A Partnership Model for Integrating Technical Communication Habits throughout Undergraduate Engineering Courses

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Abstract

The ability to communicate well is an important skill for engineers in the workplace. This descriptive study describes a collaboration between a writing specialist and an engineering instructor to integrate writing instruction into engineering coursework. The sample included all 12 students in a junior level Chemical Engineering (CHME) laboratory course. These same students were followed through the next course in the sequence, taught by the same chemical engineering instructor. Intensive guidance was provided to students in the junior level lab, including co-taught lectures, feedback on drafts, and required revision tasks. Scaffolds and team-taught activities were gradually faded for the remaining lab reports, but the engineering instructor continued to provide ongoing and individualized feedback on all lab reports. In both courses, students drew upon a set of collaboratively–developed online resources. Data collection included statistics of students' use of online writing resources, student self-reports, lab report grades, in-class writing exercises, and teaching artifacts. Results from the self-reports indicate that students perceived the lab report writing process to be more difficult than understanding the technical engineering content of labs in the junior level course. In the senior level course, however, students' perceptions of the writing challenges varied depending on how difficult they found the technical content of the lab. Mean and median lab report scores in both junior and senior level courses were similar, suggesting that students' writing achievement was sustained over time, despite the more challenging technical content in the senior level course. These findings suggest that students in the CHME partnership study applied what they learned from the instruction and resources that collaboration among faculty of different disciplines afforded them. This descriptive study of a partnership model is offered as one example of bringing new and critical perspectives to engineering education.

Introduction

This paper describes a college-wide partnership model for integrating technical communication skills into engineering curricula. For professional engineers, the ability to communicate effectively with a range of audiences has been emphasized as a critical skill for engineering professionals [1]. Given this emphasis, different approaches to building students' professional communication skills have been implemented but with mixed results. For example, when engineering students take technical communication courses, they tend to remember information about format, but fail to apply knowledge about audience and purpose when they write engineering reports [2]. Some research has pointed out short comings in technical communication textbooks, which neglect important engineering communication skills such as data visualization and emphasize stylistic features used in the humanities [3]. Other research has found some evidence supporting the effectiveness of technical communication instruction integrated into engineering coursework [4]. Yet, fitting technical communication instruction in engineering curricula is challenging, especially given the demands of engineering coursework

[5]. Moreover, research-based instructional strategies for teaching writing are less common in engineering courses [6].

In a survey of technical communication initiatives in engineering schools in North America, Reave [7] described a promising partnership approach characterized as an authentic form of integration, one in which engineering and writing faculty collaborate in designing, delivering instruction, and assessing student outcomes. In the partnership model, students engage in the kind of writing typically required of engineers in the workplace, including laboratory reports. Students are guided by both an engineering and a writing specialist. As one example of how a partnership model can benefit students, this paper focuses on a class of 12 undergraduate chemical engineering students and traces these students' learning experiences in their junior and senior lab courses.

Literature Review

Three areas of research provide the conceptual background for this study. First, research on writing instruction programs, and in particular, on writing in the disciplines (WID) highlights distinct differences between stand-alone technical communication courses, writing across the curriculum approaches, and technical communication instruction integrated into the engineering disciplines. Second, contemporary research on best practices in writing pedagogy is discussed, as applied to communication in a professional engineering community. Finally, to address potential challenges in a partnership model, this paper looks to the research base on collaboration and consultation models in precollegiate education where educators with two distinct areas of expertise collaborate to provide effective learning experiences for students with a variety of learning needs.

Writing in the Disciplines

Writing Across the Curriculum (WAC) programs have a long history in academia. WAC views writing as critical thinking and problem solving, important components of a liberal education [8]. In 1987, McLeod defined two approaches to WAC, one grounded in cognitive science and the other in the discourse communities of academic classrooms [9]. In the cognitive approach, writing is viewed as a way of thinking and learning; in the other, writing is viewed as way of acculturating learners into the discourse community of the academic discipline. Both approaches acknowledge the important role that writing serves in learning [10]. The success of WAC, however, typically depends on WAC directors [11]. Monroe distinguishes WAC, an administrator-driven initiative from Writing in the Disciplines (WID), a faculty-driven initiative, where the primary responsibility for teaching writing rests with the disciplinary faculty.

Traditionally, WID has been characterized as writing to learn rather than learning to write. Drawing on social cognitive theory, [12] challenged this simplistic distinction, claiming that writing to learn involves more than writing to learn the academic content but also serves to acculturate learners into the discipline. These researchers studied 10 participants selected from students enrolled in a biology lab course at a large institution that emphasizes science and engineering. In the laboratory course, students wrote lab reports consisting of an abstract, introduction, methods, results, discussion, and conclusion. The researchers conducted semi-structured interviews and coded the data into six categories that provided evidence that: 1) Students were encouraged by the act of writing itself; 2) specific features of the lab report genre encouraged learning; 3) the need to write lab reports encouraged productive learning strategies such as reading the lab manual; 4) students used their lab reports as references in future situations such as studying for an exam or understanding a lecture; 5) students used their lab reports for reference in other contexts, such as writing a physics lab report; and 6) students considered learning from writing lab reports more effective than other ways of learning in science education. Researchers concluded that the structure of the lab report itself acculturates students into the scientific discourse community by providing a way of knowing in the discipline, as well as a sense of shared purpose and meaning within the scientific community.

Best Practices in Writing Instruction

Developing students' competence as writers within the discourse communities of their disciplines requires acknowledging the differences between school writing and professional writing practices [13]. In contrast to school writing that emphasizes knowledge telling and on-demand writing, best practices consistent with professional and disciplinary writing include opportunities to communicate meaningful content to real audiences, extended writing processes that allow time for planning, revision, and editing, and opportunities to act upon detailed feedback [13, 14, 15].

Modern psychological theory conceptualizes writing as a social activity [16]. In this view, writing is shaped by the community, the ways that individuals interact with one another, and the prior experiences writers bring to the community. Graham [16] explains how students must learn what to expect in a writing community, even at the doctoral level. To extrapolate from Graham's example, college students must negotiate expectations as they move from one disciplinary writing community to another and from instructor to instructor.

Instructional feedback is critical for the improvement of writing skills. In a review of instructional feedback, Graham [16] found that formative feedback from adults and peers improved students' writing performance. Forms of feedback included comments on students' papers and the use of a rubric with specific criteria. Graham cautioned, however, that the impact of feedback is dependent on individual differences. For example, struggling writers may need more support in identifying parts of the text that need revision as well as specific strategies to revise the text. [16]

In a meta-analysis of effective instructional practices for teaching writing to young adults, Graham and Perrin [17] found that the most effective practices focused on teaching students strategies for planning, revising, and editing their writing. Deane [13] described how these writing practices are enacted in a community of writers. For example, when classrooms are structured as writing communities, students have opportunities to communicate for authentic purposes and produce meaningful content, such as products of inquiry activities. The writing process is extended so that students have opportunities to write and revise drafts, along with the responsibility to respond to detailed feedback. Students engage in the discourse of the community by collaborating and reviewing each other's writing.

How are these writing practices integrated into upper-level engineering courses, where the focus is typically on advanced content? To support students' writing about advanced content, Yalvac et al. [18] developed an intervention that restructured the classroom writing community to create a professional setting in which students could imagine themselves as scientists. Following Herrington [19], Yalvic and colleagues argued that it was difficult for students to imagine themselves in professional roles because the content was challenging to master and that undergraduate students needed a more learner-centered environment. Therefore, Yalvac and colleagues designed an instructional approach in which students were randomly assigned to a group (i.e., a side in a debate). The debate was facilitated by a teaching assistant because of the assumption that students might be more likely to take risks and ask questions without the instructor present. In this in-class activity, students were asked to present their findings from a research project. Then they were prompted to defend their findings. For example, they were asked questions such as "What is the main point of your paper?" and "What examples did you use to support your conclusions?" After each side presented their findings, students asked each other and the teaching assistant specific questions, such as what to include or not include in their paper, questions about the data analysis, or how to handle opposing evidence. Students then revised their papers. The researchers scored the papers using a rubric that assessed organization, mechanics, style, clarity of content, synthesis, argumentation, and visual communication of results. They compared students' averaged writing scores with those of a previous class of students who wrote the same assignment, but without the intervention (i.e., the debate). Researchers concluded that embedding writing assignments into engineering courses is not sufficient for improving writing. Students must have opportunities for feedback and revision as well as opportunities to interact with the content and engage in discussion in a learning-centered environment.

Integrating Writing into the Disciplines through Partnerships

Engineering education has long recognized the importance of technical communication, but there has been considerable variation in approaches to teaching communication skills. Writing across the curriculum approaches have been increasingly favored over "stand-alone" technical communication courses [20]. Ford and Riley [21] provided examples of a number of different writing programs integrated into engineering curricula. In some programs, support is provided by writing tutors, technical communication faculty, and others external to schools of engineering. In some programs, engineering faculty take primary responsibility for teaching technical communication within the context of their engineering courses, supported by online resources and writing centers. Other engineering schools embed technical communication faculty within engineering schools to support integration [21].

According to Reave, partnerships are the only authentic forms of integration. The partnership model depends on the expertise and collaboration between faculty in two different disciplines. In a partnership, faculty from different disciplines collaborate in instructional design, delivery, and assessment. For example, faculty together decide on an area of the course where writing instruction might prove helpful and they collaborate in developing assignments and objectives. According to Reave [7], the partnership model is rare in engineering education. Other forms of integration in engineering education include team teaching, communication modules, and feedback offered by English faculty.

Although the partnership model Reave [7] described is rare in engineering education, pre-collegiate education provides numerous examples of how faculty from different disciplines and areas of expertise work together to teach students with a variety of learning needs. One such example is the collaboration of special education teachers with subject area teachers. Deemed a “high-leverage practice” by the Council for Exceptional Children, the collaboration model draws on collective expertise and allows for educators to share responsibility for student learning [22]. For example, collaborative activities include instructional design, team-teaching, and sharing of assessment data, as well as small group or individualized instruction provided by the special education teacher, outside of class time. This is consistent with what Reave [7] characterized as the partnership model.

Initially, the collaboration model posed challenges for educators and schools including scheduling, definition of roles, and issues related to different pedagogical models. More recently, however, research has provided compelling evidence of the effectiveness of these models in improving student learning [22]. Other benefits have also been cited, including the introduction of new teaching strategies [23].

Writing in the Discipline models, including those in engineering education, might benefit from the lessons learned from the special education collaboration models. For example, Carter [12] explains that disciplinary faculty typically acquire writing skills through acculturation in the discipline, over an extended period of time, rather than by direct instruction. Expertise thus acquired through apprenticeship is often tacit, making it difficult for disciplinary experts to articulate their knowledge to others [24]. Thus, Elton argues that partnership is necessary.

As in the special education collaboration model, partnership models in engineering education can benefit students, especially those who need direct instruction. Educators with expertise in writing and writing pedagogy can offer strategies for the direct instruction of writing skills, but they cannot do this without the disciplinary expertise of engineering faculty. Research in writing has long established the connection between content knowledge and writing about content [25], as well as reciprocal relationships between writing about content and thinking about content [26].

The Context for the Partnership Study

The context for the study reported here is a college-wide technical communication initiative that integrates the development of written, oral, and visual communication skills into the undergraduate curriculum across seven engineering and computer science programs [27]. One feature of this program is the integration of required communication products in designated courses throughout the four years of the students’ undergraduate programs. These products, specifically tailored to the kinds of communication products assigned to engineers in the workplace, include technical memos, oral presentations, posters, laboratory reports, and senior design proposals and reports. Additionally, the program leverages online technology to provide common resources for students and faculty across programs. In the early stages of program development, engineering faculty worked with an outside consultant to develop online resources focusing on technical memoranda, lab reports, and design proposals and reports.

In the next stage of program development, the University assigned a writing specialist (the second author) to the engineering college to support the integration of technical communication instruction across seven engineering and computer science programs. The writing specialist teaches first-year technical communications courses and collaborates with the engineering faculty in updating and enhancing the online resources that are integrated into the upper level disciplinary courses. The writing specialist also visits upper-level courses to explain the online resources, present guest/team-taught lectures, and provide group feedback on assignments.

The study reported here focuses on 12 chemical engineering students in their discipline-based chemical engineering lab courses, taken in the spring of their junior year and the fall of their senior year. Both courses, taught by the first author (engineering instructor) incorporated online resources. The writing specialist and engineering faculty collaborated in the enhancement of the available online resources for lab reports. These resources included learning modules on lab notebooks, formal lab report structure, tools for writing and editing written documents, and researching and citing existing work, as well as modules on the different sections of a lab report, including the visual display of results.

Methodology

This research provides an in-depth description of instructional strategies, learning resources, and assignments in chemical engineering students' junior and senior lab courses. This descriptive study of educational practices received approval from the Institutional Review Board and all 12 students in the course agreed to participate. Data collection included teaching artifacts, in-class "writing to learn" (WTL) activities, 6 lab reports completed in the junior lab and 5 completed in the senior lab course. A self-report questionnaire was administered at the end of both courses. The questionnaire assessed students' perception of different instructional strategies, including team teaching, online resources, and difficulty of lab content and writing assignments. Students also reported how much they felt their writing improved during the course. Additionally, students' writing skills were assessed and tracked over time, through instructor's grades on the lab assignments in both courses.

Instructional Interventions

In the junior course, the engineering instructor assigned the first lab on temperature sensors. The first full lab report was assigned in an extended writing process in which students had opportunities for feedback on drafts of assigned lab sections (e.g., presenting the data, discussing the results, and writing the abstract) before composing the full lab report. The engineering instructor provided individual feedback to each student through the course Learning Management System (LMS). After reviewing students' writing, the engineering instructor and writing specialist planned two team-taught presentations. The first presentation focused on the visual presentation of data. De-identified examples of students' plots were shared during the lectures, and students were guided to identify errors and discuss ways of improving the data displays. The second presentation focused on composing abstracts. In this class session, the online resources on abstracts were used as examples. Students brought a draft of their temperature sensor lab abstract, and they were guided to color code their abstract to find the abstract components, i.e., topic introduction, the purpose, methods, results, and conclusion. In this session, students also completed a WTL activity to assess the students' understanding of the underlying concept of the lab.

After receiving feedback and participating in the two team-taught class sessions, students revised and compiled all the report sections into their final lab report for grading. Thus, students were intensively guided for the first report and then scaffolds were faded. Students wrote the remaining lab reports without an extended writing/revision process, but the engineering instructor continued to provide guidance and feedback on each of the five remaining lab reports. In addition, the writing specialist reviewed the lab reports, identified common errors, and shared examples of sentence revisions.

In the senior-level lab course, the engineering instructor used similar instructional strategies, but there were no team-taught presentations. Thus, direct support from the writing specialist was faded, and the students depended solely on the engineering instructor for guidance. This is an example of how a partnership model can support seamless integration of technical communication into engineering coursework by gradually releasing responsibility for instruction to the engineering faculty.

At the end of each semester, the questionnaire was administered. All 12 students agreed to participate and completed a questionnaire at the end of their junior and senior courses.

Results

Results of this study are presented here in three areas: 1) WTL responses collected from students during the team-taught presentations; 2) quantitative and qualitative data from the self-report questionnaire administered at the end of both junior and senior level courses; and 3) scores from students' lab reports.

Student Work Samples

During the team-taught class sessions, students engaged in WTL activities. First, they were asked to write one sentence explaining the purpose of the temperature sensor lab, a lab in which students measured the response time of four different temperature sensors. In the present study, only 2 of the 12 students failed to identify the purpose of the lab, providing incorrect, vague, or incomplete responses (i.e., "to measure water from cold to hot" and "distinguish the most sensitive sensor"). The second WTL activity was intended to encourage creativity by asking students what the title of the lab report would be if it were a story. Eleven of the 12 students wrote titles more typical of lab report titles (e.g., "Thermal time constants of various temperature sensors") than story titles but one student's title was especially creative and specific, "The aluminum temperature probe that could measure the quickest!." Finally, the third WTL prompt evoked creativity: "If the instruments could talk, what would the thermistor say to the thermometer?" The two students who had difficulty explaining the purpose of the lab in one sentence provided responses here that demonstrated understanding: “I'm faster than you” and "You’re slow.” This is consistent with other research that found that some students can demonstrate understanding through creative activities, even when they appear to lack understanding when tested in traditional ways [28]. Other examples of creative, yet meaningful responses include “Why do you take so long to change your temperature?” and “My tau is better” in reference to the thermal time constant. Overall, half of the students had creative and accurate responses, two had technically correct responses that were not very relevant to the lab (e.g., “Cheap, old-fashioned”), and the other four had vague responses or did not submit answers to the prompt.

During these lectures, most students actively participated in answering questions that were posed to the class, and many asked questions that showed that they were paying attention in class (e.g., “Would it be better to plot all of the data on one plot?”). In the past, the engineering instructor has asked students in one-on-one meetings to analyze how they can improve their own plots, but usually they are unable to see the obvious errors that they have made. During the team-taught classes, students were provided opportunities for oral and written discourse in the disciplinary community. For example, students shared their thinking in paired and whole group discussions and engaged in WTL activities. As students became acculturated into the discourse community of the discipline, they were able to articulate their thinking and identify the errors in their classmates’ plots. The engineering instructor observed that this level of discourse and self-evaluation seldom occurred in individual writing conferences.

Students’ Self Reports

A self-report questionnaire was administered at the end of each course. The questionnaire assessed students’ perceptions of how much their writing improved, the importance they attached to different aspects of technical writing, and their perceptions about the usefulness of different instructional strategies and resources. The questionnaire also included items that assessed students’ perceptions about the difficulty of the technical content in the lab projects in relation to perceived challenges in writing about that same content. The questionnaire items and analyses are presented here in the order in which they appeared to the students (See also Appendix A for the items and tabulated student responses).

Students were asked to report how much they thought their writing improved on different aspects of the lab report. Students reported on a Likert scale of 1 to 5, with 1 indicating little or no improvement and 5, the most improvement Table 1 shows students’ perceived areas of improvement in the junior level course, as compared with the senior level course.

Table 1. Perceived Improvements in Writing Skills

On a scale of 1 to 5 (not at all – extremely), please indicate to what degree you feel your writing has improved from the beginning to the end of the course. (1 = Not at all; 2 = Slightly; 3 = Moderately; 4 = Very much; 5 = Extremely).						
	Junior-Level Course			Senior-Level Course		
	Mean	Median	SD	Mean	Median	SD
Responding to the client's request (or information required in the lab report)	3.5	4.0	1.2	3.3	3.5	1.0
Organizing the lab report	4.0	4.0	0.7	3.8	4.0	0.9
Conveying information clearly	3.9	4.0	0.7	3.7	4.0	0.8
Conveying information accurately	3.9	4.0	0.9	3.6	4.0	0.9
Writing concisely	4.1	4.0	0.7	3.5	3.0	1.1
Constructing effective data displays	4.3	4.0	0.6	4.0	4.0	1.0
Writing up the results and discussion	3.9	4.0	0.8	3.5	3.5	1.2
Writing abstract	4.3	4.0	0.7	3.8	4.0	0.9
Revising and editing your writing	3.7	4.0	1.2	3.4	3.0	1.2
Writing lab reports (overall)	4.0	4.0	0.7	3.8	4.0	0.9

On average, students reported perceived improvements in all aspects of the lab reports. In the junior class, the most improvement was reported in areas of instructional emphasis (i.e., writing abstracts (4.3) and constructing data displays (4.3). Students perceived their most improvement in constructing data displays (4.0) in their senior class where the engineering instructor placed emphasis on the accuracy and format of data presentation.

Students were asked to report the perceived value of different learning experiences and how much they thought different learning experiences contributed to improvement in writing skills. Students reported on a Likert scale of 1 to 5, with 1 indicating the least valuable and 5 the most valuable. Table 2 shows the perceived value of learning experiences provided in the junior level course, where students engaged in an extended writing process for the first lab on temperature sensors. These scaffolds were not provided in the senior course, except for the instructor feedback. Students valued the feedback and the extended writing process more than the lectures (direct instruction). It is interesting, however, that students perceived they improved the most in the topics of the two lectures (i.e., data displays and writing abstracts) as shown in Table 1.

Table 2. Students' Perceptions of Learning Experiences

On a scale of 1 – 5 (not at all – extremely), please indicate to what degree you feel each of the following contributed to your skills in writing lab reports. (1 = Not at all; 2 = Slightly; 3 = Moderately; 4 = Very much; 5 = Extremely).						
	Junior-Level Course			Senior-Level Course		
	Mean	Median	SD	Mean	Median	SD
The team-taught lecture on data displays and results	3.8	4.0	1.0	3.7	4.0	1.4
The team-taught lecture on abstracts	3.8	4.0	1.1	2.8	3.0	1.0
The opportunity to write/draft the temperature sensor lab, component by component	4.4	5.0	0.8	2.7	3.0	0.9
The feedback you received on the temperature sensor lab	4.3	4.5	0.9	2.8	3.0	1.0
The opportunity to revise the temperature sensor lab, based on feedback	4.5	5.0	0.7	3.1	3.0	1.1
Feedback/comments provided by the instructor on the Assignments submitted through Blackboard.	4.7	5.0	0.7	2.4	3.0	1.0

In the senior class, the scaffolded instruction was faded. There was no opportunity for extended writing processes nor were their formal lectures on writing topics. However, the online resources were still available and feedback from the engineering instructor continued throughout the senior level class. Feedback included comments on lab reports, delivered through tools in the Learning Management System (LMS) and individual writing conferences with students. Students continued to consider instructor feedback valuable (3.71), especially when compared to other available learning resources (see Table 3).

Students were asked to rate their satisfaction with the online modules as learning resources. They reported how much they thought the resources contributed to their skills in writing lab reports, on a scale of 1 to 5, from not at all useful to extremely useful. Table 3 shows how useful students found the different online modules. In the junior course, students reported the modules on data and results (Module 10) and researching and citing work (Module 7) as most useful, with a mean of 3.42 for both modules. In the senior course, students reported they most valued the module on abstracts (3.27).

Table 3. Students' Perceptions of Online Resources and Instructor Feedback

On a scale of 1 – 5 (not at all – extremely), please indicate to what degree you feel each of the following contributed to your skills in writing lab reports. (1 = Not at all; 2 = Slightly; 3 = Moderately; 4 = Very much; 5 = Extremely).						
	Junior-Level Course			Senior Level Course		
	Mean	Median	SD	Mean	Median	SD
The online modules (in general)	3.2	3.0	1.3	3.7	4.0	1.4
Module 1: Introduction to the Course	3.2	3.0	1.2	2.8	3.0	1.0
Module 2: Pre-Lab and In-lab (notebooks)	3.3	3.0	1.1	2.7	3.0	0.9
Module 3: Lab Report Structure	3.0	3.0	1.0	2.8	3.0	1.0
Module 4: MS Word Tools	3.2	3.0	1.2	3.1	3.0	1.1
Module 5: Letter of Transmittal	3.2	3.0	1.2	2.4	3.0	1.0
Module 6: Abstract	3.3	3.0	1.2	3.1	3.0	1.0
Module 7 Researching and citing work	3.4	3.0	1.2	3.3	3.0	1.0
Module 8: Subject Matter: Lab Report Introduction	3.3	3.0	1.2	2.6	3.0	1.1
Module 9 Methods & Materials	3.3	3.0	1.2	2.8	3.0	1.2
Module 10 Data and Results	3.4	3.0	1.2	3.0	3.0	1.1
Module 11: Discussion	3.3	3.0	1.1	3.0	3.0	1.1
Module 12: Appendix	3.3	3.0	1.1	3.0	3.0	0.9
Instructor Feedback	4.7	3.0	0.7	2.7	3.0	1.3

The junior course was the students' first opportunity for formal instruction in the structure of lab reports and the modules served to introduce students to the discourse of the discipline. As chemical engineering students, these students previously took courses in chemistry, with labs and lab reports, but the lab reports required in chemical engineering were more formal and more structured than in their previous labs. Students found Module 7 (researching and citing existing work) a useful module contributing to their learning. Module 7 was expressly developed by the engineering liaison librarian for engineering research. For example, the Module included searching for patents and formatting bibliographies in styles common in engineering disciplines.

As previously explained, instruction emphasized the visual communication of results and it is not surprising that students looked to Module 10 (Data and Results) for additional guidance. Other modules students reported helpful were Modules 6 (Abstract), 8 (Introduction), and 9 (Methods and Materials), which were required sections in all lab reports.

Understanding Technical Content and Writing about Content

Students were asked to report on the perceived difficulty of each lab's technical content and the perceived difficulty of the writing process. They rated the difficulty on a scale of 1 to 5, 1 the easiest, and 5 the most difficult. Tables 4 and 5 show students' perceptions of the difficulty of lab content vs. the difficulty of writing about the content in the junior level and senior level courses, respectively.

Table 4. Perceived Difficulty of Lab Content vs. Written Report in Junior Course

Lab Content: On a scale of 1 – 5 (Not difficult at all – Extremely difficult) how difficult was it to understand the scientific principles demonstrated in each of the following labs? (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult). Written Lab Report: On a scale of 1 – 5 (Not difficult at all – Extremely difficult) how difficult was it to ***write*** each of the following lab reports? (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult).						
	Lab Content			Written Lab Report		
Lab Content	Mean	Median	SD	Mean	Median	SD
Temperature Sensor	1.5	1.0	1.0	2.8	2.5	1.3
Gas Delivery System	2.1	2.0	0.9	2.6	3.0	1.0
Tray Dryer	1.9	2.0	1.0	2.5	2.2	1.0
Pipe Flow	1.3	1.0	0.5	1.8	2.0	1.0
Shell & Tube Heat Exchanger	2.2	2.0	0.9	2.5	2.0	1.2
Double Pipe Heat Exchanger	1.6	1.0	0.8	2.3	2.0	1.2

As shown in Table 4, in the junior course, students perceived writing the report more difficult than understanding the content of the report. In the senior course (see Table 5), however, students' perceptions of the difficulty of content and that of writing the lab were similar. The senior lab content focused on more complex engineering systems. Thus, it is not surprising that the students perceived both the writing and technical content of the lab to be about equally difficult (See Table 5).

Table 5. Perceived Difficulty of Lab Content vs. Perceived Difficulty of Written Report in Senior Course

Lab Content: How difficult was it to understand the science principles demonstrated in each of the following labs: (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult).

Written Lab Report: How difficult was it to ***write*** each of the following lab reports? (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult).

	Lab Content			Written Lab Report		
	Mean	Median	SD	Mean	Median	SD
Fermentation	1.6	1.0	0.8	1.7	2.0	0.8
Absorption	2.7	2.0	1.1	2.9	3.0	0.9
Distillation	2.2	2.0	0.8	2.3	2.0	0.7
Evaporator	2.7	3.0	1.1	2.5	2.0	1.1
Fuel Cell	1.6	1.0	0.7	1.6	1.0	0.7

Students' Comments

Students' responses to the open-ended questionnaire items serve to interpret the quantitative self-report data. Students were asked to comment on their learning experiences and what helped them improve their writing. Students reported that they valued feedback above all else because, as one student reported, "The comments and feedback are the most helpful. I've seen my grades improve directly due to the feedback specific to me." Another student explained, "I kept getting notes about being more concise… Keeping this in mind helped the other papers be better." Students valued feedback above the online modules: "I don't think the modules were as helpful as the specific edits and comments to my own writing." In the senior level course, again students reported how much they valued feedback: "I really liked the one-on-one meetings. They really helped steer/assure me toward the right direction." And "(The instructor's) comments acted as a supervisor would."

Consistent with the quantitative data, students reported they valued opportunities for extending the writing process:

> Keep that temperature sensor report with drafts, it helped a lot (junior level)
>
> I think the modules could be slimmed down to allow for actual writing & revising & response to feedback (junior level)
>
> . . . allowing a rewrite of the sections as you grade it (junior level)

Students also reported valuing the lectures that provided direct instruction and exemplars. One student noticed what was missing in the senior level course, when scaffolds were faded: “Show samples to give students an idea of good presentation and reports (I believe you actually did do this last semester, which was very helpful/good)”. Another student noted the difference between the first scaffolded lab and the other labs in the junior level course, and recommended: “Spend a class on it, like how it was taught that one class”

Although the quantitative data indicated that students appreciated the lectures less than the opportunities for feedback and revision, their comments confirmed how much they learned about the target concepts emphasized in the lectures, namely, the abstracts (including writing concisely) and visual communication. Their comments show they are internalizing the discourse of the discipline:

> Graphs need to be formatted so that (they’re) understandable (junior level)
>
> Understanding how to fully explain a graph (junior level)
>
> How to display results better and referring to them (junior level)
>
> Learning to get my point across more clearly with (fewer) words (junior level)
>
> How to write more …. concisely (junior level)
>
> Learning how to write the abstract (junior level)
>
> Utilizing tables and figures effectively are important for technical communication skills (senior level)
>
> How to present data well (senior level)
>
> I also think ‘what can this mean’ and elaborate more on data. (senior level)
>
> Being more concise and making recommendations based on the original request (senior level)

Note that these last two comments from the senior level questionnaire show how students are beginning to equate “good writing” with communicating the message clearly.

When asked to explain insights about writing lab reports, students made connections between content and the communication of content. Notably, such comments as these were provided only on the senior level questionnaire:

> The more you understand a process, the better you can communicate it
>
> Understanding underlying principles and being able to apply them

The better you understand a process, the more you can elaborate on it and explain it clearly in a lab report

Sound background and theoretical knowledge (needed for writing lab reports)

Keep the objectives (of the lab) in mind

(Instructors need to) stress the skill of understanding the entire process

I found that writing conclusions were (sic) the most difficult part

Lab Report Grades

In the junior class, students wrote six lab reports, four of which required a full report, including the temperature sensor lab written in a scaffolded and extended writing process. In the senior level class, students wrote five lab reports without opportunities for revision. Students' lab reports were graded by the chemical engineering instructor using an 8-point proficiency scale from 1 (poorly written and incomplete) to 8 (outstanding). Students were given scores on each lab report section. Each section had required components, for example the abstract required an overview, purpose statement, methods, results, and conclusions/recommendations. For other sections, such as the discussion, specific required components (for example determination of an overall heat transfer coefficient) were detailed in the instructor's assignment memo. The proficiency levels and descriptors are provided in Appendix B. The 8-point scale was chosen to allow for greater differentiation between an outstanding paper and a good paper that could still be improved. Students' scores on the 8-point scale were accompanied by qualitative feedback directed toward improvement. For example, feedback included such comments as "Cut words from the abstract to make it more concise" or "Remember to include the units in the plot." Thus, students were guided to improve their writing on the revision tasks.

Students' scores on three lab report sections (the abstract, visual communication/format of results, and discussion of results) were analyzed. Writing abstracts and visual communication of results were targeted for intensive instruction, as previously explained. The discussion section scores were included in the analysis because all the reports required a discussion of the results (In some labs, students were not required to include all the report sections). Moreover, scores on the discussion section were deemed likely to reflect students' understanding of content

Tables 6 and 7 provide comparison of students' lab report scores on three lab report sections (i.e., abstract, results, and discussion) in the junior and senior level courses, respectively. In the junior course, four lab reports were required (as shown in Table 6); other laboratory activities required only informal writing, such as lab notebooks, and so they were not included in the analysis of technical writing skills. In the senior course, lab reports were required for all five labs.

Table 6. Lab Report Scores in the Junior-Level Course

	Abstract			Visual/Results			Discussion		
Lab Content	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Temp Sensor	6.7	7.0	1.3	6.0	6.0	1.5	6.9	7.0	1.2
Pipe Flow	6.7	7.0	1.4	7.1	7.0	0.8	6.4	6.0	1.1
Double Pipe Heat Exchanger	6.6	7.0	0.7	7.0	7.0	0.9	6.6	7.0	0.8
Shell & Tube Heat Exchanger	6.9	7.0	1.0	5.9	6.0	1.0	6.4	7.0	1.4

Table 7. Lab Report Scores in the Senior-Level Course

	Abstract			Visual/Results			Discussion		
Lab Content	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Fermentation	6.1	6.0	1.2	6.5	6.5	1.1	6.5	6.0	1.1
Fuel Cell	6.3	6.0	0.9	6.8	7.0	1.1	6.9	7.0	1.0
Evaporation	6.3	6.5	1.2	6.6	7.0	1.2	6.1	6.5	1.6
Absorption	6.9	7.0	0.8	6.6	7.0	1.4	6.3	6.0	1.0
Distillation	6.4	7.0	1.4	6.6	7.0	1.2	6.3	6.5	1.5

Note: Lab Report writing proficiency scores are reported on an 8 point scale, with 1 the weakest and 8 the strongest.

Although students were assigned labs in rotations, with students conducting the labs in different orders, nonetheless, the data show similar means for abstracts and discussions across all lab report topics. On the other hand, student scores for visual communication of results varied widely across all lab topics. Results show similar mean scores on all sections of all lab reports, except the visual communication of results in the junior-level Shell and Tube Heat Exchanger lab. The low mean (5.9) on the results section of the Shell and Tube lab may be because this lab was the most complex lab of the semester, and the report required more complex plots and data tables than the other labs. This finding suggests that engineering students may be especially challenged to transfer their visual communication skills to new content.

Overall, mean lab report scores in both junior and senior-level courses were similar suggesting that students sustained writing proficiency over time, even when scaffolds were faded and content became increasingly difficult.

Discussion

Previous research [29] has found that engineering students may think of themselves as "good at math" and "poor at writing." The results of the present study show interactions between perceptions of content difficulty and perceptions of difficulty in writing about content. In the junior-level course, students perceived writing more difficult than content, although they received intensive guidance and feedback on the writing. This initial guidance and feedback, together with relatively high grades in writing (as shown in the mean scores on junior lab reports) may have bolstered their confidence as writers and prepared them to tackle more challenging technical content in the senior class. Their confidence in themselves as writers (as shown in their reports of improvement in writing skills) may have reduced the cognitive burden, enabling them to focus on content.

Students' writing scores did not decline in the senior level class, despite the increasing difficulty of technical content and faded scaffolds. These findings are limited in that this is a descriptive study and there is no intent to generalize results to a population. However, results of this particular study suggest that intensive guidance and an extended writing process in early stages of learning to write lab reports may have long-term benefits for students. In the present study, an embedded writing specialist in the engineering school supported the extended writing process and collaborated in the guidance and feedback provided at the beginning of the junior course. Moreover, this same writing instructor introduced these same students to technical writing, during their first-year technical writing course, Short Engineering Reports. Thus, the partnership model provided both a foundation and continuity across all four years of the students' engineering program. Characterized by integration, consistency, and collaboration, our partnership model apparently brought students along a path toward increasing their competence and confidence in communicating more of more complex content. Future research might study other ways partnerships can leverage resources and instructor time to provide more such learning opportunities for students (and faculty).

Conclusion and Lessons Learned

In working together to teach the same students both science content and communication skills, we learned about each other's disciplines. We became more understanding about the challenges students face when they work in two different disciplines. When technical communication skills are integrated and expected in disciplinary engineering courses, students are working across technical and non-technical disciplines. Students may face the same challenges we faced as we worked across disciplines to provide an integrated learning experience for students.

We learned that:

- Understanding content and writing about content are inextricably intertwined.
- Students face challenges when they are expected to acquire both technical content and writing skills at the same time.

- Collaborative teaching can assist students in understanding how writing about content and understanding the content are connected.
- When writing skills are scaffolded, most students can improve their writing.
- Online resources can leverage the instructors' time so that more time can be spent on providing feedback rather than presenting instruction on the structure of lab reports.

In the present study, the authors found that working together was facilitated by a partnership model in which faculty from different disciplines were members of the same academic (engineering) community. When faculty from different disciplines work together over time within the same academic community, the disciplinary community is enriched by ideas and language from both disciplines. This in turn facilitates engineering students' development of effective communication skills at the same time that they develop technical skills. The partnership model supported students during the extended writing process; the partnership also supported the engineering instructor's workload during the period of the extended writing process; and perhaps most importantly, the partnership model expanded the boundaries of the disciplinary community.

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Appendix A. Survey Items and Responses

Survey Section A. On a scale of 1 to 5 (not at all – extremely), please indicate to what degree you feel your writing has improved from the beginning to the end of the course. (1 = Not at all; 2 = Slightly; 3 = Moderately; 4 = Very much; 5 = Extremely).												
	Junior-Level Course						Senior-Level Course					
	Not at all	Slightly	Moderately	Very much	Extremely	Median	Not at all	Slightly	Moderately	Very much	Extremely	Median
Responding to the client's request (or information required in the lab report)	8.3%	8.3%	25.0%	41.7%	16.7%	4	0.0%	25.0%	25.0%	41.7%	8.3%	3.5
Organizing the lab report	0.0%	0.0%	25.0%	50.0%	25.0%	4	0.0%	8.3%	25.0%	41.7%	25.0%	4
Conveying information clearly	0.0%	0.0%	25.0%	58.3%	16.7%	4	0.0%	8.3%	25.0%	58.3%	8.3%	4
Conveying information accurately	0.0%	8.3%	16.7%	50.0%	25.0%	4	0.0%	16.7%	16.7%	58.3%	8.3%	4
Writing concisely	0.0%	0.0%	16.7%	58.3%	25.0%	4	0.0%	16.7%	41.7%	16.7%	25.0%	3
Constructing effective data displays	0.0%	0.0%	8.3%	58.3%	33.3%	4	0.0%	8.3%	16.7%	41.7%	33.3%	4

Number of Students' Perceptions of Learning Experiences												
On a scale of 1 – 5 (not at all – extremely), please indicate to what degree you feel each of the following contributed to your skills in writing lab reports. (1 = Not at all; 2 = Slightly; 3 = Moderately; 4 = Very much; 5 = Extremely).												
	Junior-Level Course						Senior-Level Course					
	Not at all	Slightly	Moderately	Very much	Extremely	Median	Not at all	Slightly	Moderately	Very much	Extremely	Median
The team-taught lecture on data displays and results	0.0%	8.3%	33.3%	33.3%	25.0%	4	8.3%	0.0%	8.3%	25.0%	16.7%	4
The team-taught lecture on abstracts	0.0%	16.7%	25.0%	25.0%	33.3%	4	8.3%	16.7%	33.3%	16.7%	0.0%	3
The opportunity to write/draft the temperature sensor lab, component by component	0.0%	0.0%	16.7%	25.0%	58.3%	5	8.3%	16.7%	41.7%	8.3%	0.0%	3
The feedback you received on the temperature sensor lab	0.0%	0.0%	25.0%	25.0%	50.0%	4.5	8.3%	16.7%	50.0%	0.0%	8.3%	3
The opportunity to revise the temperature sensor lab, based on feedback	0.0%	0.0%	16.7%	25.0%	58.3%	5	8.3%	8.3%	41.7%	16.7%	8.3%	3
Feedback/comments provided by the instructor on the Assignments submitted through Blackboard.	0.0%	0.0%	16.7%	25.0%	58.3%	5	16.7%	16.7%	33.3%	8.3%	0.0%	3

Number of Students' Perceptions of Online Resources and Instructor Feedback On a scale of 1 – 5 (not at all – extremely), please indicate to what degree you feel each of the following contributed to your skills in writing lab reports. (1 = Not at all; 2 = Slightly; 3 = Moderately; 4 = Very much; 5 = Extremely).												
	Junior-Level Course						Senior-Level Course					
	Not at all	Slightly	Moderately	Very much	Extremely	Median	Not at all	Slightly	Moderately	Very much	Extremely	Median
The online modules (in general)	8.3%	25.0%	25.0%	25.0%	16.7%	3	8.3%	0.0%	8.3%	25.0%	16.7%	4
Module 1: Introduction to the Course	8.3%	16.7%	41.7%	16.7%	16.7%	3	8.3%	16.7%	33.3%	16.7%	0.0%	3
Module 2: Pre-Lab and In-Lab (notebooks)	8.3%	8.3%	50.0%	16.7%	16.7%	3	8.3%	16.7%	41.7%	8.3%	0.0%	3
Module 3: Lab Report Structure	8.3%	16.7%	50.0%	16.7%	8.3%	3	8.3%	16.7%	50.0%	0.0%	8.3%	3
Module 4: MS Word Tools	8.3%	16.7%	41.7%	16.7%	16.7%	3	8.3%	8.3%	41.7%	16.7%	8.3%	3
Module 5: Letter of Transmittal	8.3%	16.7%	41.7%	16.7%	16.7%	3	16.7%	16.7%	33.3%	8.3%	0.0%	3
Module 6: Abstract	8.3%	8.3%	50.0%	8.3%	25.0%	3	8.3%	8.3%	50.0%	16.7%	8.3%	3
Module 7: Researching and citing work	8.3%	8.3%	41.7%	16.7%	25.0%	3	8.3%	0.0%	50.0%	25.0%	8.3%	3

Module 8: Subject Matter: Lab Report Introduction	8.3%	8.3%	50.0%	8.3%	25.0%	3	16.7%	0.0%	41.7%	8.3%	0.0%	3
Module 9: Methods & Materials	8.3%	8.3%	50.0%	8.3%	25.0%	3	16.7%	8.3%	41.7%	8.3%	8.3%	3
Module 10: Data and Results	8.3%	8.3%	41.7%	16.7%	25.0%	3	8.3%	8.3%	50.0%	8.3%	8.3%	3
Module 11: Discussion	8.3%	8.3%	50.0%	16.7%	16.7%	3	8.3%	8.3%	50.0%	8.3%	8.3%	3
Module12: Appendix	8.3%	8.3%	50.0%	16.7%	16.7%	3	0.0%	25.0%	41.7%	8.3%	8.3%	3
Instructor Feedback	8.3%	8.3%	50.0%	16.7%	16.7%	3	16.7%	16.7%	33.3%	8.3%	8.3%	3

Number of Students Reporting Perceived Difficulty of Lab Content vs. Written Lab Report in Junior Course												
Lab Content. On a scale of 1 – 5 (Not difficult at all – Extremely difficult) how difficult was it to understand the scientific principles demonstrated in each of the following labs? (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult). Written Lab Report. On a scale of 1 – 5 (Not difficult at all – Extremely difficult) how difficult was it to ***write*** each of the following lab reports? (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult).												
Junior-level Course.												
	Lab Content						Written Lab Report					
	Not Difficult	Slightly Difficult	Moderately Difficult	Difficult	Extremely Difficult	Median	Not Difficult	Slightly Difficult	Moderately Difficult	Difficult	Extremely Difficult	Median
Temperature Sensor	75.0%	8.3%	8.3%	8.3%	0.0%	1	16.7%	33.3%	8.3%	33.3%	8.3%	2.5
Gas Delivery System	33.3%	25.0%	41.7%	0.0%	0.0%	2	16.7%	25.0%	33.3%	16.7%	0.0%	3
Tray Dryer	41.7%	33.3%	16.7%	8.3%	0.0%	2	16.7%	33.3%	33.3%	16.7%	0.0%	2.5
Pipe Flow	66.7%	33.3%	0.0%	0.0%	0.0%	1	41.7%	33.3%	8.3%	8.3%	0.0%	2
Shell & Tube Heat Exchanger	25.0%	41.7%	25.0%	8.3%	0.0%	2	16.7%	41.7%	25.0%	8.3%	8.3%	2
Double Pipe Heat Exchanger	58.3%	25.0%	16.7%	0.0%	0.0%	1	25.0%	41.7%	16.7%	8.3%	8.3%	2

Number of Students Reporting Perceived Difficulty of Lab Content vs. Written Lab Report in Senior Course

Survey Section G. Lab Content. On a scale of 1 – 5 (Not difficult at all – Extremely difficult) how difficult was it to understand the scientific principles demonstrated in each of the following labs? (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult).

Survey Section H. Written Lab Report. On a scale of 1 – 5 (Not difficult at all – Extremely difficult) how difficult was it to ***write*** each of the following lab reports? (1 = Not difficult at all; 2 = Slightly difficult; 3 = Moderately difficult; 4 = Difficult; 5 = Extremely difficult).

Senior-level Course.												
	Lab Content						Written Lab Report					
	Not Difficult	Slightly Difficult	Moderately Difficult	Difficult	Extremely Difficult	Median	Not Difficult	Slightly Difficult	Moderately Difficult	Difficult	Extremely Difficult	Median
Fermentation	58.3%	16.7%	16.7%	0.0%	0.0%	1	41.7%	33.3%	16.7%	0.0%	0.0%	2
Absorption	8.3%	41.7%	8.3%	33.3%	0.0%	2	0.0%	33.3%	41.7%	8.3%	8.3%	3
Distillation	16.7%	41.7%	33.3%	0.0%	0.0%	2	8.3%	41.7%	33.3%	0.0%	0.0%	2
Evaporator	8.3%	33.3%	33.3%	8.3%	8.3%	3	8.3%	41.7%	25.0%	0.0%	8.3%	2
Fuel Cell	50.0%	33.3%	8.3%	0.0%	0.0%	1	41.7%	25.0%	8.3%	0.0%	0.0%	1

Appendix B. Grading Proficiency Levels and Descriptors

Score	Rating Title	General Rubric Descriptor
8	Excellent	1.All of the required components in this section are included. 2. Communication is exceptionally clear. 3. Appropriate details contribute to the reader's understanding
7	Proficient	1. All required components in this section are included. 2. Communication is generally clear. 3. There is sufficient detail in most of the components.
6	Competent	1. Most of the components in this section are included. 2. Communication is generally clear. 3. Minor details may be missing.
5	Approaching Competence	1. Most of the components in this section are included. 2. Communication may be at times unclear. 3. Insufficient details may interfere with reader's understanding.
4	Below Expectations (Structure)	1. Two or three components are missing from this section. 2. Communication of provided information is generally clear. 3. Missing important details.
3	Below Expectations (Structure & Communication)	1. Two or three components are missing from this section. 2. Communication is generally unclear. 3. Lack of detail significantly interferes with the reader's understanding.
2	Unacceptable (Report Structure)	1. Most of the components in this section are missing. 2. Communication of provided information is generally clear. 3. Missing important details.
1	Unacceptable (Report Structure & Communication)	1. Most of the components in this section are missing 2. The information is unclearly communicated. 3. There is insufficient detail for a reader to understand.
0	Missing	Section is missing.