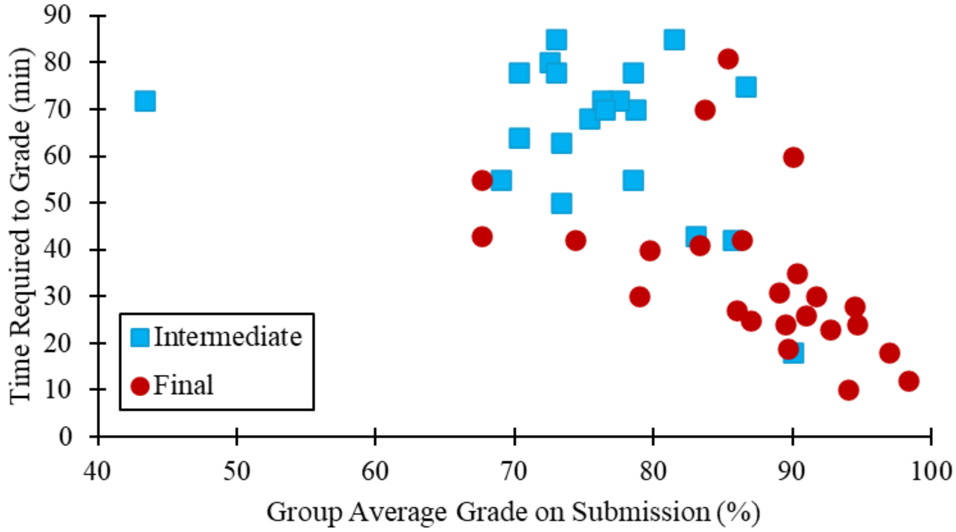

Figure 4. The time required to grade intermediate (blue square) and final (red circle) submissions of written deliverables of varying quality as measured by overall group average grade. Three submissions receiving a zero grade are omitted to aid in viewing data. The omitted submissions required 2 min, 12 min, and 40 min to grade. Intermediate submissions are those which students received feedback on and submitted a follow up submission. Final submissions are the last submission for each deliverable. Error in time required to grade is not pictured but is estimated to be on the order of 5 minutes for each submission.

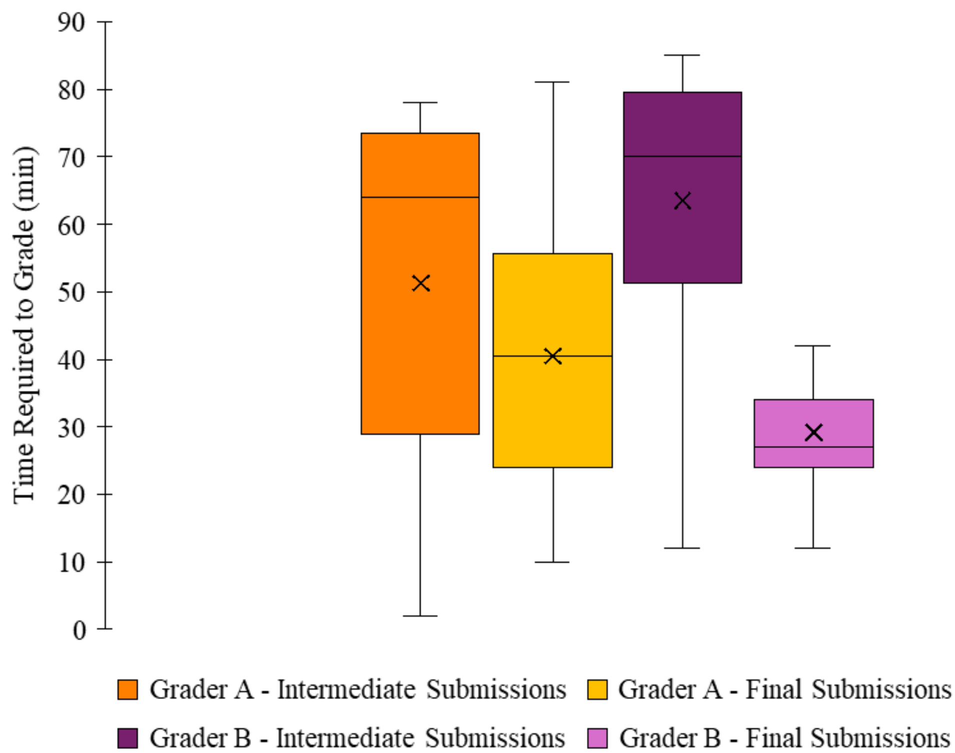

Figure 5. The time required to grade intermediate (Int., dark) and final (Fin., light) submissions for Grader A (orange) and Grader B (purple). The box spans between the upper and lower quartile and the whiskers show the minimum and maximum grading time. The median is indicated by a horizontal line inside the box while the mean is represented by the '×'. Intermediate submissions are those which students received feedback on and submitted a follow up submission. Final submissions are the last submission for each deliverable.

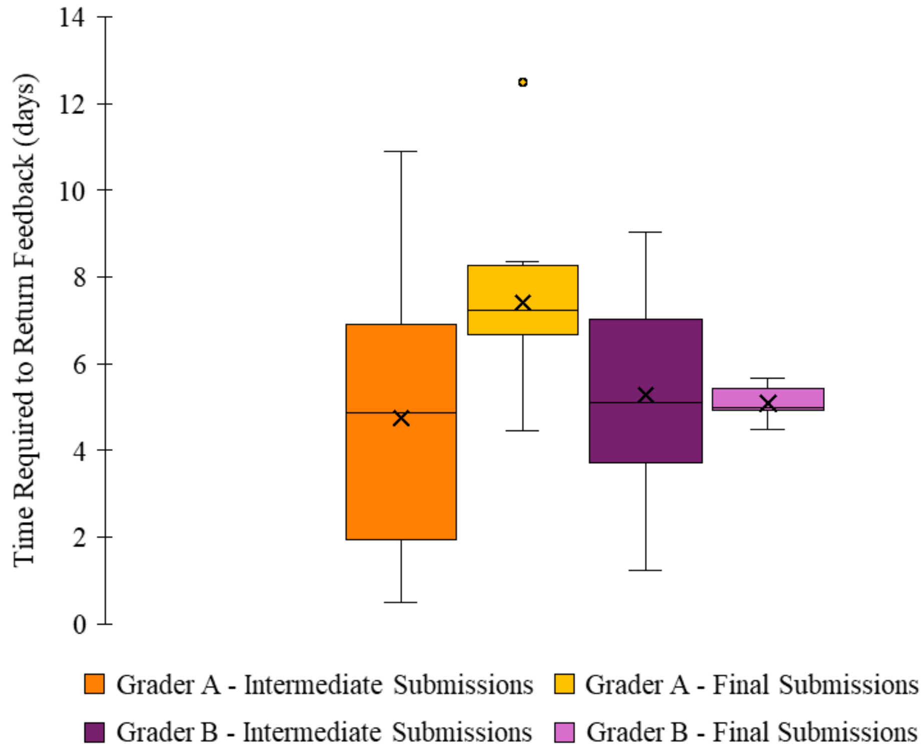

Figure 6. The time required for Grader A (orange) and Grader B (purple) to return feedback for intermediate (Int., dark) and final (Fin., light) submissions. Final submissions are the last submission for each deliverable. The box spans between the upper and lower quartile and the whiskers show the minimum and maximum grading time. The median is indicated by a horizontal line inside the box while the mean is represented by the '×'. Intermediate submissions are those which students received feedback on and submitted a follow up submission. One outlier (the small circle) represents a single final submission for Grader A in which the report was submitted 5 days prior to the final deadline but was not graded until all final reports were graded together.

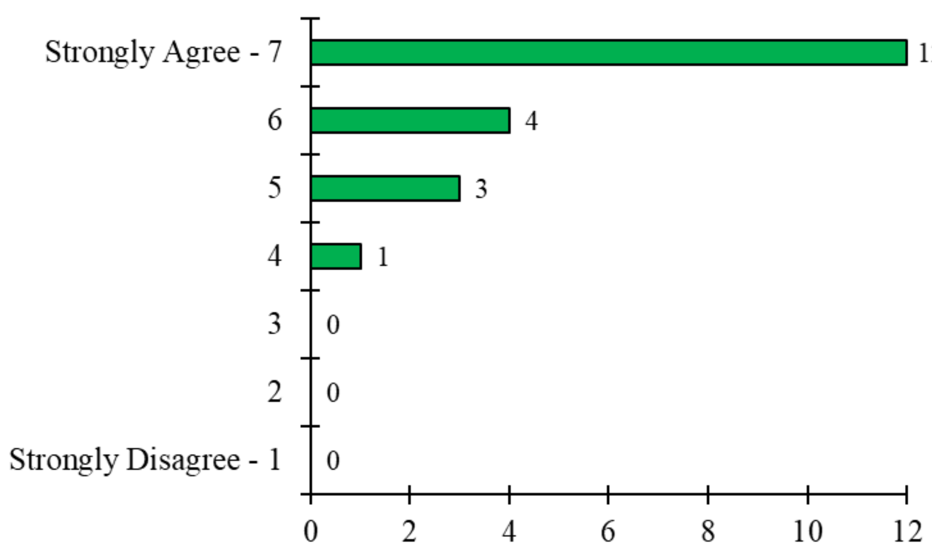

Figure 7. Student responses to the end-of-course survey question "How much do you agree with the following statement? Using standards-based grading (rubric + flexible deadlines + revisions) for the reports and memos improved my writing quality." Numbers to the right of the bars represent the total number of responses. Students receive 2% extra credit on their course grade if ≥85% of the class fills out the end of course evaluations prior to the release of final grades.

In anonymous end-of-course evaluations, students were asked questions regarding the new rubric and submission system. Students were asked to rate their agreement with the statement "Using standards-based grading (rubric + flexible deadlines + revisions) for the reports and memos improved my writing quality" according to a seven-point Likert scale, where 7 represents Strongly Agree and 1 represents Strongly Disagree. Of the twenty responses, student responses had a mean of 6.35 ± 0.93 and a median of 7.

Additionally, students were asked "Please elaborate on your response to the agree-disagree question below. In particular, please address if your writing quality changed (and how) as a result of (a) having greater clarity of expectations with a standards-based rubric (compared to other rubrics used in other courses), (b) having multiple submission attempts, (c) having flexible deadlines, or (d) other reasons." A simple qualitative analysis of the responses found that all 17 written responses spoke positively of the rubric and only 5 responses contained any negative language. Positive responses from students focused on a) having clearer expectations of what each section of the deliverable should contain, b) flexible deadlines reducing stress, and c) increased writing quality by allowing for multiple submissions. Negative responses almost entirely described the removal of a hard deadline making it more difficult to motivate teammates to meet internal deadlines. For example, one positive response included:

> *I liked the rolling deadlines because they allowed me more time to work on the assignments without feeling rushed, which I think led to better overall results. I think having clear expectations for the reports, as outlined by the rubric, made writing them easier, as they helped me focus on what to write. I think the multiple submission attempts also made it less stressful overall because there's a chance to improve if you do things incorrectly or poorly the first time around.*

An example of a response with both positive and negative feedback was:

> *I thought the revisions and standards based grading were beneficial to writing quality, but I think having slightly stricter deadlines or additional check–ins would allow teams to stay on track better and prevent one groupmate from holding the whole group back from additional submissions.*

Discussion

Overall, the new standards-based rubric provided several perceived advantages over the grid-based rubric previously used by the instructors while still allowing for grading of individual team roles. First, the practice of defining each standard of quality in the final reports helped the instructors clarify their desired goals for writing and formatting and likely made the instructors' expectations clearer to students. Qualitatively, student responses to the end-of-course evaluation survey suggest that students agree that the rubric clarified expectations compared to other course's rubrics. The simple binary choice of 'standard met' vs. 'not met'/'almost' essentially removed any agonizing over how much partial credit to give. Comparing all grades across the semester, the new rubric resulted in relatively consistent grades between instructors, between type of deliverable (Table 1), and across experimental topics and student role (Table 2), indicating that the design of the standards is general enough to be applied in multiple contexts.

After using the rubric, the instructors felt that some standards could be adjusted to provide further disambiguation, improve clarity, or to better address the desired standards/expectations. For example, under Style, the current standard is written as ‘Concise, precise language that is formal but not flowery’, but this standard could be broken down into ‘Concise and precise language’ and ‘Formal but not flowery language’. As another example, there are more standards that examine whether the type of content in a section is appropriate – e.g., whether the results are accurately presented, but fewer standards that clearly address whether the results or discussion are appropriate to the experimental goals. Additionally, because standards were all weighed equally, there was essentially more emphasis placed on content and style rather than accuracy or critical thinking.

In terms of the time spent grading, the instructors initially had hoped that removing partial credit on standards and increasing the number of individual items assessed might reduce grading time because instructors would have to spend less time explaining why a lower grade was received. Unfortunately, grading time was likely not reduced (at least not substantially), although quantitative analysis was not possible because the time required to grade reports using the previous rubric was not measured. However, the instructors feel that the new rubric format likely improved the *quality* of the feedback, as it became easier to indicate how a report failed to meet expectations, and it did so without requiring long written comments. Additionally, for intermediate submissions, instructors knew that the feedback was more likely to be reviewed and acted upon (a positive outcome for learning!), so it is possible that they gave greater care to how feedback was supplied. Students seemed to agree; many end-of-course evaluation responses highlighted the opportunity to incorporate feedback as a positive outcome of the new system, and nearly all students believed that the process helped improve their writing quality. Anecdotally, one instructor had, in past years, received complaints about the number of comments and annotations given– that is, students seemed overwhelmed by the volume of feedback. With the new alternative assessment system, the instructor felt students seemed to like (or at least were less put off by) having so much detailed feedback, as it helped them improve their skills (and their grade) more readily, and no responses in the end-of-course evaluation described having too much feedback as an area for improvement.

In reviewing the timing and number of student submissions, it became clear that there were several different ‘styles’ of submissions by student groups. It is likely unsurprising to any seasoned instructor, but the data in this study concretely show that less proactive submission styles (‘rough draft’ and ‘out-of-time’) generally resulted in lower final grades, whereas submission styles focused on regular submissions or high initial attention to quality generally resulted in higher final grades.

Regardless of submission styles, most students tended to resubmit reports until they either (a) ran out of time to do so or (b) they reached a sufficiently high grade (usually >90%). Notably, most reports reached this final state after one round of detailed feedback. That is, 10 of 12 in the 'standard' style only had two total submissions, and even for the 'rough draft' strategy, for which all but one report had three total submissions, one of these three submissions did not meet standards and did not actually receive any detailed feedback. Only 3 out of 24 total reports received two or three rounds of feedback.

For intermediate submissions, the time between a report being submitted and receiving a grade was generally less than a week, which is significantly less than in past years when all reports for a given unit were submitted and graded at once. Once students began submitting reports, there was an almost constant stream of reports needing to be graded. Perhaps counterintuitively, instructors felt less burdened by grading compared to previous years because the grading load was more distributed. That is, it was easier to find an hour or two to grade a report or two, rather than feeling like one needed to find 5-10 hours to grade many reports at once.

One last observation of this preliminary data analysis is that many student groups likely spent far less time writing and resubmitting their reports for Unit Gamma – that is, they spent more time writing and revising the reports that 'came first' (Units Alpha and Beta) and possibly ran out of time to work on that for Unit Gamma, as evidenced by 4 'out-of-time' submissions of the 8 total student groups, whereas there were 0 'out-of-time' submissions for Units Alpha and Beta. One possible solution would be to move the 'suggested' submission dates earlier. That being said, grades for initial Unit Gamma submissions were relatively higher than those for Units Alpha and Beta, suggesting that students may also have 'figured out' how to navigate the course expectations and did not necessarily need as much time on their third report.

Conclusions and future work

In this study, the instructors of a Unit Operations Laboratory course wanted to test out a method of alternative assessment for the grading of laboratory reports and memos, as alternative assessment has been shown to have numerous benefits for learning. Whatever method was implemented would need to be applied in a context in which students participated in different roles and could earn individual grades for their contributions. Thus, the instructors developed a new rubric in which each standard (or expectation for quality) was described and then graded on a binary choice of 'met'/'not met'. Each student role would be assessed on the same total number of standards, and the number of standards met could be easily scaled to a grade percentage. Furthermore, in keeping with alternative assessment practices, students would be able to resubmit reports without penalty to earn higher grades up until a final deadline.

The final rubric allowed for consistent grading across instructors and lab topics, improved clarity of expectations, and allowed for a higher quality of feedback that was likely more valued by students. Students submitted in one of several different timing styles, but most reports were returned in less than a week and only went through one round of detailed feedback. While total time spent grading was not reduced in this new method, it was more distributed and felt like less of a burden on instructors. Students also reported that the method improved their writing quality, that the flexibility on timing reduced stress, and that they appreciated the opportunity to improve their grade. Future work will include a refining of the rubric standards, potentially adding weighting to better balance the emphasis on style/formatting vs. critical thinking in key sections. Furthermore, student feedback (e.g., comments from course evaluations, focus groups) could be qualitatively assessed using emergent coding to more deeply understand themes in student experiences and perceptions. Overall, the use of an alternative assessment system (standards-based rubric + resubmission opportunities) for report grading is a promising technique to improve consistency, clarity, and the grading experience for instructors and students.

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Appendix A: Standards-Based Rubrics for 3-Person Teams

See final page of Appendix A for how the number of standards met corresponds to a grade in Canvas. Only standards that have been 'met' (approximately an A- or B+ level of quality) will be counted towards the grade.

Rubric for a Report (Unit Alpha only)

				Standards Met	**Current Grade**
Unit #: Alpha	**Unit Operation:** Mixing	**Team Leader:**		0 /35	0%
		Experimental Engineer:		0 /35	0%
Section: 0	**Team #:** 0	**Analyst:**		0 /35	0%

Written Communication Assessment (applies to all team members):

Topic	Standard	Meets Standard	*Almost*	*Not Yet/ Absent*	*Comments*
Style	Concise, precise language that is formal but not flowery				
	Language is largely quantitative instead of qualitative				
	Appropriate verb tenses and voice (active/passive)				
	No value judgments or subjective language				
Grammar	Few typos or syntax errors (not distracting to reader)				
Formatting & Typesetting	Document structure (cover page, table of contents, headers, section/figure/table reference numbering, etc.)				
	Text (font size, spacing, paragraph indentation)				
	Figures				
	Tables				
	Equations				
	Sig figs				
Citations & References	Citations are used (no plagiarism)				
	Citation styling follows ACS format				
	References are credible and technical				
	Total Written Communication Standards Met	**0**	**/14**		

Note: The standards for Formatting & Typesetting were kept concise for several reasons. First, the number of individual criteria was too many to list individually. Second, the expectations for these were discussed in-depth as part of lectures and as part of mid-unit feedback. Finally, compared to other aspects of writing, it is more "black and white" whether or not a student has used appropriate significant figures or created a table with appropriate formatting. The authors can share the details of these standards upon request.

Technical Assessment - Team Leader: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Abstract	Describes the context + key goals of experiments				
	Accurately, quantitatively, and concisely represents the most important methods, results, and conclusions				
	Appropriate length (~1/2 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., reference to figures or citations)				
Introduction & Theory	Describes the context and motivation for the study				
	Concisely lists the experimental objectives				
	Accurately, clearly, and concisely describes key theoretical considerations (e.g., key equations, assumptions) in an audience-appropriate way				
	Tells an organized story that smoothly transitions to the rest of the report				
	Appropriate length (~2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results)				
Discussion	Chooses the most important results (e.g., those related to key objectives) for discussion				
	Accurately interprets results in context of other experimental data and literature/theory (incl. quantitative comparison of values when appropriate)				
	Results are interpreted in light of error and uncertainty (not overinterpreted)				
	Discussion is clear and organized and tells a story				
	Appropriate length (~2-3 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., new results)				
Conclusion	Summarizes the key lab objectives and whether they were met (or if not, why not)				
	Briefly describes next steps (for the experiments, for the company, etc.) in context of the scenario described				
	Appropriate length (~1/2 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., new results or discussion points)				
Overall Story	Messaging about key objectives, methods, results, and conclusions is consistent throughout the report				
	Total Technical Standards Met	*0*	/21		
	Total Standards Met by Team Leader	***0***	**/35**		

Technical Assessment - Expt Engr: **0**					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Methods: PFD	Accurately represents process layout without being overly detailed				
	Digitally constructed, neatly laid out with legible text, free or mostly free of typos				
	Uses standard engineering iconography				
Methods: Apparatus	Describes brand/model of process equipment and supplemental instrumentation (a table is OK)				
	Describes key features of process equipment accurately without being overly detailed				
	Refers to and works with PFD				
	Appropriate length (~1/2-1 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., procedures)				
Methods: Experimental Procedures	Describes key procedural steps in a technical way such that someone with different equipment could replicate experiments				
	Does not include instructions for equipment operation (e.g., calibration, startup, shutdown)				
	Written as a narrative summary, not as instructions or a step-by-step procedure				
	Appropriate length (~1/2-1 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., analysis or results)				
Appendix: HAZOP and Safety Recommendations	Thoughtful exploration of deviations, causes (including multiple causes for deviations when appropriate), and consequences				
	Thorough exploration of all relevant guide word / deviation combinations				
	Each cause should have an accurate and unique consequence/action taken				
	Actions should be in context of the scenario and should rectify the situation (e.g., not just notification of lab manager)				
	Concisely lists all key chemical/electrical/etc. hazards and corresponding safety precautions				
	Refers to SDS sheets, HAZOP, and other technical sources as necessary				
Appendix: Raw Data	Reports all raw data utilized in the analysis				
	Data tables organized so as to be easily navigated				
	Total Technical Standards Met	*0*	/21		
	Total Standards Met by Experimental Engineer	***0***	**/35**		

Technical Assessment - Analyst: ***0***					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Methods: Data Analysis, Error & Uncertainty Analysis	Describes methods for manipulation of data, including key equations (may refer to those in introduction), software used, statistical methods, etc.				
	Data analysis methods are appropriate for achieving the stated objectives				
	Concisely summarizes methods for propagation of error				
	Describes methods for estimation of uncertainty				
	Error propagation methods described are appropriate for achieving the stated objectives				
	Uncertainty estimation methods described are appropriate for achieving the stated objectives				
	Written in narrative (not step-by-step) style				
	Appropriate length (~1-2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures, results, sample calculations)				
Results	Chooses the most important results (e.g., those related to key objectives) for presentation				
	Accurately summarizes results presented				
	Data reported includes accurate or practical estimations of uncertainty				
	Description of each result highlights the salient point				
	Key results are represented in appropriate figures or tables that are designed to showcase the salient point				
	Presents results in an organized and clear way				
	Appropriate length (~2-4 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., methods or discussion)				
Appendix: Sample Calculations	Provides a clear demonstration for how all key calculations were performed using sample data				
	For each sample calculation, a brief explanation of what is being done is provided				
	Source of the sample data is clear				
	Calculations are organized/easy to navigate with headers				
	Total Technical Standards Met	*0*	/21		
	Total Standards Met by Analyst	***0***	**/35**		

Rubric for a Memo (Units Beta and Gamma)

						Standards Met	**Current Grade**
Unit #:	Beta	**Unit Operation:**	Heat Exchanger	**Team Leader:**		0 /37	0%
				Experimental Engineer:		0 /37	0%
Section:	0	**Team #:**	0	**Analyst:**		0 /37	0%

Written Communication Assessment (applies to all team members):

Topic	Standard	Meets Standard	*Almost*	*Not Yet/ Absent*	*Comments*
Style	Concise, precise language that is formal but not flowery (mild informality is OK -- ex: using "we")				
	Language is largely quantitative instead of qualitative				
	Appropriate verb tenses and voice (active/passive)				
	No value judgments or subjective language				
Grammar	Few typos or syntax errors (not distracting to reader)				
Formatting & Typesetting	Document structure (cover page, email message, memo header, section headers, section/figure/table reference numbering, etc.)				
	Text (font size, spacing, paragraph indentation)				
	Figures				
	Tables				
	Equations				
	Sig figs				
Citations & References	Citations are used (no plagiarism)				
	Citation styling follows ACS format				
	References are credible and technical				
Overall Story	Messaging about key objectives, methods, results, and conclusions is consistent throughout the memo				
	Total Written Communication Standards Met	**0**	**/15**		

Note: The standards for Formatting & Typesetting were kept concise for several reasons. First, the number of individual criteria was too many to list individually. Second, the expectations for these were discussed in-depth as part of lectures and as part of mid-unit feedback. Finally, compared to other aspects of writing, it is more "black and white" whether or not a student has used appropriate significant figures or created a table with appropriate formatting. The authors can share the details of these standards upon request.

Technical Assessment - Team Leader: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Email Message	Clearly describes the purpose and contents of the memo and attachments				
	Written in the style and format of a professional email (header, salutation, body, closing, signature, list of attachments)				
	Appropriate length (body is ~2 paragraphs)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results)				
Summary Statement	Describes the context + key goals of experiments				
	Accurately, quantitatively, and concisely represents the most important results and conclusions				
	Appropriate length (1 paragraph)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., detailed methods or discussion)				
Results & Discussion	Chooses the most important results (e.g., those related to key objectives) for presentation				
	Accurately summarizes in the text any data that is presented				
	Description of results written to highlight the salient point				
	Results are reported with practical estimations of uncertainty (in text, figures, tables, etc.)				
	Key results are represented in appropriate figures or tables (no more than 3) that are designed to showcase the salient point				
	Accurately interprets results presented in context of other experimental data and literature/theory				
	Results are interpreted in light of error and uncertainty (not overinterpreted)				
	Presents ideas in an organized and clear way				
	Appropriate length (~2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures)				
Conclusion	Summarizes the key lab objectives and whether they were met (or if not, why not)				
	Briefly describes next steps (for the experiments, for the company, etc.) in context of the scenario described				
	Appropriate length (1 paragraph)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., new results or discussion points)				
	Total Technical Standards Met	0	/22		
	Total Standards Met by Team Leader	**0**	**/37**		

Technical Assessment - Expt Engr: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Introduction	Concisely describes the experimental objectives				
	Accurately, clearly, and **very** concisely describes key theoretical considerations (e.g., concepts, assumptions) in an audience-appropriate way				
	Provides a very brief and accurate overview of experimental procedures				
	Tells an organized story that smoothly transitions to the rest of the memo				
	Appropriate length (~1/2 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results)				
Attachment: PFD, Apparatus, & Experimental Procedures	PFD accurately represents process layout without being overly detailed				
	PFD is digitally constructed, neatly laid out with legible text, free or mostly free of typos				
	PFD uses standard engineering iconography				
	Describes brand/model and key features of process equipment/supplemental instrumentation accurately without being overly detailed				
	Description of apparatus refers to and works with PFD				
	Describes key procedural steps in a technical way such that someone with different equipment could replicate experiments				
	Does not include instructions for equipment operation (e.g., calibration, startup, shutdown)				
	Written as a narrative summary, not as instructions or a step-by-step procedure				
	Appropriate length (~2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results, theory)				
Attachment: HAZOP and Safety Recommendations	HAZOP: Thoughtful exploration of deviations, causes (including multiple causes for deviations when appropriate), and consequences				
	HAZOP: Thorough exploration of all relevant guide word / deviation combinations				
	HAZOP: Each cause should have an accurate and unique consequence/action taken				
	HAZOP: Actions should be in context of the scenario and should rectify the situation (e.g., not just notification of lab manager)				
	Concisely lists all key chemical/electrical/etc. hazards and corresponding safety precautions				
	Refers to SDS sheets, HAZOP, and other technical sources as necessary				
	Total Technical Standards Met	*0*	/22		
	Total Standards Met by Experimental Engineer	***0***	**/37**		

Technical Assessment - Analyst: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Attachment: Data Analysis & Additional Results	Describes methods for manipulation of data, including key equations (may refer to those in introduction), software used, statistical methods, etc.				
	Data analysis methods/approach are appropriate for achieving the stated objectives (e.g., consistent with theory)				
	Description of data analysis written in narrative (not step-by-step) style				
	Accurately and concisely summarizes (and, if relevant, interprets) key additional results				
	Additional supplementary results are reported with practical estimations of uncertainty (in text, figures, tables, etc.)				
	Additional results are represented in appropriate figures or tables that are designed to showcase the salient point				
	Interpretation of results is only done when critical to understanding, and when present, is done in light of error and uncertainty (not overinterpreted)				
	Appropriate length (remaining key results are presented concisely)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures, sample calculations)				
Attachment: Error & Uncertainty Analysis	Completely and concisely summarizes methods for propagation of error				
	Completely describes methods for estimation of uncertainty				
	Uncertainty estimation methods described are appropriate for achieving the stated objectives				
	Error propagation methods described are appropriate for achieving the stated objectives				
	Content is organized/easy to navigate				
	Appropriate length (error propagation and uncertainty analysis is presented concisely)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures, sample calculations)				
Attachment: Raw Data & Sample Calculations	Reports all raw data utilized in the analysis				
	Data tables organized so as to be easily navigated				
	Provides a clear demonstration for how all key calculations were performed using sample data				
	For each sample calculation, a brief explanation of what is being done is provided				
	Source of the sample data is clear				
	Calculations are organized/easy to navigate with headers				
	Total Technical Standards Met	*0*	/22		
	Total Standards Met by Analyst	***0***	**/37**		

Grade Conversion Table: Report

# of Standards Met	Grade in Canvas (%)
35	100
34	99
33	97
32	96
31	94
30	93
29	91
28	90
27	88
26	87
25	85
24	83
23	82
22	80
21	78
20	77
19	75
18	73
17	72
16	70
15	68
14	67
13	65
12	63
11	62
10	60
≤ 9	0

Grade Conversion Table: Memo

# of Standards Met	Grade in Canvas (%)
37	100
36	99
35	97
34	96
33	94
32	93
31	91
30	90
29	89
28	87
27	86
26	84
25	83
24	81
23	80
22	78
21	77
20	75
19	73
18	72
17	70
16	68
15	67
14	65
13	63
12	62
11	60
≤10	0

Appendix B: Standards-Based Rubrics for 2-Person Teams

See final page of Appendix B for how the number of standards met corresponds to a grade in Canvas. Only standards that have been 'met' (approximately an A- or B+ level of quality) will be counted towards the grade.

Rubric for a Report (Unit Alpha only)

						Standards Met		**Current Grade**
Unit #:	Alpha	**Unit Operation:**	Mixing	**Team Leader/Expt Engr:**		0	/46	0%
Section:	0	**Team #:**	0	**Analyst:**		0	/46	0%

Written Communication Assessment (applies to all team members):

Topic	Standard	Meets Standard	*Almost*	*Not Yet/ Absent*	*Comments*
Style	Concise, precise language that is formal but not flowery				
	Language is largely quantitative instead of qualitative				
	Appropriate verb tenses and voice (active/passive)				
	No value judgments or subjective language				
Grammar	Few typos or syntax errors (not distracting to reader)				
Formatting & Typesetting	Document structure (cover page, table of contents, headers, section/figure/table reference numbering, etc.)				
	Text (font size, spacing, paragraph indentation)				
	Figures				
	Tables				
	Equations				
	Sig figs				
Citations & References	Citations are used (no plagiarism)				
	Citation styling follows ACS format				
	References are credible and technical				
Overall Story	Messaging about key objectives, methods, results, and conclusions is consistent throughout the report				
	Total Written Communication Standards Met	**0**	**/15**		

Technical Assessment - Team Leader/Expt Engr: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Abstract	Describes the context + key goals of experiments				
	Accurately, quantitatively, and concisely represents the most important methods, results, and conclusions				
	Appropriate length (~1/2 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., reference to figures or citations)				
Introduction & Theory	Describes the context and motivation for the study				
	Concisely lists the experimental objectives				
	Accurately, clearly, and concisely describes key theoretical considerations (e.g., key equations, assumptions) in an audience-appropriate way				
	Tells an organized story that smoothly transitions to the rest of the report				
	Appropriate length (~2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results)				
Methods: Apparatus	Describes brand/model of process equipment and supplemental instrumentation (a table is OK)				
	Describes key features of process equipment accurately without being overly detailed				
	Refers to and works with PFD				
	Appropriate length (~1/2-1 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., procedures)				
Discussion	Chooses the most important results (e.g., those related to key objectives) for discussion				
	Accurately interprets results in context of other experimental data and literature/theory (incl. quantitative comparison of values when appropriate)				
	Results are interpreted in light of error and uncertainty (not overinterpreted)				
	Discussion is clear and organized and tells a story				
	Appropriate length (~2-3 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., new results)				
Conclusion	Summarizes the key lab objectives and whether they were met (or if not, why not)				
	Briefly describes next steps (for the experiments, for the company, etc.) in context of the scenario described				
	Appropriate length (~1/2 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., new results or discussion points)				
Appendix: HAZOP & Safety Recommendations	Thoughtful exploration of deviations, causes (including multiple causes for deviations when appropriate), and consequences				
	Thorough exploration of all relevant guide word / deviation combinations				
	Each cause should have an accurate and unique consequence/action taken				
	Actions should be in context of the scenario and should rectify the situation (e.g., not just notification of lab manager)				
	Concisely lists all key chemical/electrical/etc. hazards and corresponding safety precautions				
	Refers to SDS sheets, HAZOP, and other technical sources as necessary				
	Total Technical Standards Met	*0*	/31		
	Total Standards Met by Team Leader	***0***	**/46**		

Technical Assessment - Analyst: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Methods: PFD	Accurately represents process layout without being overly detailed				
	Digitally constructed, neatly laid out with legible text, free or mostly free of typos				
	Uses standard engineering iconography				
Methods: Experimental Procedures	Describes key procedural steps in a technical way such that someone with different equipment could replicate experiments				
	Does not include instructions for equipment operation (e.g., calibration, startup, shutdown)				
	Written as a narrative summary, not as instructions or a step-by-step procedure				
	Appropriate length (~1/2-1 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., analysis or results)				
Methods: Data Analysis, Error & Uncertainty Analysis	Describes methods for manipulation of data, including key equations (may refer to those in introduction), software used, statistical methods, etc.				
	Data analysis methods are appropriate for achieving the stated objectives				
	Concisely summarizes methods for propagation of error				
	Describes methods for estimation of uncertainty				
	Error propagation methods described are appropriate for achieving the stated objectives				
	Uncertainty estimation methods described are appropriate for achieving the stated objectives				
	Written in narrative (not step-by-step) style				
	Appropriate length (~1-2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures, results, sample calculations)				
Results	Chooses the most important results (e.g., those related to key objectives) for presentation				
	Accurately summarizes results presented				
	Data reported includes accurate or practical estimations of uncertainty				
	Description of each result highlights the salient point				
	Key results are represented in appropriate figures or tables that are designed to showcase the salient point				
	Presents results in an organized and clear way				
	Appropriate length (~2-4 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., methods or discussion)				
Appendix: Raw Data	Reports all raw data utilized in the analysis				
	Data tables organized so as to be easily navigated				
Appendix: Sample Calculations	Provides a clear demonstration for how all key calculations were performed using sample data				
	For each sample calculation, a brief explanation of what is being done is provided				
	Source of the sample data is clear				
	Calculations are organized/easy to navigate with headers				
	Total Technical Standards Met	*0*	/31		
	Total Standards Met by Analyst	***0***	**/46**		

Rubric for a Memo (Units Beta and Gamma)

					Standards Met	**Current Grade**
Unit #: Beta	**Unit Operation:** Heat Exchanger	**Team Leader/Expt Engr:**			0 /48	0%
Section: 0	**Team #:** 0	**Analyst:**			0 /48	0%

Written Communication Assessment (applies to all team members):

Topic	Standard	Meets Standard	*Almost*	*Not Yet/ Absent*	*Comments*
Style	Concise, precise language that is formal but not flowery (mild informality is OK -- ex: using "we")				
	Language is largely quantitative instead of qualitative				
	Appropriate verb tenses and voice (active/passive)				
	No value judgments or subjective language				
Grammar	Few typos or syntax errors (not distracting to reader)				
Formatting & Typesetting	Document structure (cover page, email message, memo header, section headers, section/figure/table reference numbering, etc.)				
	Text (font size, spacing, paragraph indentation)				
	Figures				
	Tables				
	Equations				
	Sig figs				
Citations & References	Citations are used (no plagiarism)				
	Citation styling follows ACS format				
	References are credible and technical				
Overall Story	Messaging about key objectives, methods, results, and conclusions is consistent throughout the memo				
	Total Written Communication Standards Met	**0**	**/15**		

Technical Assessment - Team Leader/Expt Engr: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Email Message	Clearly describes the purpose and contents of the memo and attachments				
	Written in the style and format of a professional email (header, salutation, body, closing, signature, list of attachments)				
	Appropriate length (body is ~2 paragraphs)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results)				
Introduction	Concisely describes the experimental objectives				
	Accurately, clearly, and **<u>very</u>** concisely describes key theoretical considerations (e.g., concepts, assumptions) in an audience-appropriate way				
	Provides a very brief and accurate overview of experimental procedures				
	Tells an organized story that smoothly transitions to the rest of the memo				
	Appropriate length (~1/2 page)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results)				
Results & Discussion	Chooses the most important results (e.g., those related to key objectives) for presentation				
	Accurately summarizes in the text any data that is presented				
	Description of results written to highlight the salient point				
	Results are reported with practical estimations of uncertainty (in text, figures, tables, etc.)				
	Key results are represented in appropriate figures or tables (no more than 3) that are designed to showcase the salient point				
	Accurately interprets results presented in context of other experimental data and literature/theory				
	Results are interpreted in light of error and uncertainty (not overinterpreted)				
	Presents ideas in an organized and clear way				
	Appropriate length (~2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures)				
Attachment: Error & Uncertainty Analysis	Completely and concisely summarizes methods for propagation of error				
	Completely describes methods for estimation of uncertainty				
	Uncertainty estimation methods described are appropriate for achieving the stated objectives				
	Error propagation methods described are appropriate for achieving the stated objectives				
	Content is organized/easy to navigate				
	Appropriate length (error propagation and uncertainty analysis is presented concisely)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures, sample calculations)				
Attachment: HAZOP & Safety Considerations	HAZOP: Thoughtful exploration of deviations, causes (including multiple causes for deviations when appropriate), and consequences				
	HAZOP: Thorough exploration of all relevant guide word / deviation combinations				
	HAZOP: Each cause should have an accurate and unique consequence/action taken				
	HAZOP: Actions should be in context of the scenario and should rectify the situation (e.g., not just notification of lab manager)				
	Concisely lists all key chemical/electrical/etc. hazards and corresponding safety precautions				
	Refers to SDS sheets, HAZOP, and other technical sources as necessary				
	Total Technical Standards Met	0	/33		
	Total Standards Met by Team Leader	**0**	**/48**		

Technical Assessment - Analyst: 0					
Topic	**Standard**	**Meets Standard**	***Almost***	***Not Yet/ Absent***	***Comments***
Summary Statement	Describes the context + key goals of experiments				
	Accurately, quantitatively, and concisely represents the most important results and conclusions				
	Appropriate length (1 paragraph)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., detailed methods or discussion)				
Conclusion	Summarizes the key lab objectives and whether they were met (or if not, why not)				
	Briefly describes next steps (for the experiments, for the company, etc.) in context of the scenario described				
	Appropriate length (1 paragraph)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., new results or discussion points)				
Attachment: PFD, Apparatus, & Experimental Procedures	PFD accurately represents process layout without being overly detailed				
	PFD is digitally constructed, neatly laid out with legible text, free or mostly free of typos				
	PFD uses standard engineering iconography				
	Describes brand/model and key features of process equipment/supplemental instrumentation accurately without being overly detailed				
	Description of apparatus refers to and works with PFD				
	Describes key procedural steps in a technical way such that someone with different equipment could replicate experiments				
	Does not include instructions for equipment operation (e.g., calibration, startup, shutdown)				
	Written as a narrative summary, not as instructions or a step-by-step procedure				
	Appropriate length (~2 pages)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., results, theory)				
Attachment: Data Analysis & Additional Results	Describes methods for manipulation of data, including key equations (may refer to those in introduction), software used, statistical methods, etc.				
	Data analysis methods/approach are appropriate for achieving the stated objectives (e.g., consistent with theory)				
	Description of data analysis written in narrative (not step-by-step) style				
	Accurately and concisely summarizes (and, if relevant, interprets) key additional results				
	Additional supplementary results are reported with practical estimations of uncertainty (in text, figures, tables, etc.)				
	Additional results are represented in appropriate figures or tables that are designed to showcase the salient point				
	Interpretation of results is only done when critical to understanding, and when present, is done in light of error and uncertainty (not overinterpreted)				
	Appropriate length (remaining key results are presented concisely)				
	Contains appropriate content and no inappropriate/extraneous content (e.g., experimental procedures, sample calculations)				
Attachment: Raw Data & Sample Calculations	Reports all raw data utilized in the analysis				
	Data tables organized so as to be easily navigated				
	Provides a clear demonstration for how all key calculations were performed using sample data				
	For each sample calculation, a brief explanation of what is being done is provided				
	Source of the sample data is clear				
	Calculations are organized/easy to navigate with headers				
	Total Technical Standards Met	*0*	/33		
	Total Standards Met by Analyst	***0***	**/48**		

Grade Conversion Table: Report

# of Standards Met	Grade in Canvas (%)
46	100
45	99
44	98
43	97
42	96
41	95
40	94
39	93
38	92
37	91
36	90
35	89
34	88
33	86
32	85
31	84
30	83
29	81
28	80
27	79
26	77
25	76
24	74
23	73
22	71
21	70
20	69
19	68
18	66
17	65
16	64
15	63
14	61
13	60
≤12	0

Grade Conversion Table: Memo

# of Standards Met	Grade in Canvas (%)
48	100
47	99
46	98
45	97
44	96
43	95
42	94
41	93
40	92
39	91
38	90
37	89
36	88
35	86
34	85
33	84
32	83
31	81
30	80
29	79
28	78
27	77
26	76
25	74
24	73
23	72
22	71
21	70
20	69
19	68
18	66
17	65
16	64
15	63
14	61
13	60
≤12	0

Appendix C: Traditional Grid-Based Rubrics for 3-Person Teams

Rubric for a Report (Unit Alpha only)

Written Communication Assessment (applies to all team members):							
Topic	**Points Per Topic**	**Unacceptable/Missing 0.0**	**Marginal 0.4**	**Acceptable 0.6**	**Good 0.8**	**Excellent 1.0**	**Points Earned**
Style	4	Writing style is completely unprofessional.	Major use of informal or flowery language or major misuse of voice/tense (e.g., uses first or second person, uses incorrect verb tenses).	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Writing style is professional technical, and concise. No use of "flowery" or informal language (including contractions). Uses third person voice with appropriate passive/active construction. Uses appropriate verb tenses.	
Organization & Format	8	Formatting is wildly inconsistent, including having no page numbers and has dangling lines of text. Font changes several times.	Format is often inconsistent. Has no headers, no page numbers, and/or has several dangling lines of text. Font changes 1-2 times for no reason. Large blank spaces throughout the report. Report is either much too long or much too short.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Format (font, spacing, etc.) is consistent throughout. Uses headings and subheadings to visually organize the material with appropriate spacing between sections and around figures/tables. Has page numbers. No dangling lines of text. Report is of appropriate length.	
Grammar & Construction	4	Very distracting number of errors.	Numerous errors - somewhat distracting to reader.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Negligible errors.	
Equations, Figures, & Tables	6	No equations, figures, or tables provided.	Figures and tables are mostly formatted incorrectly. Proper equation format not followed. Incorrect placement in document.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Negligible observed figure, table or equation format errors. Correct placement. Tables, figures and equations enhance the quality of the report.	
Citations	4	No citations made in-text (plagiarized). Reference list is missing or lacks any standard format.	References are used incorrectly. Material is not always translated to own words (plagiarism). Citations and reference list have numerous formatting errors.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	References are used correctly and support the author's work. Material is translated into own words. Citations and reference list have negligible formatting errors.	
References	4	References are missing.	Several references from dubious (not primary or edited) sources (Wikipedia, course notes, etc.) If AI is used, Appendix of prompts and responses not provided.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	All references show good scholarship (are either primary sources of data or are edited versions of it from a verified reference). If AI is used, it is cited in-text, and prompts and responses are provided as an Appendix.	
						Total Points	0

Technical Assessment - Team Leader:

Topic	Points Per Topic	Unacceptable/Missing 0.0	Marginal 0.4	Acceptable 0.6	Good 0.8	Excellent 1.0	Points Earned
Abstract	8	Incomplete, key results missing.	Description of goals, methods, results, and findings very limited, and disorganized. Summary not helpful to the reader. Many elements not required in an abstract and too long.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Complete and concise description of goals, methods, results and findings clearly presented and explained thoroughly. Proper contextualization of objectives in the lab situtation. Results and finding include quantitative results (if possible) and establish the relationship between independent and dependent experimental variables	
Introduction and Theory	10	Introduction is haphazard or missing.	Explanation of theory, objectives, and project relevance contains major mistakes or omissions, is poorly organized, and does not lead into the rest of the report.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Project objectives, applications, and relevance are clearly presented. Demonstrates a clear understanding of theory. Completely summarizes relevant equations, assumptions, and theory. Organized explanation that leads into rest of report.	
Discussion	12	No discussion of results.	Limited interpretation or heavy over-interpretation of the results. No evidence showing whether results are as expected or not. No generalization of results. Not concise.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Concise discussion providing reasonable interpretation and insight into key features of the results. Includes evidence showing whether results are as expected or not (and if not, why that might be). Generalization of results given to show application to other situations.	
Conclusion	5	Conclusion is haphazard or missing.	Summarizes some of the project situation, goals, and key findings, but in a very indirect manner or by including irrelevant materials. Introduces new information related to the project. Conclusions too general or over-reach the analysis (not warranted by results). Does not communicate relevance of results to original problem.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Completely summarizes project siutation, goals, and key findings without introducing new information. Relate results to general interest or other implications for design.	
						Total Technical Points for Leader	0
						Total Score (Technical Pts x 2 + Written Communication Score)	0

Technical Assessment - Experimental Engineer:							
Topic	**Points Per Topic**	**Unacceptable/Missing 0.0**	**Marginal 0.4**	**Acceptable 0.6**	**Good 0.8**	**Excellent 1.0**	**Points Earned**
Apparatus (including PFD)	9	Written description and PFD of apparatus are haphazard or missing.	Several major errors or missing elements in either the the written description or schematic; alternatively, is missing either the schematic or the written description	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	All experimental components are clearly described and their functions explained adequately. Clear and helpful schematic included. Does not include information that would be irrelevant/unnecessary to helping a reader knowledgeable in engineering to reproduce the work.	
Procedures	10	Procedures mentioned haphazardly or not at all.	Procedures are overly long and/or overly specific or alternatively lack enough clarity to reproduce the data. Voice is inappropriate for a procedures section (e.g., written as instructions instead of a description) and/or includes a large amount of inappropriate content (e.g., description of data analysis).	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Professional, clear, precise, and organized description of experimental (in-lab) procedures written at the level of detail so that data collection could be reproduced on similar (not identical) equipment; experimental design presented.	
Appendix - HAZOP and Safety Considerations	8	HAZOP and safety considerations are missing.	Analysis is superficial (e.g., addresses minimal number of parameter/guide word combinations, includes only a single cause of each deviation) and node chosen is superficial or unimportant. Safety considerations are superficial and do not provide insight beyond what is provided in lab handout.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	HAZOP analysis thoroughly addresses all relevant parameter/guide word combinations at one critical node. Analysis is thoughtful and includes multiple potential causes for deviations where relevant. Safety considerations are thorough and include insight from HAZOP as well as other sources (e.g., SDS pages)	
Appendix - Data Collection	8	Data are either missing or haphazardly recorded.	Deficient in more than two characteristics.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	All relevant data are measured, shown to be reproducible, accurate, and are well-presented. No unimportant data are included. Correct use of sig figs throughout.	
						Total Technical Points for Experimental Engineer	0
						Total Score (Technical Pts x 2 + Written Communication Score)	0

Technical Assessment - Analyst:							
Topic	**Points Per Topic**	**Unacceptable/Missing 0.0**	**Marginal 0.4**	**Acceptable 0.6**	**Good 0.8**	**Excellent 1.0**	**Points Earned**
Error and Uncertainty Analysis	8	No mention of data uncertainty or error analysis.	Minimal or missing description of how data uncertainty and error analysis was performed. Minimal or missing explanation of potential sources of data uncertainty and error. Data uncertainty and error analysis was applied and performed with significant mistakes.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Complete description of how data uncertainty and error analysis was performed including error propagation and statistical tools applied. Complete explanation of potential sources of data uncertainty and error. Data uncertainty and error analysis was applied and performed correctly.	
Data Analysis	10	No mention of how data was analyzed.	Description of data analysis is minimal/unclear, and may be missing several critical references to theory, equations, calculations methods, and correlations. Difficult for reader to re-construct non-trivial operations that convert raw data into data for interpretation. Written in a "step-by-step" style.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Complete explanation of how the data were analyzed. Includes references to relevant theory, equations, calculation methods, and correlations where applicable. Trivial calculations (e.g., mean and standard deviation) described very briefly. Non-trivial operations described in enough detail to allow the reader to reconstruct the conversion of raw data into an interpretable result. Written in a narrative style (not step-by-step procedure).	
Results	10	Description of results is haphazard (showing complete misunderstanding of concepts) or missing.	Some of the results relevant to project objectives are presented, but many results are presented that are either irrelevant or derived from incorrect data collection or analysis, or are missing. Organization lacking. Little or no statistical analysis of results.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	All the results relevant to project objectives are presented. Relevant data, trends, and statistics of the results are completely and concisely described but not interpreted. Organization makes it clear how the results relate to project goals.	
Appendix - Sample Calculations	7	Sample calculations not included, erroneous, and/or unreadable.	Numerous calculations are erroneous and/or irrelevant. Explanations for where values came from and what they resulted in are unclear. Sig figs are inappropriate throughout.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Relevant sample calculations are precise, well-explained and complete; it is clear where sample values came from (e.g., what experimental conditions) and what results were calculated from those sample values. Sig figs are appropriate throughout.	
						Total Technical Points for Analyst	0
						Total Score (Technical Pts x 2 + Written Communication Score)	0

Rubric for a Memo (Units Beta and Gamma)

Written Communication Assessment (applies to all team members):								
Topic	**Points Per Topic**	**Unacceptable/Missing 0.0**	**Marginal 0.4**	**Acceptable 0.6**	**Good 0.8**	**Excellent 1.0**	**Points Earned**
Style	4	Writing style is completely unprofessional.	Major use of informal or flowery language or major misuse of voice/tense (e.g., second person, uses incorrect verb tenses).	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Writing style is professional, technical, and concise. Style is slightly less formal than for a formal report, but still does not use "flowery" language or contractions (is okay to use first person voice in a memo). Uses appropriate passive/active construction. Uses appropriate verb tenses.	
Organization & Format	8	Formatting is wildly inconsistent, including having no page numbers and has dangling lines of text. Font changes several times.	Format is often inconsistent. Has no headers, no page numbers, and/or has several dangling lines of text. Font changes 1-2 times for no reason. Large blank spaces throughout the report. Report is either much too long or much too short.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Format (font, spacing, etc.) is consistent throughout. Uses headings and subheadings to visually organize the material with appropriate spacing between sections and around figures/tables. Has page numbers. No dangling lines of text. Report is of appropriate length.	
Grammar & Construction	4	Very distracting number of errors.	Numerous errors - somewhat distracting to reader.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Negligible errors.	
Equations, Figures, & Tables	6	No equations, figures, or tables provided.	Figures and tables are mostly formatted incorrectly. Proper equation format not followed. Incorrect placement in document.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Negligible observed figure, table or equation format errors. Correct placement. Tables, figures and equations enhance the quality of the report.	
Citations	4	No citations made in-text (plagiarized). Reference list is missing or lacks any standard format.	References are used incorrectly. Material is not always translated to own words (plagiarism). Citations and reference list have numerous formatting errors.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	References are used correctly and support the author's work. Material is translated into own words. Citations and reference list have negligible formatting errors.	
References	4	References are missing.	Several references from dubious (not primary or edited) sources (Wikipedia, course notes, etc.) If AI is used, attachment of prompts and responses not provided.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	All references show good scholarship (are either primary sources of data or are edited versions of it from a verified reference). If AI is used, it is cited in-text, and prompts and responses are provided as an attachment.	
						Total Points	0

Technical Assessment - Team Leader:

Topic	Points Per Topic	Unacceptable/Missing 0.0	Marginal 0.4	Acceptable 0.6	Good 0.8	Excellent 1.0	Points Earned
Email Message	8	Email message unacceptable or missing	More than one important piece of information is missing. Writing is unclear and/or unprofessional (too informal or personal). Does not clearly indicate the purpose or importance of the memo. Wording is vague, not concise.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Contains all required information. Indicates the purpose and importance of the memo, as well as general idea of the contents. Is written clearly and professionally.	
Summary Statement	12	Incomplete or missing	Incomplete and/or long-winded description of memo contents. Descriptions of purpose, conclusions, and recommendations unclear and disorganized.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Enables reader to identify contents of memo. Concisely states purpose of the experiment and gives short quantitative summary of the conclusions and recommendations.	
Introduction	10	Introduction is haphazard (potentially showing complete misunderstanding of concepts) or missing.	The experiment goals and/or importance are unclear. Basic approach summarized, but includes a lot of incorrect, inappropriate, and/or irrelevant background or procedures. Section overall is too long or too short.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Completely and concisely describes experiment goals and importance. Clearly summarizes basic approach to the problem, reviewing critical background and providing an overview of the procedures.	
Conclusion	5	Conclusion is haphazard or missing.	Description of the objectives, critical conclusions, and/or critical recommendations is lacking. Conclusions too general or over-reach the analysis (not warranted by results). Length is too long or too short.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Completely and concisely describes the experimental objectives and the most important conclusions and recommendations. Length is appropriate for a memo.	
						Total Technical Points for Leader	0
						Total Score (Technical Pts x 2 + Written Communication Score)	0

Technical Assessment - Experimental Engineer:

Topic	Points Per Topic	Unacceptable/Missing 0.0	Marginal 0.4	Acceptable 0.6	Good 0.8	Excellent 1.0	Points Earned
Attachment - Raw Data	10	Data are either missing or haphazardly recorded.	Deficient in more than two characteristics.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	All relevant data are measured, shown to be reproducible, accurate, and are well-presented. No unimportant data are included. Correct use of sig figs throughout.	
Attachment - Apparatus and Methods	15	Written description and PFD of apparatus are haphazard or missing.	Several major errors or missing elements in either the the written description or PFD; alternatively, is missing either the PFD or the written description. Lots of irrelevant or unnecessary detail provided.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	All experimental components are clearly described and their functions explained adequately. Clear and helpful PFD is included. Does not include irrelevant or unnecessary information for someone with an engineering background.	
Attachment - HAZOP and Safety Considerations	10	HAZOP and safety considerations are missing.	Analysis is superficial (e.g., addresses minimal number of parameter/guide word combinations, includes only a single cause of each deviation) and node chosen is superficial or unimportant. Safety considerations are superficial and do not provide insight beyond what is provided in lab handout.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	HAZOP analysis thoroughly addresses all relevant parameter/guide word combinations at one critical node. Analysis is thoughtful and includes multiple potential causes for deviations where relevant. Safety considerations are thorough and include insight from HAZOP as well as other sources (e.g., SDS pages)	
						Total Technical Points for Experimental Engineer	0
						Total Score (Technical Pts x 2 + Written Communication Score)	0

Technical Assessment - Analyst:								
Topic	**Points Per Topic**	**Unacceptable/Missing 0.0**	**Marginal 0.4**	**Acceptable 0.6**	**Good 0.8**	**Excellent 1.0**	**Points Earned**
Results and Discussion	15	Description of results and discussion is haphazard (showing complete misunderstanding of concepts) or missing.	Multiple descriptions are lacking, and the link between data analysis, results, and conclusions is unclear. Includes incorrect, improper, and/or irrelevant results, figures, and/or discussion material. Is too short or too long.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Briefly describes how the data were collected and analyzed. Focuses on the key experimental results and connects those to the conclusions drawn. Uses no more than 3 figures/tables to supplement the written text to support key points. Discussion relating results to theory is limited to critically important observations.	
Attachment - Data Analysis and Additional Results	10	Description of data analysis is missing. Additional results show a complete misunderstanding of concepts or are missing entirely.	Description of data analysis is minimal/unclear, and may be missing several critical references to theory, equations, calculations methods, and correlations. Difficult for reader to re-construct non-trivial operations that convert raw data into data for interpretation. Written in a "step-by-step" style. Additional results poorly explained or contain major errors. Many critical figures/tables either missing or irrelevant.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Complete explanation of how the data were analyzed. Includes references to relevant theory, equations, calculation methods, and correlations where applicable. Trivial calculations (e.g., mean and standard deviation) described very briefly. Non-trivial operations described in enough detail to allow the reader to reconstruct the conversion of raw data into an interpretable result. Written in a narrative style (not step-by-step procedure). Additional results that did not fit in the main memo body are concisely explained and supported by appropriate figures and tables.	
Attachment - Error and Uncertainty Analysis, Sample Calculations	10	Data and uncertainty analysis is haphazard or entirely missing. Sample calculations not included, erroneous, and/or unreadable.	Largely missing description of how data uncertainty and error analysis were performed including error propagation and statistical tools applied. Largely missing explanation of potential sources of data uncertainty and error. Data uncertainty and error anaylsis were applied and performed with mistakes. Numerous calculations are erroneous and/or irrelevant. Explanations for where values came from and what they resulted in are unclear. Sig figs are inappropriate throughout.	Closer to "Marginal" than "Excellent"	Closer to "Excellent" than "Marginal"	Complete description of how data uncertainty and error analysis was performed including error propagation and statistical tools applied. Complete explanation of potential sources of data uncertainty and error. Data uncertainty and error anaylsis was applied and performed correctly. Relevant sample calculations are precise, well-explained and complete; it is clear where sample values came from (e.g., what experimental conditions) and what results were calculated from those sample values. Sig figs are appropriate throughout.	
						Total Technical Points for Analyst	0
						Total Score (Technical Pts x 2 + Written Communication Score)	0