Peer Review and Reflection in Engineering Labs: Writing to Learn and Learning to Write

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Abstract

Clear communication of complex technical concepts vexes both undergraduate engineering students and professors who often throw up their hands exclaiming, "Why can't students write?" Instead of decrying students' skills or blaming the English department, the engineering department in this study decided to reframe writing as a process of collaboration, rather than a final product.

Working with an English faculty member embedded in our department, we designed a peer review and reflection activity for junior and senior level chemical engineering laboratory courses. We hypothesized that incorporating this would improve student writing by providing more writing time and facilitating knowledge transfer from lower-level composition courses.

We collected data in a senior chemical engineering laboratory course (N=52). Students completed a survey about their past writing courses. After conducting their experiment, students wrote short technical report drafts and then participated in a peer review session. They were given instruction about genre and stylistic conventions for lab reports. They filled out a peer review rubric to guide them in giving feedback and wrote a short reflection about the process, including what they learned. Students revised their reports based on feedback from their peer reviewer and the instructor and turned in a reflective memo to explain changes they made in the revision process. Students also provided feedback on the process. We repeated this process with long reports a few weeks later. We conducted qualitative analysis on the student work.

Students critiqued their peer's work, finding everything from mechanical and grammatical errors, troubled tables, figures, and calculations, to issues with coherence and logical flow of ideas. While students did not have sufficient background to give technical feedback on the first short report, they were able to on the long reports. Students responded positively overall to the process and reflected on their own writing. The revision process resulted in significant gains in conceptual understanding, $t(51)= 12.01$, $p < 0.0001$, with a large effect size, ($d = -1.68$). Scores increased for 49 out of 52 students at an average improvement of 33.97% (SD = 20.41%). The revision process vastly improved their understanding of the technical content and interpretation of their results, as well as the overall quality of writing of technical reports.

Embedding the process of writing in a lab setting provides a structured opportunity for students to review their own work and another's critically. As we have shown in this study, engineering students can be guided toward improved technical writing.

Introduction

Broadly, communication is a critical skill that is valued in professional and academic settings [1]. However, for many students, writing is a chore, disconnected from their disciplinary focus, especially if that focus is in a science, technology, engineering or mathematics (STEM) field. Although many STEM majors take a technical writing course, such courses are still typically taught outside of the STEM major, sending the message to students that writing is not central to

STEM disciplines. To combat this issue, many have argued for *writing across the curriculum* and taking a discipline-specific view of writing.

A challenge, even for these approaches, is engaging students in authentic writing that is foundational to solving contextual and socially just design problems [2]. Whereas the focus of much core engineering coursework is focused on building technical, disciplinary knowledge, many have argued for approaches that also prepare students to approach engineering problems more holistically, considering the ethics and consequences of their work [3]. For instance, in students struggle to consider the ways their designs might cause harm, even when well intentioned. And because most programs provide few opportunities for students to frame—and reframe—engineering problems from different points of view, students tend to frame engineering problems from only one, often dominant point of view. We argue the writing process can hold a key role in developing framing practice, as it can be threaded into core coursework to support technical understanding that is contextual and open to critique.

In this paper, we detail our approach to and student outcomes from a comprehensive and collaborative writing intervention. Our approach supports students to develop as critical thinkers and writers in tandem with technical understanding. Our approach builds on past research on writing in engineering, writing as process, specific writing strategies, and professional identity formation.

Writing in engineering

Many faculty note that students are not as competent in technical writing as we would wish, apparently not retaining what they learn in technical writing courses [4]. While some place blame on English departments for not adequately preparing students, others take seriously the idea of writing across the curriculum (WAC) and writing in the discipline (WID) approaches [5]. Researchers have long argued for such approaches [6]. Although notoriously complicated, a number of universities have sought to better integrate technical writing courses and engineering courses [4, 7-13]. In some instances, this has involved professional development for engineering faculty on teaching writing [14, 15], providing classroom-tested technical writing tasks [16], and more commonly, close collaboration between engineering faculty and a technical writing instructor from the English department or a writing center [13]. For instance, faculty from English and civil engineering co-designed and co-taught a course, with the writing instructor providing feedback on drafts [9]. Students appreciated getting feedback from the writing instructor, who they viewed as having relevant expertise. However, others have argued that engineering faculty should also attend to and give feedback on writing, in part to reinforce to students that writing is an engineering practice [17].

Managing grading and feedback is a significant challenge for engineering faculty who teach courses that include writing [18]. One approach to alleviate this is to train graduate TAs [19]. Another is to consider shorter writing tasks. In a study that contrasted student learning related to writing 1-page synopses versus a long technical report, Hoffa and Freeman concluded that students who wrote synopses scored as well on exams as did those who wrote long reports [20]. Not surprisingly, students reported they preferred writing the synopsis to the long report, but felt they retained the concepts better, learned them more deeply, and felt they performed better on the exam as a result of writing the long report (a perception not validated by actual test scores).

In a similar comparison, student writing quality also showed greater improvement from shorter, more focused writing tasks [21].

Learning to write in a discipline

When writing is primarily taught outside the field of study, students receive the message that it is not meaningful in the discipline, and programs that offer generic academic supports such as writing tutoring outside the major fields of study not only reify this message, they also send a message to faculty that they can offload teaching of writing to external entities [10]. Engineering faculty are often reluctant to teach writing, in part because their efforts sometimes seem in vain [10, 22, 23].

Students need to learn the conventions of engineering genres—technical reporting and communication [1, 24]. One aspect of writing in specific genres is considering audience [25]; often, students think only of the teacher or instructor as the audience because they have not been asked to write for an authentic audience in schools settings. This is especially true for technical report writing in engineering laboratory assignments, where students tend to not perceive situations in which an audience might exist [26]. Instead, they tend to write as a means to justify that they followed their laboratory and technical processes accurately, with an audience (i.e., an instructor) in mind who has sufficient expertise to judge this.

Although a common place to focus on writing in engineering has been short and long reports in laboratory courses [20, 23, 26-30], others argue for a broader consideration of the various forms of professional writing common to industry [1]. Yalvac et. al. [31], inspired by WAC/WID approaches and research on learning [32] refined a pedagogical strategy that specifically targeted higher level writing skills (synthesis and argumentation) for undergraduate biomedical engineering students enrolled in a core systems physiology course. In the original version, students role-played as researchers working on unsolved problems. To make the scenario more learner and community-centered, they instead placed the students in a role they could more easily imagine: graduate students assisting a research professor preparing for a conference. The assignment was scaffolded, beginning with mini lectures that explicated the difference between *synthesizing* literature and *analyzing* it, followed by small group debate presentations where students discussed their main argument, evidence, and counter-arguments. Based on comparison to the prior iteration, students in this course showed improvement in argumentation, synthesis, and analysis, with the least amount of improvement in the mechanics of writing.

Writing to learn disciplinary content and practices

Research has shown the effectiveness of writing-to-learn approaches in engineering [25, 29, 33, 34]. Students learn technical content and develop their understanding of engineering practices through the writing process [24, 35-37].

Specific writing strategies

We consider several research-based strategies for supporting student writing, first explaining the strategy, and then detailing its research base.

Pre-writing. Pre-writing tasks provide opportunities for students to consider what they know and don't know about a topic, to organize their writing, and to plan their approach to writing [36, 38, 39]. It includes all activities that culminate in a piece of writing: minute papers, reflections, assigned readings and responses, prelab assignments and discussions, and documenting the experiment itself.

Multimodal writing. This form of writing means incorporating multiple modes, such as images, audio, video, and text, and following discipline-specific or genre conventions [40]. Within engineering genres, this commonly means interpreting tables and figures that display data or results.

Feedback and revision. Feedback needs to be specific and useful [41]. However, feedback, even when it is specific, is not always *used*; faculty sometimes labor over giving extensive feedback, only to have it ignored. One reason our feedback has limited impact is because we are not asking students to actually use it [42, 43]; unless we require students to revise and improve their work [44], the feedback is may be taken as a value judgment of the student's writing ability, rather than as an opportunity to learn and grow as a writer [45-47].

Peer review. While peer review seems to be an appealing way to off-load grading time and effort onto students, faculty may worry that the feedback students receive from their peers will not be effective [43]; indeed, without training or structure, students may give superficial feedback ("Great job") or even poor feedback [43, 48]. While there are many variants of peer review, here we focus on the role peer review can have in supporting the peer reviewer's own learning [49]—meaning the value of peer review is for the person doing the reviewing [50-52]. Peer review has been shown to enhance retention of concepts for undergraduates in engineering coursework [53], to support improvement in understanding [23, 54] and in writing quality [55, 56]. While students tend to see value in the peer review process, they admit that they are unlikely to engage in it if not required to [57].

Reflection. Across disciplines, research has shown that reflection on what and how one has learned supports comprehension and retention [34, 42, 58, 59]. Even simple strategies, such as end-of-class "minute papers" that ask students to reflect on what they learned in class and what remains unclear can provide opportunities for students to organize their understanding [60]. This approach is effective regardless of instructor level of experience and across levels of student ability [61]. The reflective process can be effectively integrated into a peer review process [52, 54].

Identity as writing engineers

As seniors in a chemical engineering degree program, the students in our study have begun to form engineering identities. The structure of our program—as is typical of many—in which students take technical writing early in their degree programs in the English Department, signals to them that writing is a schoolish task and one that is not central to the work of engineers [62]. Because of the perceived inauthentic nature of writing technical reports, students tend not see such writing as involving their engineering identities [26]. In contrast, engineers reportedly spend approximately 1/3 or more of their time writing [63, 64], and graduates tend to be viewed

by industry as lacking writing skills [1]. We therefore also consider research on professional engineering identity formation as a means to enhance student learning and development.

Identity is often characterized as "double-sided," meaning students identify themselves in certain ways, and others—including institutions—identify students in certain ways [65, 66]. While students may hold and develop many identities (e.g., as college students, young adults, engineering students, athletes, etc.), this double-sided characterization draws attention to the role the institution might play in the professional formation of engineers. For instance, a department can identify students as engineering majors, and the students themselves identify as future engineers more strongly once admitted [67]. But when considering what it means to be a professional engineer and do the work of engineering, unless students have other sources of first-hand knowledge (e.g., through a parent who is an engineer, or through an internship), they must rely on their engineering coursework to show them the way. Students seldom connect their English composition courses to writing in engineering [22]. Studies investigating students' conceptions of engineers demonstrate that they do not typically associate writing with engineering [68].

Writing assignments in core engineering courses signal to students some of the ways writing might matter in the discipline, and contribute to the sense of what it means to be an engineer [26]. When writing is not graded by engineers, or not part of the grading rubric, it can reinforce the message that writing is not part of the work of engineers [10, 14]. To support students to view engineers as writers, a number of programs have been developed and tested. For instance, engineering faculty reframed writing as a design process [22, 44], and they have used fiction novels as sources for brief design projects [69]. Others have argued strongly for the need to better align writing tasks with industry practice [1], where engineers are viewed as writers [70].

Methods

Study design and research purpose

We sought to develop an innovative and collaborative cross-campus approach to supporting the development of technical writing, and desired to understand the impacts of our approach. We were guided by the tenets of design-based research, the hallmark research method of the learning sciences [71-73]. In this approach, researchers develop and test their theories about how to support learning by designing learning experiences and implementing them under normal classroom conditions. In this study, we report on the first iteration, which has informed department-wide changes that we are studying.

The collaboration between the English and engineering departments came out of a desire to improve writing to better prepare students for industry; although faculty gave copious feedback on student writing, they observed little improvement. By happenstance, we connected with faculty from English, who met with the engineering faculty to learn more about their approach to teaching writing. Early in this collaboration, a writing instructor familiar with technical communications was embedded in the engineering department. The writing instructor's goals are to understand student needs and strengths as writer-engineers and to assist in design and implementation of new learning experiences that capitalize on student strengths to advance the goal of improving writing.

As is common in the design-based research approach, we documented student experiences and student work. We specifically sought to investigate the following research questions:

- To what extent does a comprehensive writing process approach support chemical engineering undergraduates to improve in their writing and conceptual understanding?
- How might a comprehensive writing process approach support chemical engineering undergraduates to develop identities as *engineers-who-write*?

The use of "might" in the second research question is appropriate to this method, which assumes that the same designed learning experience can affect students in different ways depending on variables which are often outside of the instructor's control.

Participants & Setting

We collected data in one senior chemical engineering laboratory course at a large, Hispanic-serving, research university in the southwestern US. Students provided informed consent to participate in the research study, which had received ethical approval from our Intuitional Review Board (N=52; 95% of students enrolled in the course). We invited all students enrolled in the course to participate.

Course description

The course is a one-credit lab class that is the third in a series of four lab courses. The class is scheduled for one 3-hr block each week. Laboratory experiments covered topics in heat and mass transfer and unit operations. Students conduct experiments to study the operation of process equipment such as heat exchangers, distillation columns, and wetted wall columns, which they had learned about in the previous two semesters. The lab course was taught by a chemical engineering faculty member, a writing instructor, and was assisted by a lab supervisor and three undergraduate peer learning facilitators.

Students performed two experiments, each spanning 6 weeks. In this study, we focus on the first experiment. At the beginning of the semester (Week 1 in Figure 1), we introduced topics such as plagiarism, citations, and error analysis and discussed the changes we were implementing in the class. We stressed the importance of writing. This discussion informed students about the changes and sought student buy-in. Before Week 2, students learned about the experiment to be performed in week 3 by answering a list of ten pre-lab questions. These questions pertained to the theoretical background and experimental plan of the experiment. The course instructor graded and provided feedback before Week 2, during which the course instructor met with each experiment team to discuss the pre-lab questions as well as formulate a data analysis plan.

After conducting an experiment (Week 3) and completing data analysis (Week 4), the students prepared short (up to 4 pages) technical reports (Appendix A) to concisely summarize the objectives, procedures and analysis, results, conclusions and recommendations of the experiment. After a draft report was submitted, the students participated in a three-hour peer-review session during which the course instructors gave short (30 min) tutorials on the peer review process and elements of good technical reports (Week 5). Students formed pairs and reviewed each other's reports. A formative, rather than summative, rubric focused on evaluating

the writing (Appendix B) was given to the student reviewers to fill out, including criteria such as genre convention (structure and organization), coherence, multimodal components (figures and tables), and credibility (references). Students then exchanged their reviews and discussed with each other their questions and comments. Many students engaged in extensive discussions about the technical content of the reports as well. At the end of the peer review session, students were asked to write a short reflection on lessons they learned as a writer: "Before you leave, write a brief reflection below on lessons you've learned as a writer from this peer review session."

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
In class	Intro, plagiarism, citations, error analysis	Discussion of pre-lab	Group experiment		Instruction on peer review process, Peer review		(Beginning of next experiment)
Student work	Reflection on plagiarism Scaffolded individual pre-lab written responses	Refined pre-lab Job safety assessment report		Post-lab analysis, calculations, & graphs	Draft report Reflection on peer review process		Revised report due Reflection memo on revision process
Feedback	on technical content by instructor	on technical content by graduate learning facilitators		on technical content by graduate learning facilitators	on technical content by instructor; peer on writing (and technical content)	Optional - on technical content & writing by instructor; on writing by writing instructor	Grades assigned by instructor

Figure 1. Overview of the comprehensive writing process we developed and tested

In addition to the feedback from their peers, the students received feedback focused on the technical content from the instructor. The students then engaged in a revision process that spanned two weeks before a final revised version of the report was submitted (Week 7). During the revision process, the students were encouraged to meet one-on-one with the course instructor and the writing instructor and to seek additional writing resources such as tutoring. Along with the revised technical report, the students submitted a reflective memo in which they detailed how they addressed comments and feedback from their peers and instructor.

This process was repeated twice, but in this paper, we focus only on the first iteration.

Data sources & analysis

We collected student work on the draft and revised versions of their short technical reports. At the end of the peer review session, students wrote a brief reflection on lessons they had learned as a writer from the peer review session. Additionally, students also wrote a reflective memo (up to 2 pages) addressed to the instructors that discussed how they had addressed comments from

their peer evaluators and the instructors. The reflective memo was submitted with the revised short report.

We conducted qualitative analysis of student work, first using open and in vivo coding to ground our findings in the data [74]. We coded student data on the two brief reflective writing assignments and focused our analysis on the results and discussion sections of the draft and final version of the report. For the reflective memos, we developed a coding scheme grounded in the data, but influenced by our theoretical framework (Table 1). Three of the codes reflect specific learning outcomes from the university's technical and professional writing courses: writing is a process, using resources, and audience awareness. "Writing to learn" is a WID concept of particular interest to this initiative, as is "writing and identity." These categories were then weighted (-1 to 1) to characterize student reflections. This range provided sufficient scope to characterize the data from our study, but future analysis of longer data sources or more frequent sampling could lead to a need to add additional categories to capture nuanced change.

Table 1. Coding scheme for reflective memos

Code	**Description**	**-1**	**0**	**1**
Writing is process	Student explains writing as a process	Writing is a final product	Ambiguous	Writing is a process
Writing to learn	Student views the writing and revision process as a way to learn content	Writing and revision are mostly about grammar	Ambiguous	Writing is a way to learn
Use resources	Student explains specific resources and strategies for improving writing	None mentioned	Describes one	Describes more than one
Writing identity	Student displays identity a STEM person or as an engineer who is also a writer	Is a STEM person, but STEM people are not writers	Ambiguous	Is a STEM person and STEM people are writers
Audience awareness	Expresses awareness of audience expectations or needs	None expressed	Teacher	Reader or audience discussed

For the report, we developed an *a priori* coding scheme based on the grading rubric (Table 2). Because we wanted to evaluate the impact of the writing intervention on students' conceptual learning, we focused on the *Results and Discussion* section of each version.

Table 2. Scoring rubric for the *Results and Discussion* section of the short reports

Technical Content Description	% Points
Results	50
1. Assessing the accuracy of calculations	
1a. Experimentally derived parameters. For example: heat transfer coefficients,	

mass transfer coefficients, distillate stream compositions	
1b. Predicted/modeled parameters. For example: convective heat transfer and mass transfer coefficients predicted from correlations, distillate stream compositions modeled by Aspen simulations	
2. Assessing the appropriateness of the tables and plots generated	
Discussion	50
1. Assessing the interpretation of results	
2. Assessing the explanations provided regarding discrepancies between experimental and modeled/predicted results	
3. Assessing the conclusions drawn regarding the performance of the experimental apparatus. For example, the degree of fouling in the heat exchanger and estimation of distillation column tray efficiency	

To analyze the effect of peer review and revision on the quality of the technical content of the reports, scores on draft and revised *Results and Discussion* section were compared using a paired samples t-test.

Results and Discussion

Writing to learn engineering content

Our first research question investigated the impact on students' technical and conceptual understanding of the experiments conducted. The revision process resulted in significant increases of student scores. A paired-samples t-test was conducted to compare scores on the *Results and Discussion* sections of the draft and revised versions. The revised scores (M = 75.96%, SD = 23.63%) were significantly higher than the draft scores (M = 41.99%, SD = 20.67%), $t(51)= 12.01$, $p < 0.0001$, with a large effect size, (d = -1.68). Scores increased for 49 out of 52 students at an average improvement of 33.97% (SD = 20.41%). While most students reported accurate calculations on their initial report, their understanding and interpretation of the results were poor. The revision process vastly improved their understanding of the technical content and interpretation of their results.

The quality of students' technical writing also vastly improved in the revision process. For instance, the *Results and Discussion* sections were better organized and more coherent, the logical flow of the content was clearer, and proper conclusions were made regarding findings from experimental results. Additionally, other writing aspects of technical reports also greatly improved, including format, convention, coherence, effective use of figures, tables and appendices, and in-text citation and bibliography. Through the revision process, some students also met individually with the course instructor and the writing instructor and submitted additional drafts for feedback. Improvements in the quality of writing from these students were especially impressive, where a draft that was once filled with awkward and vague phrasing became polished and precise.

We also reviewed the student scores to better understand who saw benefit from the peer review process. We binned students by score on the first draft to examine their average improvement (Figure 2). Results show that improvements were indeed experienced by students, regardless of

draft score. Strikingly, the students who received the lowest scores on their draft reports experienced the largest gains.

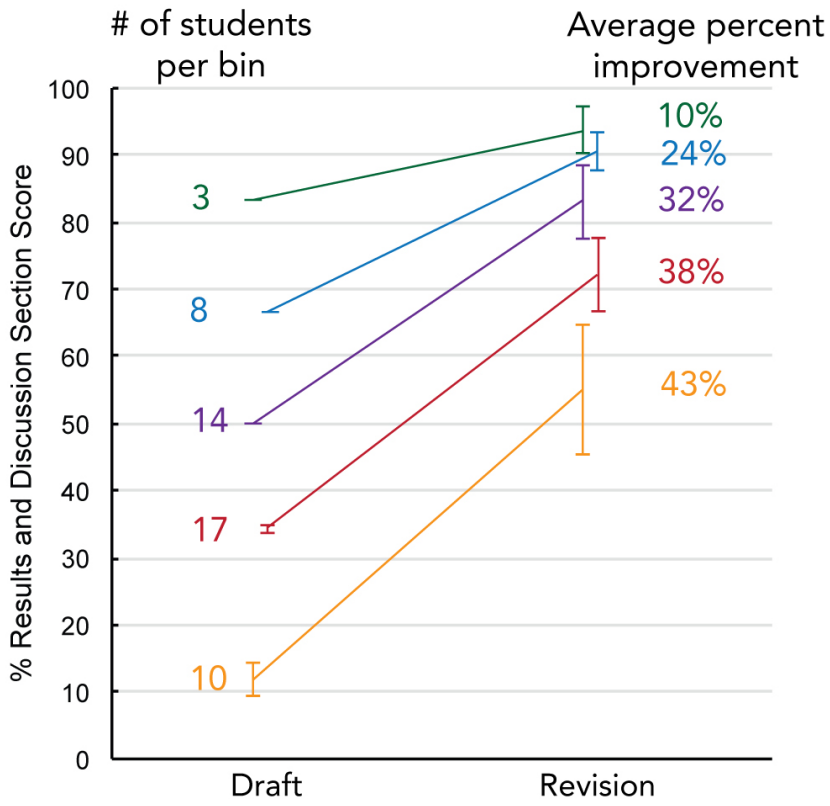

Figure 2. Student scores before and after revision on the *Results and Discussion* section of the short technical report. Scores were binned into 5 groups. Average percent improvements are reported. Lines are staggered to improve readability.

We additionally compared the gain scores made by students who scored below 50% on the draft to those who scored 50% or above using an unpaired samples t-test. Those in the bottom at the draft stage (M = 39.82% gain, SD = 23.76%, n = 27) gained significantly more compared to those in the top (M = 27.66% gain, SD = 13.92%, n = 25). This analysis confirms the finding in Figure 2 that students who began with lower scores made larger gains in conceptual understanding.

Finally, we highlight that students' comments underscore that they had opportunities to learn about their own writing process by serving as a peer reviewer, and that it was the process of serving as a peer reviewer—more than getting feedback from their peers—that was so valuable:

> "By reading [my partner's] report, I was reminded of a lot of points I neglected in my own."
>
> "By editing his language, I was able to practice using concise and definitive language of my own."

Students' views of writing and their identities as engineers-who-write

Our second research question focused on characterizing students' stance as writers, especially in relation to their nascent identities as engineers. In their reflections, 70% of students mentioned one resource, and 15% mentioned several resources to help them improve their writing (Figure 3). This suggests that students are well aware of various available resources. For instance, they mentioned meeting with the course instructor and writing instructor for feedback and guidance, asking peers for feedback—many students expressed wishing peer review was part of lab courses—and studying examples of successful reports to guide their revisions.

In terms of audience, 42% viewed the teacher as the primary audience, making statements such as, "The examples of a well-written report were a good guide on what is expected once the final report is due," while 28% lacked any sense of audience, meaning only 30% discussed the needs or expectations of a specific or authentic audience, stating, for example, "I got a really good impression of how the audience will read my report and which points I can elaborate for clarity." This finding aligns to previous research showing that students expect to write primarily for the teacher, which in turn erodes the authenticity of writing activities [26]. In a survey of faculty perceptions about writing, faculty tended to view students as able to write for appropriate audiences [18].

In considering the writing and revision process, 30% of students described focusing on accuracy of aspects such as mechanics and grammar: "fix errors," "fix formatting," or "use citation manager," while only 21% on writing and revision as a means to learn: "To better my writing I will finalize my figures first then construct my conclusions around them," or, "I need to go back and think through the experiment and my results more carefully." This finding, that few viewed writing as a means to learn, stands in sharp contrast to the results of our first research question, which found that all 95% of students showed improvement in their technical content knowledge. This is similar to findings elsewhere showing that even when students acknowledge that writing is important in engineering, they still do not see it as enhancing their technical knowledge [12].

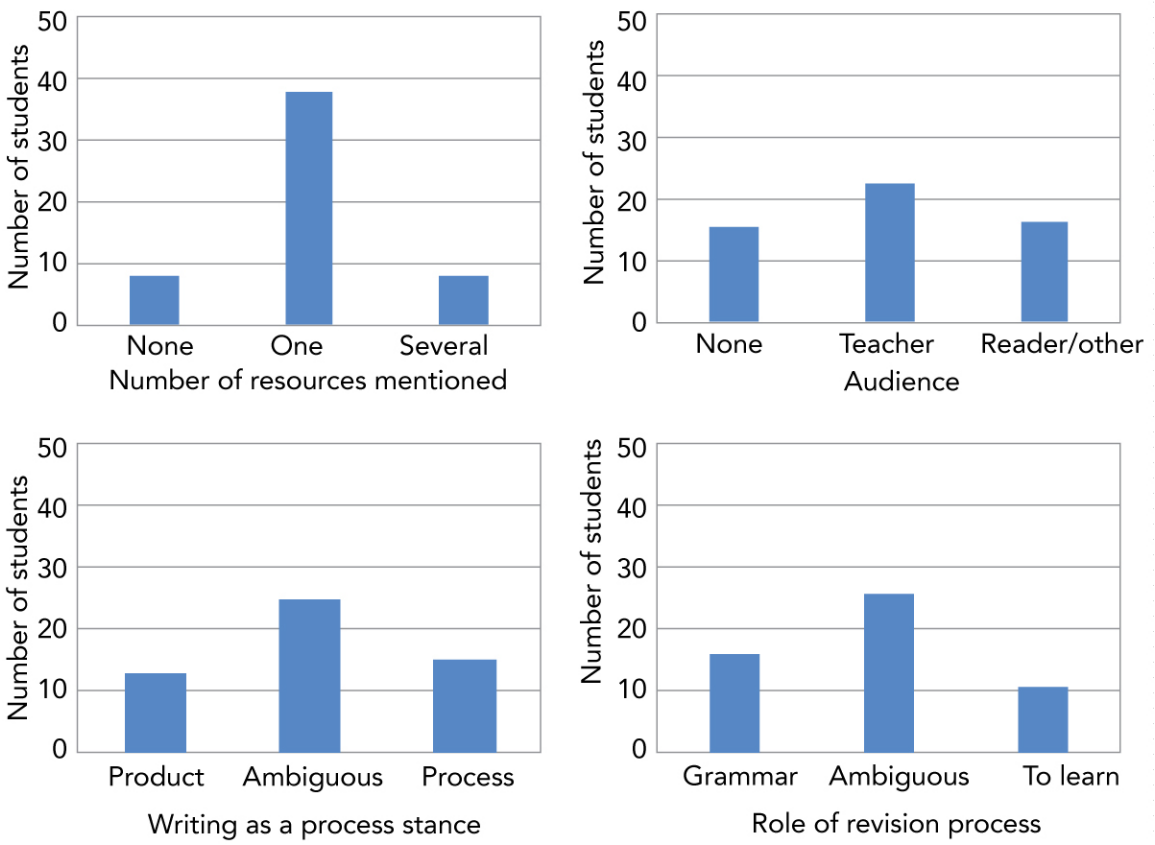

Figure 3. Students reflective memos, coded to identify their awareness of resources, their attention to audience, the stance on writing as process, and the role of the writing-revision process.

In terms of student descriptions of product versus process views of writing, 25% focused on product and 28% on process (Figure 3). This relates to how students identified as engineers who are also writers: 38% displayed evidence of the engineers-as-writers stance, stating, “it is important to present a narrative even in technical writing…the flow of concepts, ideas, and data presented needs to be coherent, organized and readable,” compared to 19% who displayed the engineers are not writers stance, stating, “I learned…how to make better graphs and tables and how to use proper color…within tables and figures” (Figure 4). We calculated frequencies of these two categories within each reflective writing sample; we found (1) no co-occurrences engineer-as-writer and writing-as-product and (2) no co-occurrences of engineers-are-not-writers and writing-as-process (Figure 5). This finding empirically affirms the idea that learning and identity are coupled processes, as proposed elsewhere [75].

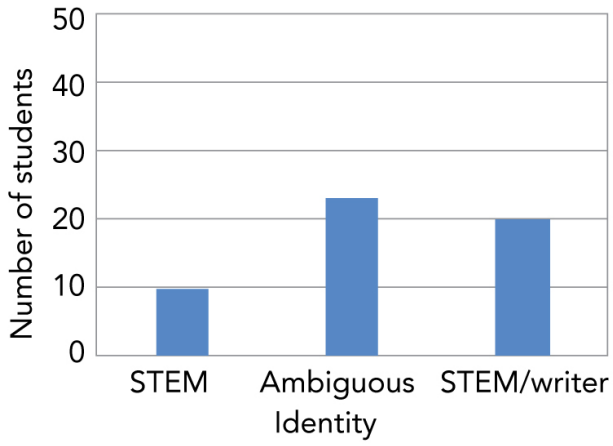

Figure 4. Students reflective memos, coded based on the degree to which they displayed evidence of STEM people/engineers-as-writers stance

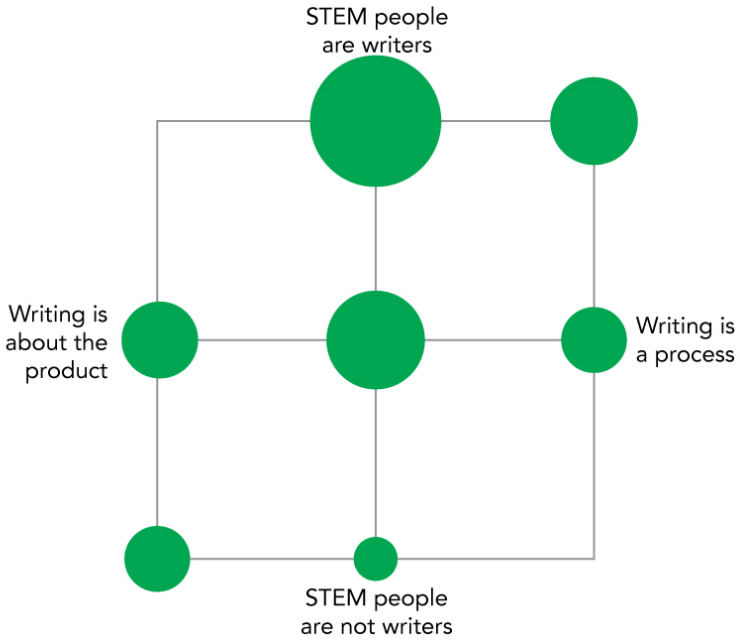

Figure 5. Co-occurrences of codes related to engineer-as-writer and writing-as-process.

Conclusions

We found improvements in student writing that exceeded prior course outcomes. Students' writing and conceptual understanding of the content improved as a result of the process. We also found that over a third of students displayed the engineer-as-writer identity.

Significance. In many papers addressing ways to improve writing in engineering, the authors discuss ways to minimize the time spent on writing, fearing this will result in a sacrifice of time and scope on content. Our results affirm that the writing process, especially when invested in fully and comprehensively, supports students to jointly develop and deepen their technical

understanding and writing abilities, all which enhance their understanding of engineering as a writing profession.

Limitations. Although promising, this work was conducted in a single course with a non-random population, at a university with a somewhat unique profile. Our status as a research university serving a diverse population, many of whom work and are primary care-takers, and/or first generation college attendees, makes our results relevant to other universities who serve similar populations. While many research universities can enhance student learning through co-curricular interventions, we have found that because of the various responsibilities our students bear, we have found the greatest impact to be interventions that happen in the classroom.

Future work. As this study is part of on-going design-based research, we look forward to refining our approach and spreading this practice across the core chemical engineering curriculum. For instance, peer reviews next year will place more emphasis on the benefits writers gain from reading other students' work, and reflection prompts will be more precisely worded to elicit more detailed responses. Alignment to industry practice, as recommended in the literature [1, 14], will be taken into consideration. As we are also in the midst of a major curricular change process, we expect to expand significantly into other core courses that are employing design challenges that include a social justice lens [2] and helping our students consider their framing of engineering problems more holistically [3]. For instance, we have added an assignment on writing professional emails to the first-year course, and students in all core courses write various design documents. We will additionally work on enhancing student buy-in about the importance and value of writing. To this end, alumni will be invited to talk to the students either in person or via Skype. As we refine, we aim to share our results and approach with other departments.

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Appendix A: Short Technical Report Instructions

Short Laboratory Report Guidelines

The Short Reports should be similar to what is often called an "Executive Summary". A well-written executive summary should be short enough that busy executives (your boss) will read it all, yet substantive enough that it contains everything that the boss or executive needs to appreciate the reasons for the work, the key results, and the conclusions or recommendations. For this class, the Short Report will be a stand-alone report, with a typical length of 3-4 pages, not counting references or appendices. Short reports are difficult to write well, because one must be very selective about what goes in the report, and must have a very clear understanding of the most important things that need to be communicated. The following specific guidelines are provided for this class.

- The length should be 3-4 pages, including figures and tables, but excluding reference list or appendices. Font size should be no smaller than 11 pt., and margins should be no less than 0.75 in. Figures and tables also need to adhere to margin limits.

- It should summarize in a concise manner the following elements (the report structure specified below reflects these elements):
    - What were the objectives of the experiment?
    - What procedures and analysis were followed?
    - What were the important results and what do they mean?
    - What are your conclusions and/or recommendations and how are they supported by what you did (this should relate to the stated objectives)?

- Writing should be concise, but precise and substantive. Fluff and filler that is not important should be avoided. Theory or computational details should not be discussed at length in the report body, but should be clear to follow in appendices that are part of the report or submitted separately, as described further below.

- Well-chosen (and well-prepared) graphs, tables or figures are appropriate, and can be extremely valuable in achieving effective communication of key points in a clear and concise manner. The number must be limited to keep length down, and discussion must be more focused than in a long report. They should have a thorough descriptive caption (1-3 sentences) and labels that allow the graphic or table to be understood on its own (remember units!).

- For this class, the organization should be similar to a report. The following sections should be included:
    - Cover Sheet (does not count in page count): title of experiment, date of experiment, your name, the names of your lab partners. Title should be informative and reflects the content of the report.
    - Introduction: one or two paragraphs that concisely state the objectives of the experiment.

- Procedures and Analysis: Brief (~ 0.5 page) summary of experimental procedure, nature of data obtained, and analysis used to provide results.
- Results and Discussion: This is the meat of the report: 1.5-2 pages summarizing important results, explanation and interpretation of those results. Here it is appropriate to consider/discuss what the results mean, how they compare to theory, and how they relate to the objectives of the lab. Tabulated results and/or graphs are appropriate in this section, but you must be selective – they should be important and directly support your discussion. It is also very important comment on sources and magnitudes of error derived from the experiment and analysis, especially when this impacts the analysis or conclusions. Plotted or tabulated quantities derived from experimental data should generally have error bars (with the basis of those error bars noted), and/or comments in caption or the table/figure.
- Conclusions and Recommendations: ~0.5 page summarizing major conclusions or recommendations – this may relate to what you learned from the lab, or even to the equipment, procedure or analysis.
- References (does not count in page limit): Use ACS formats exist for references. For this class, use numbers in square brackets in the report, in the order of citation, and a References Cited list in numerical order in the References section. All references must be complete, and should be cited in the report.
- Appendices: Every Short Report for this class should be accompanied by a well-documented (and commented) spreadsheet that contains complete data and calculations covered in the report. See "What to Turn In" below. You may also want to have Appendices included as part of the report, which is fine. If included as part of the report, they should be numbered and properly titled and/or labelled. Figures and tables in Appendices normally need captions, just as in the report body.

WHAT TO TURN IN

- On short report due date: submit report and a separate Excel file through Learn by 1:00 pm of the due date. Bring two double spaced had copies of the report to lab on the day short report is due for peer review session.

- On revised short report due data: submit revised report and a separate Excel file through Learn by 5:00 pm of the due date.
-

GRADING SHEME FOR REVISED SHORT REPORT

CBE 418L: Revised Short Report Grading	
Length, format, aesthetics	/15
Cover Page	/15
Introduction and Objectives	/20
Procedures and Analysis	/20

Results and Discussion	/80
Conclusions and Recommendations	/20
References	/10
Appendices and Calculations	/20
TOTAL	/200

Appendix B: Short Technical Report Peer Review Rubric

Peer review rubric

Short Laboratory Report Peer Review

- Submit short report on Learn by 1:00 pm on due date and bring two, double spaced hard copies to class for peer evaluation.
- After peer evaluation, scan and upload your peer review rubric and feedback to Learn.
- 20 points will be given for your peer review participation and submission of rubric and feedback.

The idea of peer review is to assist your partner to write a more understandable, effective report. In the process, you will probably see where your own report can be improved by seeing what is both effective writing and presentation of ideas, but also what is not working well (yet) in your peer's work.

It's important to use language that encourages, rather than discourages, your partner. No one likes to share their writing only to be told it's lousy. Think in terms of "effectiveness," or "opportunities for revision or editing."

The rubric below contains the criteria for proving your evaluation. You can both critique and praise your partner's efforts by noting what still needs work and what is meeting or exceeding the criteria. Be precise about your concerns: tell the writer exactly what paragraphs or sentences are unclear. Make suggestions for how they can reword sentences for clarity or concision, for example.

Concerns *Areas that Need Revision Work: Re-writing*	**Criteria** *Standards for Assignment Writing*	**Well Done!** *Evidence of Meeting or Exceeding Standards*
	Length, format, aesthetics: The report should be 3-4 pgs., including figures and tables. Font is 11-12 pt. and legible, margins are no less than .75". Figures and tables are placed appropriately within the text and margins of the page.	

	Genre Conventions (Structure and Organization): Ensure your peer's report conforms to the reader's expectations for a lab report by including all sections: Cover Page, Introduction and Objections, Procedures and Analysis, Results and Discussion, Conclusions and Recommendations, and References.	
	Coherence: When you read each section, you understand it. Sentences are clear and concise, and reasonably follow from one idea to the next. Transitions from one idea to the next are smooth.	
	Multimodal Components (Figures and Tables): Ensure Figures and Tables are concise and descriptive of what they illustrate. Figures and Tables are placed within or beside the relevant discussion of the point they make. In other words, Figures and Tables relate to the text they are near, are properly formatted, and understandable.	

	Credibility **(References):** In-text and bibliographic references are included and formatted consistently. Care has been taken with in-text citations and appropriately crediting other scholars. **(Miscellaneous):** Proper use of capitalization and properly formatted equations. Uncertainties reported for all calculated values.	

Include additional comments for your partner below:

Finally, underline words, phrases, or sentences that need editing for grammar, spelling, or punctuation. This is the last thing you'll do during peer review, and the last thing you'll do when you revise your own report, but you need to thoroughly proofread and edit before you submit your final draft of the lab report for grading.

Before you leave, write a brief reflection below on lessons you've learned as a writer from this peer review session.