Assessing the Value of Different Techniques for Teaching Technical Communication Skills

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Worldwide, the development of strong communication skills is considered critical for success in the 21st century workplace (Ananiadou 2009). Yet, in practice, emphasizing these so-called "soft skills" has been challenging in "crowded" curricula (Lundy 2015), and especially in engineering education. In response to an identified need for instructional resources and strategies to teach communication skills, engineering faculty at the University of New Haven have been collaborating to develop technical communication curriculum, including a series of online modules. The present study is a pilot study intended to evaluate the implementation of selected instructional resources and strategies integrated into a chemical engineering laboratory course, where students were required to write bi-weekly technical memos based on the results of experimental work.

One innovative aspect of this pilot project was the team-taught approach to instruction. In this laboratory course, the engineering instructor collaborated with a writing instructor to plan and deliver instruction. Although team-teaching between engineers and writers is not new, few instances involve bringing the communication curriculum and writing instructor into the engineering classroom, as was done in this study. For example, Harvey et al. described engineering students' attitudes toward writing in a communication course in which engineering faculty attended two of four sections of the communication course (Harvey 2000). Qualitative responses to items assessing attitudes toward writing and anecdotal data showed that the students perceived a disconnect between writing assignments in communication classes and their work as engineers.

Context for the study:

The present study was conducted in a chemical engineering laboratory course. The course consists of a weekly lecture session (75 minutes) and a weekly laboratory session (4 hours). Students complete six laboratory modules, each two weeks in duration, during the laboratory sessions (see Table 1). Most modules require two in-class laboratory periods to complete, one period designated as a planning period and the other as an experimental period. Following the first laboratory period, students write a planning report (a technical memo) in groups of 3-4 and following the experimental period the students individually write a summary report (a technical memo). The final laboratory module requires a 20-minute group presentation and a full laboratory report. Thus, the course, as implemented in the past, required 10-14 written assignments, but had been lacking instruction in writing.

Methods:

In the present study, writing instruction was integrated into one section of the chemical engineering laboratory course described above. Students enrolled in this course (N=17) were provided writing instruction targeted toward the technical memos or laboratory reports students wrote based on their results in laboratory. Four different instructional approaches were used: (1) online instructional modules available on the University's course delivery platform, (2) assignment-specific writing feedback delivered by the engineering professor, (3) in-class lectures on best practices using student work samples as exemplars, and (4) a revision cycle facilitated by small writing groups (2 or 3 students) with both the professor of engineering and the writing instructor present. The techniques were evaluated primarily by student reflection at the end of the semester. Additionally, student writing assignments were evaluated to determine students' performance on selected writing tasks. Table 1 describes the writing tasks assigned throughout the course.

Table 1: Assignments given in the Fall 2016 course

Laboratory Module	Assignments (all technical memos)
Temperature Sensing Experiment	Individually written Technical Memo (1 week turn around) Individually written revision (1 week turn around)
Double Pipe Heat Exchanger	Group-written Planning Report (1 week turn around) and Individually written summary report (1 week turn around)
Pipe Flow Experiment	Group-written Planning Report (1 week turn around) and Individually written summary report (1 week turn around)
Double Effect Evaporator	Group-written Planning Report (1 week turn around) and Individually written summary report (1 week turn around)
Absorption Column	Group-written Planning Report (1 week turn around) and Individually written summary report (1 week turn around)
Distillation Column	Group-written Planning Report (1 week turn around) and Individually written summary report (1 week turn around)
Final Project	Full Laboratory Report (3 week turn around)

Instructional Strategies:
Instruction in technical communication skills was delivered in a variety of formats: lectures, online modules, small group revision cycles, and feedback on assignments on both the technical and writing aspects.

Lectures: The lectures on writing were delivered in six 10-15 minute segments in the lecture sessions. Content for writing lectures (technical communication and data displays) was taken from the text: *Clarity, Organization, Precision, Economy: A Technical Writing Guide for Engineers*, which was available to students online, at the university library, and in paperback form at the school bookstore. Additionally, the writing lectures demonstrated best practices in communication, which were exemplified in selections of writing or data presentations from students' own work (used with student permission). Using exemplars of student writing has been found to support student understanding of writing quality (To 2016). These lectures were also used to close each topic of the course. Thus, students had an introduction to each topic in lecture (primarily technical content), then they completed experimental work on the topic (in laboratory sessions), and finally they were provided an opportunity for closure by discussing best practices for presenting their data.

Online Resources: In addition to delivering writing instruction in lectures, online modules were made available for students as a reference. Online writing tools and classrooms are becoming more prevalent in college composition pedagogy (Griffin 2013). In our study, we used online modules developed by engineering faculty at the University of New Haven. These modules were designed to be integrated into four courses across engineering disciplines (chemical, mechanical, civil, and electrical/computer science). In our study, we provided students one set of these modules, which was developed specifically for junior and senior laboratory courses to teach the form and function of laboratory reports. The topics for the modules deployed in this class are shown in Table 2. Appendix B shows the associated learning outcomes. These resources were posted on Blackboard for students to use as a reference as they completed their final laboratory reports. Statistics tracking (a feature of Blackboard) recorded the number of times modules were accessed. Additionally, students' perceptions about the effectiveness of the modules was collected at the end of the course through a questionnaire.

Table 2: Online modules deployed on format and function of Laboratory Reports. See Appendix B for associated learning outcomes.

Module Number	Module Topic:
1	Structuring your laboratory report: Front matter, body, and back matter
2	What is a letter of transmittal?
3	Responding with appropriate detail: The abstract
4	Structuring laboratory reports in MS Word
5	Researching and citing work
6	Understanding your subject matter: The introduction
7	The methods, equipment, and materials section
8	Discussion, conclusions, and recommendations

Small Group Writing Sessions: For the small group writing sessions, the engineering instructor placed the 17 students into one of six groups of 2 or 3 students. The engineering instructor assigned students to groups based on their grasp of the technical content and their writing skills on their first assignment. For example, two groups were deemed "stretch groups" proficient in both content and technical communication. Other groups included those who would benefit from instruction in response to task (content), organization, clarity, or economy (writing concisely). Following the concept of the "6-trait" writing rubric (Spandel 2005), the writing instructor developed a multi-trait rubric that included six traits specific to technical writing: (1) response to task, (2) organizational structure, (3) clarity, (4) economy, (5) precision, and (6) data displays. Four of these traits (clarity, organization, precision, and economy) were based on the technical communication textbook used in the engineering school (Adams 2014). Consistent with research on rubric use as a self-evaluation tool (Andrade 2009), the purpose of this multi-trait rubric was to provide students a language to describe and evaluate their own writing. Students' lab reports were read and scored by the writing instructor prior to the small group sessions to prepare for providing specific guidance during the feedback session.

In these small group sessions (20 minutes in length), the engineering and writing instructors reviewed the rubric criteria (See Appendix A). Students were provided "clean copies" of their reports. The instructors and students reviewed the reports with the students and encouraged the students to self-evaluate their writing by highlighting passages in their reports that showed strengths and weaknesses. Instructors then provided feedback, emphasizing the previously identified areas targeted for instruction. At the end of the small group session, the students were assigned a revision of their reports, based on the feedback they received in the session. Students were given one week for their revision and the writing rubric was used for grading. Thus, this assignment was graded solely based on communication of their work.

Feedback: Feedback has long been associated with improved performance (Elawar 1985). In one recent study, Lipnevich and Smith found that university students perceived detailed comments as the most useful form of feedback (Lipnevich 2009). In writing, in particular, feedback has been found to improve student performance, yet providing detailed feedback has been challenging for teachers to accomplish (Parr 2010). In previous years, feedback on student assignments had focused on technical content. This year, in addition to feedback provided in the small group writing sessions (on the first technical memo assignment), the engineering instructor provided detailed feedback on students' communication skills, when they submitted the planning and lab reports (see Table 1). For example, rubrics provided to students for other assignments included elements of technical communication (which had not been included in previous years' scoring criteria). These new rubrics included criteria similar to those identified in the multi-trait technical communication rubric used to score the first technical memo. After the introduction to the traits in the small group writing sessions, criteria such as "presentation of data" or "use of precise language" were familiar to students. In addition to feedback through the rubric, the engineering instructor provided students written comments at the end of their papers using the language introduced in the multi-trait rubric.

Implementation Time: Utilizing lecture time to incorporate feedback on students' reports took approximately 1-2 lecture periods from the semester. The small group writing sessions were completed over the course of a week in either the 4-hour laboratory section or the 75-minute lecture period. This was done in the middle of the semester, during the week coinciding with fall break, when a laboratory experiment is not historically done. Thus, no labs were removed to facilitate the writing groups. Only one additional assignment was completed as a result of this study (the technical memo revision). Incorporating the e-modules reduced class time spent on discussing formal laboratory report format. Thus, the study did not require significant additional effort for students, nor instructor; however, it was facilitated by a small class size and the use of a writing instructor who was assigned partial time for the course.

Results:

Students' perceptions and usage of the instructional resources and strategies were measured through a questionnaire, usage statistics (for online resources), and written products submitted before and after the small group feedback and revision cycle.

Students' Use of Online Resources

As previously described, online modules were posted on Blackboard, the course delivery platform. Students were encouraged to access these resources to support writing their final laboratory report. Usage was tracked through the Blackboard "User Statistics" tool. These statistics calculated the number of times each student accessed any portion of the set of online writing support modules. The total number of times each of the 17 student accessed the online resources as tracked by the Blackboard system was averaged. In all, student access totaled 91 times, with a mean of 5.35, and standard deviation of 4.36. Student access ranged from none at all (one student) to 14 times, with a median of 6 times. The system did not track the time students spent in reviewing the resources, nor were data available for individual resources used by students. In the questionnaire administered at the end of the course, students reported that the online resources were moderately useful (See Table 4 for data on perceived usefulness of different instructional techniques and resources).

Results of the Questionnaire:
To collect data on students' perceptions of instructional strategies and resources, students completed a questionnaire that assessed their perceptions of the value of each instructional strategy at the end of the semester. Using "a post then pre" design (Rockwell 1989), a single survey administered at the end of the course, asked students to report their attitudes toward technical communication before and after they participated in the course.

Self-evaluations: Students were asked which aspects of their writing they perceived had improved 1) over the course of their first three years in the engineering school, and 2) during the semester course described in the present study. The responses were collected on a 4-point Likert Scale with a score of (4) associated with "a great deal" of improvement and a score of (1) associated with "not at all." Table 3 shows the mean response of students' self-evaluations of writing skills during the first three years and after participation in the semester course.

Table 3: Student perceptions on which aspects of their writing improved. A score of 4 is associated with "A great deal" and a score of 1 is associated with a response of "Not at all.

Survey Question:	Mean Before	Mean After
Responding to an assignment	3.29	3.53
Writing Organization	3.24	3.65
Writing Clearly	3.06	3.71
Writing Economically	2.82	3.41
Writing with Precision	3.00	3.65
Creating Effective Data Displays	3.29	3.65
Writing Technical Reports Quickly	2.53	3.18

As shown in Table 3, students perceived their greatest gains to be in writing clearly, economically, quickly, and with precision. The student's believed their strongest communication skills, initially, were in creating effective data displays and in responding to assignment. Both of these skills had been emphasized in two courses taken in their freshman year and one in their sophomore year. Students reported clarity, economy, and precision as weaker areas prior to this course. These three areas are covered in their communication textbook (Adams, 2014), but this was primarily assigned as a resource in their freshmen and sophomore courses. In both the lectures and the small group writing sessions in the present study, clarity, economy, and precision were reviewed and explained. During the small group writing sessions, students reported that they were unfamiliar with these skills. Another interesting finding is that students perceived they could write more quickly after participating in the laboratory course. It is unclear whether this is due to the extent of writing assigned (which would be true of previous years as well) or due to the writing instruction that was incorporated during this specific semester.

Perceptions on the effectiveness of different teaching techniques: Students were asked to assess the effectiveness of different strategies that may have improved their writing during the semester (See Table 4). Students found most strategies extremely helpful (mean scores >3.5 on a 4 point scale) with the exception of learning from their classmates during group assigned technical memos. One student's response written as a recommendation for improving technical communication instruction may explain why learning from peers was perceived as less effective than other strategies: "It's *fun (*emphasis added) learning by knocking an anonymous writer but more difficult to exercise personal criticism." Apparently, this student found self-evaluation and response to personalized feedback more valuable than anonymous peer review. Student's feedback to both the engineering and writing instructor on incorporating this level of writing instruction was positive, in agreement with the data in Table 4.

Table 4: Student perceptions on how helpful various teaching techniques were at teaching writing. A score of 4 is associated with "A great deal" and a score of 1is associated with a response of "Not at all"

Teaching Method:	Mean Score
1. Lectures delivered on good writing habits or presentations	3.76
2. The opportunity to revise a report, based on feedback	3.65
3. The feedback given on reports	3.71
4. The small group writing session	3.65
5. The resources available on blackboard for writing laboratory reports	3.59
6. Learning from other students while writing group reports	3.47

Perceptions on the Importance of Writing: Students were asked five questions on the importance of writing in the field of engineering. Students ranked the importance of writing in the field of engineering on a 4-point Likert Scale with a score of (4) associated with "a great deal" of importance and a score of (1) associated with "not at all." Students reported what their perceptions were before and after participating in the laboratory course. Table 5 shows the "before and after" means for each question.

Table 5: Average scores for student perceptions on the importance of writing. A score of 4 is associated with importance level "A great deal" and 1 associated with a response of "Not at all"

Survey Question:	Before	After
1. How important are writing skills for a successful career in engineering?	3.07	3.93

2. How important is it for an engineering student to spend time writing lab reports?	2.86	3.64
3. How important is it for an engineering student to have good writing skills?	3.23	3.85
4. How much does an engineering student need to know about the lab content to write a successful lab report?	3.14	3.93
5. How much can your engineering professor assess what you know about content knowledge from your writing?	3.14	3.64

These data show that students' perceptions about the importance of writing changed during the course; they claimed they attached a greater importance to technical communication skills after participating in the course (see items 1 to 3 in Table 5). Students' responses to items 4 and 5 show that students perceived an increased understanding about the connection between thinking about content and writing about it. They reported that understanding content was a prerequisite for writing clearly and they reported that they came to realize that their engineering professor could assess their understanding of content, based on their written communication. Since Vygotsky (Vygotsky 1978), scholars have recognized "writing to learn" as a pedagogical tool. More recently, Prain and Hand (Prain 2016) reviewed past and current research on writing as an epistemological tool, particularly in science education. They reaffirmed the value of writing as a sense-making and reasoning resource for students in domain-specific literacies. In the present study, the written discourse that involved explaining the complex calculation and results of laboratory experiments, together with the verbal discourse in which students engaged as they discussed their own writing, may have contributed to students' understanding and appreciation of how writing both supports acquisition of content and serves as a vehicle of the assessment of content.

Open Ended Questions: The survey included four open-ended questions: 1) What were your most significant problems with technical communication skills? 2) What recommendation would you have for teaching technical communication in this course? 3) What recommendation would you have for teaching technical communication in the engineering schools as a whole? And 4) What particular advice stuck with you?

In responding to the first open-ended question, students identified areas of weakness, naming specific traits from the rubric, as follows: economy (2), clarity (4), organization (2), precision (2), data displays (3). These data show that students had developed a language to describe and evaluate technical writing skills. In addition to identifying traits by name, students also explained their weaknesses. For example, one student wrote, "I would tend to write longer sentences to explain something that should be fairly simple/straightforward." Another student, who identified his weakness as clarity, explained "the reader does not always understand what I am trying to say." Two students identified problems in the area of content. One student described difficulty with response to the assignment ("The worst problem is to understand the whole lab"). Another student described difficulty calculating the data and connected his lack of understanding about the equations with inability to articulate ideas in writing. ("If I could not calculate the needed results, I could not explain the procedure of the lab and the outcome")

Students' recommendations for teaching technical communication in the course ranged from "None" to requests for more feedback, writing exemplars, and more opportunities for self-evaluation. As one student put it, "It's fun learning by knocking an anonymous writer, but more difficult to exercise personal criticism." Recommendations for teaching technical communication in the engineering school included requests for more technical communication assignments and instruction:

- "Increase the amount of writing in engineering courses"
- "More technical memos on simpler situations that are easier to communicate/discuss with an audience"
- "More experience before senior year"
- "Offer a week (course) with our expert in the field"
- "Having an available writer to help students improve communication skills"
- "Clearer explanations and rubrics"
- "Examples of what was done well and not done well"

These responses show that at the end of the semester, the students expressed appreciation for instruction in writing, they perceived the value of communication skills, and they indicated a desire for more instruction and opportunities to hone their skills.

Finally, students were asked to describe advice they perceived as most salient. Their responses showed the power of discourse as a writing pedagogy. As one student put it, "While reviewing my work, I can hear Dr. Simson's voice in my head saying 'Nope, get rid of that.' 'You can shorten that.' 'This is good.' Hearing those voices while I read over my report helps me out." Other students reported using "think-aloud" self-evaluation strategies, such as asking themselves: "Did I say too much?" "Is my point clear?" "What else can emphasize my findings?"

Lab Reports and Revisions

The engineering instructor graded students' original submissions for technical accuracy and content, as a usual practice in the chemical engineering lab course. Additionally, the writing instructor scored each report and revision for written communication, using the same multi-trait technical communication rubric developed for the small group feedback sessions. The reports were scored on a 5-point scale, using the same technical communication traits developed for the small group feedback sessions. In all, 15 of the 17 students submitted revisions that were evaluated. Table 6 shows the mean scores and standard deviations on the original and revised submissions. Additionally, students' effort on the revision task was measured by comparing the number of revisions each student made, using the "Comparison" tool in MS Word. Of the 15 students who submitted a revision, 14 students are included in the comparison data (one student submitted the revision in a format, which did not allow comparison in MS Word). The number of revisions per student ranged from 33 to 175 with a median of 70.

Table 6: Scores on baseline reports and their revisions according to the 5-point rubric shown in Appendix A

	Initial Paper		Revision	
Metric:	Mean	St. Dev.	Mean	St. Dev.
Overall Score	3.34	0.94	3.93	0.93
Clarity	3.33	0.82	3.80	0.76
Organization	3.41	0.82	4.20	0.94
Economy	3.27	0.46	3.67	0.48
Precision	3.73	0.96	4.13	0.74
Data Displays	2.93	1.10	3.47	0.74
Task	3.66	1.23	4.33	0.98
Word Count	757	278	641	178

On the baseline reports, the writing instructor found "creating effective data displays" to be the weakest aspect of students reports (2.93). During the small group sessions, both the writing and engineering instructors provided feedback about errors in presenting data. The majority of students had well labeled plots with units, titles, and effective use of space. However, the students often didn't combine data series on single plots to compare data, they often did not use trend lines effectively and frequently did not choose the proper selection of data to display (there was a tendency to display all data, not just important data). This may explain the contrast in the instructors' evaluations of student's data displays (as the weakest of the six areas) and the student's reporting that they felt confident in their abilities in creating data displays, even at the start of the semester (see Table 3 discussed previously). In the case of data displays, the disconnect may be because students had been receiving instruction in creating data displays as well as numerous data display assignments, since their freshmen year. They had internalized some of the more basic skills (in formatting, for instance), but had not achieved the higher level skills. These findings suggest that students may need more specific and earlier feedback on the presentation of data that is less focused on format, and more focused on content.

Of the 15 students who submitted revisions 14 (93%) improved their overall score and 1 (6%) student showed no change in overall score. This student, although he revised his paper based on feedback, had only minor communication errors in his original submission, and therefore received a score of 5 in all rubric traits. This was one of the students who had been placed in a "stretch group" where emphasis was placed on writing more effectively to their audience or improving their conclusions based on their already well presented and well communicated data. Paired-sample t-tests (not shown) were conducted on the scores of their baseline paper and their revisions and the improvements in each of the six categories were found to be statistically significant. The most significant gains were in the categories of: organization, data displays, and responding to the task. Students had the lowest gains in precision (which also had the highest initial score) and on economy (a 12% improvement on their initial score). However, word counts on the revisions were 15% lower on average than the baseline papers and the range narrowed (see reduction in standard deviation in Table 6) indicating that students' economy did improve.

The results also indicated strengths and weaknesses that students had upon the start of the year; students were weakest at creating good data displays and strongest at writing with precision.

These data show that these engineering students expended varying degrees of effort on the revision task. These data also show, not surprisingly, that students improved their writing after revision. Because this study was not designed to assess student performance or to test causality, improvements cannot be attributed to any particular instructional strategy, including revision. Particularly in lab courses, which typically require students to produce written reports after every lab, there is little time for revision. Future research might study how effective the revision process is for honing students writing skills and whether or not participation in a revision cycle on one particular lab report facilitates transfer of written communication skills to new pieces of writing (e.g., lab reports on different topics).

Conclusion and Implications:

In summary, the questionnaire asked students to report the perceived utility of different instructional strategies, on a scale of 1 to 4, with 4 being the most useful. The results of this study show that students perceived the lecture format (3.76) and feedback on reports (3.71) among the most helpful of the instructional strategies implemented. This may be because the lecture used exemplars of student work to model good communication skills. The use of peer models may have contributed to students' motivation and self-efficacy (Schunk 2007). Additionally, the lecture, which was integrated into the engineering course and delivered by the engineering instructor, may have provided students an opportunity to see connections between understanding of content and expression of that content. Students also cited the small group sessions (3.65) and opportunities for revision (3.65) as the next most useful instructional strategies. Notably, the small group sessions and revision task occurred at the beginning of the semester, providing students a language to discuss their writing. Previous research has demonstrated the value of discourse in knowledge construction about engineering concepts (Kittleson 2004). The present study suggests that discourse about communicating content knowledge may be equally beneficial.

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Appendix A: Multi Trait Technical Writing Rubric for Temperature Sensing Lab

Scoring Advice		Examples	
Criteria	Indicators (in this assignment)	Strengths	Weaknesses
Response to Assignment	Identifies purpose of lab: to compare different types of temperature sensors Shows data that compare different sensors (e.g., in a comparison table or response times of all sensors plotted on one graph) Provides raw data (i.e., equations, calculations) Includes specs of sensors and computer program		
Organization	First paragraph identifies purpose of lab experiment and ends with results (i.e., response times of sensors) Organizes description of procedures, data analysis, and results, using headings as appropriate Concludes by discussing implications for client/end-user (i.e., which sensor is best and why) Includes raw data in an appendix, rather than in the report		
Clarity	Constructs clear sentences (no run ons or fragments) Avoids misplaced modifiers		
Economy	Provides only relevant information (i.e., what is most important) Avoids repetitions/redundancies (e.g., no repetition of content, no superfluous words; procedure described once, if same for all sensors) Avoids passive voice, when possible		
Precision	Uses exact terminology, e.g., provides precise specifications of sensors (diameter, read-out display), rather than general description		
Data Displays	Uses accurate labels (e.g., in titles, axis labels) Rounds up decimal points, as appropriate Highlights important information		

Appendix B: Writing Modules Deployed via Blackboard and Associated Learning Outcomes

Module	Module Topic	Module Learning Outcomes
1	Structure your lab report: Front Matter, Body & Back Matter	Determine needed content to respond to your customer and for others to replicate your work.
2	What is a letter of transmittal?	Able to construct a simple letter of transmittal with standard format highlighting key anomalies in the work.
3	Responding with appropriate detail: The abstract	Synthesize content in response to customer stated outcomes. Summarize work and reflect on objectives. • Identify through review of examples the purpose and structure of abstracts in lab reports. Through revision, synthesize three specified COPE guidelines into governing principles for use in abstracts.
4	Building lab report structures in Word.	Able to construct table of contents, lists of information, properly formatted and numbered equations
5	Researching and citing others	Students are able to • Identify related works after searching the library • Provide proper citations for references used.
6	Demonstrating your understanding and mastery of the subject matter: The introduction.	Identify specific errors made in summarizing relevant published work in an introduction.
7	Methods and Materials	Describe the experimental or simulation process and results in a clear and easy to understand way. • Understand the ideal characteristics of strong methods and materials sections. • Describe methods and materials clearly and in a structure that allows readers to understand them.
8	Discussion: Appropriate language and organization	Discuss project data/results referencing tables and graphs. Highlight important results.
9	Conclusions/Recommendations	Evaluate project/lab with respect to customer required outcomes.