6-2019

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Publisher Citation

Li, C. Q., & Randi, J., & Sheffield, J. P. (2019, June), An Exploratory Study of Engineering Students' Misconceptions about Technical Communication Paper presented at 2019 ASEE Annual Conference & Exposition , Tampa, Florida. https://peer.asee.org/32061

An Exploratory Study of Engineering Students' Misconceptions about Technical Communication

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Introduction

This paper reports results of a mixed methods study that examined engineering students' acquisition of technical communication skills over time. In particular, this exploratory study aimed to identify persistent errors, lingering misconceptions, and challenges engineering students faced when they attempted to apply their knowledge and skills in new contexts. Communication skills are critically important for engineers. Strong writing skills empower engineers to make visible the complexities of their work to a wide range of audiences. The Accreditation Board for Engineering and Technology [1] identifies "the ability to communicate effectively" as a key student learning outcome [2]. Yet, despite its importance, technical communication often competes for time with engineering content in the typically "crowded" undergraduate engineering curricula [3].

Approaches that integrate technical communication into engineering coursework address both content and communication skills simultaneously [4]. For example, in our integrated program [5], students are expected to hone technical communication skills and immediately apply those skills to convey engineering content to a variety of audiences in technical memos set in authentic contexts. Programs that integrate technical communication instruction into engineering curricula often draw upon the expertise of both engineering and writing faculty and create spaces for collaboration and the exchange of disciplinary knowledge [4]. The co-authors of this study represent such a collaboration – one engineer who regularly teaches courses that incorporate writing assignments, one educator assigned to the College of Engineering to promote the integration of writing across the engineering curriculum, one English faculty member who directs the University's Writing Across the Curriculum initiative.[1]

Viewing Writing Though Different Lenses

This literature review brings together the perspectives of engineering educators, educational psychologists, and scholars in the field of English composition. We argue that dialog between the disciplines is a necessary conversation for educators teaching in programs that integrate engineering content and writing to ensure that our future engineers respect the power of communication and understand the importance of communicating work clearly, precisely, and above all, accurately. This "dialog between the disciplines" serves to highlight similarities and differences and reconcile sometimes conflicting perspectives. We further suggest that students also engage in a similar reconciliation process as they move from one instructor's classroom to another and from one disciplinary perspective to another.

Many engineering students tend to struggle with some of the conventions necessary to compose technical documents [6,7,8], especially because academic writing most often does not focus on technical writing conventions. Acquiring technical communication skills requires letting go of

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[1] The order of authorship is alphabetical.

some previously held understandings about writing and replacing them with new knowledge about what constitutes technical communication. The role of prior knowledge is especially critical because it can promote or impede transfer [9].

Transfer of knowledge and skills from one task to another is difficult to accomplish, even when tasks are similar or "near" [10]. In educational psychology, there is a long history of research on transfer representing diverse perspectives and theories [11]. Modern psychological theory views transfer as more than the direct application of skills; transfer involves future learning and interpretation of how prior knowledge can be used to accomplish a new task [11].

The concept of transfer has also been of interest to English scholars. Rhetoric and composition scholars typically refer to the application of writing skills across contexts as "transfer" [12]. Other research [13] focused on rhetorical knowledge transfer from a technical communication classroom to an engineering classroom. Assessing if students applied what they learned in a technical communication course to writing assignments in a later engineering course, Ford discovered that students appeared to transfer rhetorical strategies between different contexts; however, they tended to think first about the structure of their reports and second about the report's audience or context [13, p.10]. Ford's study was small—with 12 student participants—and focused on one course, a senior-level industrial engineering course. As such, while transfer is a concept that is beginning to be applied specifically to study engineering students' writing skills, the scope of such studies is still small.

In the field of composition, debates have surfaced about the ability of first-year writing instruction to "identify and instruct a transferable, universal academic discourse" [14, p. 276]. The field has recently been influenced by Meyer and Land's [15] notion of disciplinary threshold concepts: "A threshold concept can be considered a portal, opening up a new and previously inaccessible way of understanding, interpreting, or viewing something without which the learner cannot progress" (p. 3). For example, with regard to writing skills, a threshold concept might be the notion of situatedness—the idea that there is not one universal rule for how to write [16, n.p.]. Wardle and Downes [16] suggested that helping students understand this concept allows them to realize that writing is less about following rules that apply across contexts and more about having the skills to analyze a rhetorical situation and adapt one's writing accordingly. The flexibility to adapt one's writing requires an understanding of what style of writing is appropriate in any particular situation. Educational psychologists refer to this flexibility as conditional knowledge or the ability to judge what knowledge and skills to use in a particular situation [9,17].

When it comes to transfer or application of writing skills to new contexts, prior knowledge about writing can be a "double-edged sword." On the one hand, existing knowledge can serve as base to build on. On the other hand, inaccurate, inappropriate, or insufficient prior knowledge can interfere with learning [18]. These kinds of prior knowledge, or misconceptions that interfere with new learning, often persist despite instruction. Fisher, Frey, and Lapp [19] explained, "Students often possess misconceptions that negatively influence their learning, and teachers must take note of these. Misconceptions are different from factual errors, which may be corrected easily enough when students are presented with new information. Misconceptions are fundamental errors in reasoning and have a cascading effect that influences subsequent learning"

[19, p. 25]. In science education, there is considerable research on misconceptions, including the sources of students' misconceptions. Misconceptions about scientific topics have been shown to arise from many sources, including what students learn through limited observations and personal experiences, textbooks, and prior instruction [20, 21]. In one survey of students' misconceptions about psychology topics, students attributed their incorrect responses to the media, personal experiences, reading, and classroom learning [22]. In literacy, misconceptions may arise from misunderstanding vocabulary, especially technical terms [19].

Although there is little research about the *sources* of students' misconceptions about writing, a significant body of research in the field of composition studies has examined common errors in students' writing, including Connors and Lunsford's 1988 [23] national comparative study of formal errors in composition papers and Lunsford and Lunsford's [24] replication of the study twenty-two years later. Both studies describe the most common errors or error patterns found in first-year writing papers. Other research studies, in composition studies and beyond, investigate the writing errors of specific populations of students, such as international college students [25] or basic writers [26]. Other researchers, instead, have explored discipline-specific writing mistakes, typically examining one particular writing assignment rather than employing a longitudinal study design [6, 27]. This body of literature generally focuses on sentence-level grammar and usage issues, such as spelling mistakes, subject-verb agreement errors, or comma errors—or sometimes, matters of style, such as unclear pronoun referents and overuse of passive voice [28] Some other researchers in composition studies have analyzed students' writing for higher-order concerns, such as audience awareness, organization, and use of evidence [29].

In the discipline of engineering, Amare and Brammer [6] compared how students, engineering faculty, and engineering practitioners evaluated the quality of engineering memos. Their study examined higher-order concerns, such as audience awareness, as well as style and mechanics. In another study in the field of civil engineering, Conrad [7] examined the use of passives and impersonal style features in 170 practitioner reports, journal articles, and student reports, concluding "that overall, engineering texts have a frequent use of impersonal style features, but practitioners use far less compared to journal articles and student reports" 17, p. 38]. Kumari [30] studied students pursuing engineering courses in their third year, examining their information literacy skills and higher-order thinking skills. Kumari concluded that it was necessary to engage students in the "cognitive processes of writing" such as defining the rhetorical situation, setting writing goals, and organizing ideas" [30]. In another study, Fries et al. [31] found that students' grammar, spelling, and organization improved when they participated in industry-sponsored capstone projects versus simply doing design projects as case studies for a class.

Educational psychologists who study writing are concerned with the cognitive processes writers engage as they write, such as how writers use resources flexibly and in varying ways [32]. Contemporary psychological theory posits that writing (and learning) takes place in a socio-cultural context. In this view, writing is simultaneously shaped by the community and the individual differences of those in who compose writing within the particular cultural context [33]. Graham acknowledges that some writing communities emphasize the explicit teaching of writing skills, while others expects students will acquire writing skills by participating in community activities. Others, as in engineering expect students to transfer skills from one context to another. Graham cautions that while some general skills are transferable, others are not, such as those tied to a specific context. Graham's model emphasizes communication and the reader, much in the same way engineering students must learn to communicate to particular audiences. Graham calls for more dialog and research among scholars who study writing with the hope that such work will begin to blend multiple perspectives on writing.

In the field of composition studies, research on writing has identified common errors, and studies in engineering have suggested some of the challenges engineering students face as they attempt to master the stylistic features of technical writing. Few studies, however, have followed students' performance on a single genre over an extended period of time, and even fewer have examined the sources or origination of these errors. Our study bridges this gap by showing the types of errors that persist over time within the engineering memo genre and uncovering insights into students' thinking about why they make certain errors or cling to certain beliefs and writing practices. As such, our study addresses two important areas by examining what types of higher-order and lower-order writing errors persist over time, as well as revealing how prior writing knowledge and/or instruction impacts the possibility of transfer from one context to another.

Context

This study was conducted within a writing program for undergraduate engineering students at the University of New Haven. The Project to Integrate Technical Communication Habits (PITCH) is an innovative approach for developing students' technical communication skills across all the engineering and computer science programs [5]. One critical feature of this program is the integration of required communication products in designated courses throughout all four years of the engineering curriculum, beginning with technical memoranda in the first and second year courses. The expectation is that engineering students will acquire technical communication skills at the same time they learn engineering content. In engineering coursework, students apply writing skills in authentic writing tasks typically required of engineers in the workplace.

To promote the implementation of this integrative approach, an educator with expertise in writing pedagogy has been assigned to the College of Engineering to support students and faculty in the integration of writing across the engineering curriculum. One means of support and coordination is promoting the appropriate use of online resources available to students and faculty, including guidelines for reports and data displays, rubrics, and a common textbook focused on technical communication traits [34]. The textbook provides a foundation in technical writing presented as "COPE" traits, i.e., clarity, organization, precision, and economy (concision). To provide a common understanding of these technical communication traits, the College's writing instructor (second author) teaches a first-year online introductory course in technical writing, Short Engineering Reports (SER). In SER, in addition to learning about stylistic traits that distinguish technical writing from other styles, students learn to plan, write and revise technical memoranda. Students are expected to apply this knowledge and skills, when they compose the two memoranda assigned in the co-requisite engineering course, Methods of Engineering Analysis (MEA). After the students submit the first memo to their engineering instructors, the SER instructor provides students feedback and assigns revision tasks. Students also learn to self and peer review their memos, using an analytic "feedback" rubric that provides descriptors on 5 criteria: (1) technical memorandum structure/genre, (2) audience, (3) response to client's request, (4) visual communication, and (5) COPE traits. The rubric (see Appendix A) is designed to provide students an indicator of where they are in developing writing skills (i.e., novice, intermediate, or advanced). Students are expected to apply their technical writing skills to a second memo assigned at the end of MEA and then to two additional memos assigned in a second year engineering course, Introduction to Modeling of Engineering Systems (IMES), as well as to any other memos assigned throughout their program.

The sample of memos in the study reported here were drawn from MEA and IMES assignments. The assignments were cast in authentic situations as “requests for information” from supervisors or clients. A description of these requests follow:

- Project 1 “Pipeline” Memo (MEA): An engineering supervisor, Mr. Holm requests a recommendation for the design and specifications for an oil pipeline, given certain constraints.
- Project 2 “Cell Tower” Memo (MEA): A Public Relations Director requests recommendations for siting a new cell tower in a location that maximizes the number of potential customers that can be served.
- Project 3 “Solids” Memo (IMES): Mr. Graytor, the Plant Engineer, requests advice on a solids separation process, including a model that predicts behavior over time for a transient process.
- Project 4 “Pump System” Memo (IMES): The Chairman of the Public Works Authority requests a preliminary design for a pump system to fill a roof-top water tank from a large reservoir.

Methods

The purpose of this exploratory study was to identify engineering students’ common errors and misconceptions about technical writing and to investigate the sources of these misconceptions. Two research questions guided the study:

1. Which kinds of errors persisted over time across four memos?
2. What did students report as reasons for making these kinds of errors?

The mixed method study included a quantitative longitudinal component, which followed students through two required engineering courses, from the spring to the following fall semester. In this component, we scored and analyzed four memos, two written in first-year course, and two written in the second-year course. The qualitative component, an interview study, was designed to uncover students’ thinking about common and persistent errors identified in the longitudinal analysis and prompt students to articulate the sources of errors, such as a literal adherence to models, or the inappropriate application of a previously learned writing style (e.g., elaborated description, or a narrative writing style) to technical communication.

The student sample was recruited from two sections of IMES, taught by the first author. All 34 students taking IMES were invited to participate in the study, 12 of whom (8 males and 4 females) agreed to participate by contributing their memoranda to the study. Of these students, only 7 (4 males and 3 females) participated in the interviews, despite efforts to schedule the interviews at different times to accommodate students’ busy schedules.

The four technical memoranda were scored and analyzed using a research rubric with 5 criteria, corresponding to instructional topics in SER: (1) technical memorandum (structure), (2) awareness of the memo's audience, purpose, and style appropriate for technical communication, (3) response to client's or supervisor's request for information, (4) visual communication, and (5) technical writing traits (i.e., clarity, organization, precision, and concision). This research rubric (see Appendix A) was similar to the formative assessment rubric used to provide feedback in SER, except the research rubric assigned a score for each criterion, on a 5 point Likert scale from novice (with significant errors) to proficient (with few or no errors), with a score of 3 as average. Thus the highest possible total score on the memorandum was 25. The memos were scored by the SER writing instructor who was familiar with all the memo assignments. The University's Writing Across the Curriculum Director (third author) independently scored the memos for writing traits and audience. Discrepant score points were averaged. In the scoring process, the rubric was refined. For example, descriptors were illustrated with examples to promote consistency among scorers who might use the rubric for future research.

In addition to scoring the memo on rubric criteria, the IMES engineering instructor independently scored the Project 3 and Project 4 memos. Scores were based on content accuracy (e.g., results, descriptions of calculations, spreadsheets) as well as the writer's ability to communicate content accurately within the structure of a memorandum. The maximum score was 25 to facilitate comparison with the research rubric scores.

To examine students' progress over time, longitudinal analysis focused on mean scores across memos, including mean scores on each criterion. Analysis included comparisons of gains from memo 1 to memo 2 (written in MEA), gains from memo 2 to memo 3 (written in two different engineering courses), and gains from memo 3 to 4 (written in IMES). A paired two-sample t-test was used to analyze gains from one memo to the the next and between memo 1 and memo 3 (the first memo in each course).

The interviews were conducted at the beginning of the IMES course, after students had written two memos in MEA and before they wrote the two memos assigned in IMES). A two-part interview was conducted with 7 students. The first part of the interview focused on the second memorandum written in MEA. Because this memo assignment was submitted at the end of a course as a final assessment, students had not received feedback on the memo. Thus, the first part of the interview was a kind of "writing conference" informed by dynamic assessment [35]. Dynamic assessment is used in educational settings to diagnose students' level of understanding and determine where instruction should begin [36]. Dynamic assessment can also provide insight into the nature of an individual's learning and reasoning [35]. Typically, dynamic assessment interview protocols are constructed to assess students' understanding through a series of graduated prompts from least to most intrusive [36]. This approach has been used with English language learners both to diagnose writing errors and to provide specific feedback to move them to higher levels of performance [37].

In our study, participants were asked to identify their strengths and weaknesses and provide specific examples from the memo. They were also asked how they might revise the weak areas they identified. The researchers were thus able to identify their level of understanding, ranging from inability to identify strengths and weaknesses, to inability to support their judgments with examples, and to inability to revise or correct errors they noted. When students were unable to explain why their writing needed improvement, the interview revealed students' misconceptions or lack or knowledge (e.g., "I didn't know). Put another way, the purpose of this writing conference was to identify the student's zone of proximal development, as described by Vygotsky [38]. Researchers then began an instructional conversation at the point where students needed it.

The second part of the interview consisted of a semi-structured protocol. In this interview, students were asked to think about the kinds of errors discussed in the first part of the interview and to offer their ideas about why engineering students might make those kinds of errors. The interview also probed for students' understanding of the writing process, how technical writing differed from other genres, and what made writing especially challenging for engineering students.

After the interviews were completed, the engineering instructor invited the writing instructor to present a guest lecture in both sections of IMES. In this lecture based on preliminary findings about common errors, the writing instructor reviewed technical communication traits and the purpose and structure of technical memoranda. Students then engaged in a discussion of exemplars and non-exemplars. One student commented, "We learned this in SER, but it was good to review and good to know that what we learned in SER is still expected of us in IMES."

The interviews were transcribed and coded for errors and misconceptions, defined as inaccurate or insufficient prior knowledge that interferes with new learning [18]. Coding began with broad categories of writing practices that might interfere with the acquisition and appropriate application of technical writing skills. These categories included colloquialisms, literal or inappropriate use of models in textbooks or guidelines, genre-based writing practices inappropriate for technical memos, or application of previously learned stylistic conventions from narrative or essay writing to technical writing. The researchers then continued to search the corpus of data for examples of these practices. Analysis of the second part of the interviews focused on identifying underlying reasons for errors and misconceptions.

Results of the Longitudinal Analysis

The scored memos revealed patterns of strengths and weaknesses among engineering students. Table 1 shows the mean scores (on a 5-point scale) on each criterion across all four memos. The weakest area for these students was visual communication. In interviews, students repeatedly explained that visual communication was relatively new to them (e.g., "In high school, we never had to put in graphs"). The strongest area was response to the client's request. This may be because this is emphasized in the "world-of-work" memo task or it may be because of the emphasis placed on "response to assignment" in both SER and MEA courses. There is a pattern of gradual improvement from memo 1 to 3 and but mean scores across all criteria show no gain or a loss in memo 4. Further analysis of total scores revealed a similar pattern.

Table 1. Memo Scores (M ± SD) by Rubric Criteria

	Memo Genre	Response to Request	Audience/ Style	Visual Communication	COPE Traits
Memo No.	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
1 (Pipeline)	3.08 ± .90	3.50 ± .67	3.08 ± .60	1.67 ± .78	3.08 ± .47
2 (Cell Tower)	3.45 ± 1.21	3.91 ± .70	2.95 ± .61	2.73 ± 1.1	3.14 ± .64
3 (Solids)	3.67 ± .78	3.83 ± .72	3.63 ± .68	2.58 ± .90	3.13 ± .53
4 (Pump System)	3.67 ± .78	3.58 ± .90	3.29 ± .58	2.50 ± .90	3.04 ± .66
Memos 1 – 4	3.47 ± .28	3.71 ± .20	3.24 ± .30	2.37 ± .48	3.10 ± .05

The highest possible total score on each memo was 25 (including scores on all 5 rubric criteria). Table 2 shows the total mean rubric scores across 4 memos. Table 2 also shows the engineer's mean grade for technical content for memos 3 and 4. The memo score data show a similar pattern of improvement from memo 1 through memo 3 and a lower mean in memo 4. This might be attributed to the complexity of engineering content expected in the memo 4 project, or it may be the timing of the assignment, at the end of the semester, especially given that students reported feeling "rushed." Some students may not have had time to expend effort on the second and fourth memos, assigned at the end of the semester in each class. The standard deviations also support this interpretation, with more variance among the students on the second and fourth memos.

Table 2. Total Mean Score Comparisons for Memos 1 Through 4

	Memo Score	Content Score
Memo No.	Mean ± SD	Mean ± SD
1 (Pipeline)	14.3 ± 2.1	_____
2 (Cell Tower)	15.9 ± 2.8	_____
3 (Solids)	16.8 ± 2.2	20.3 ± 2.
4 (Pump System)	16.1 ± 2.4	19.5 ± 3.8

Further analysis (a paired sample t-test) found that the mean difference (2.5) between memo 1 and memo 3 was statistically significant ($p = .00$), with almost 100 % improvement from baseline memo 1 to the first memo written in the second-year IMES course. This improvement may point to the need for continued guidance (such as the "refresher" lecture in IMES) to maintain gains in technical communication skills.

Another interesting finding from these quantitative data was the close correlation between understanding content and the ability to communicate that content clearly to others. Table 3 shows the engineer's assessment of students' content knowledge as compared with the writers' assessment of communication skills in memos 3 and 4. (Note: MEA instructors' grades were not available for memos 1 and 2.)

Table 3. Pearson's Correlations for Memo 3 and Memo 4

Memo 3 (Solids)		**Memo**	**Content**
Memo	Pearson's *r*	_____	.75
Content	Pearson's *r*		____

Memo 4 (Pump System)		**Memo**	**Content**
Memo	Pearson's *r*	_____	.61
Content	Pearson's *r*		____

Qualitative Results

The results from the qualitative interview study revealed not only engineering students' misconceptions, but also the underlying reasons for these misconceptions. Exploring students' thinking about writing highlighted the particular challenges engineering students face as they learn to write memos set in authentic workplace contexts, including a conflict between "writing everything they know" for an instructor audience and communicating relevant information to the audience of the memo. One common theme that emerged from the data was the challenge of transitioning to a technical communication style, and away from other styles of writing students typically encounter in "school" assignments. A second theme was related to time constraints engineering students face in a crowded curriculum. Finally, the results showed that the writing process itself may be especially challenging for engineering students struggling simultaneously with understanding complex content and learning to communicate that content.

Old Habits Die Hard

The transition to a technical writing style proved challenging for students. The differences were salient to the students we interviewed. We found that students could articulate the differences but had to "remind themselves" that technical writing was different from "English class." Students explained how they gradually made the transition, starting with the traits, such as concision, that actually made their work easier:

- You don't need fluff in middle. It should be clear and concise. I tend to fluff it up and so that was easier for writing memos.
- Writing less (is a difference). Whatever the problem was, I'd write double [in other classes], for the word count. Now I understand why we need to cut it down.

- In English, he wanted us to write a lot and be very descriptive. But for tech memos – there's no fluff. I thought I had to write so much, but now I know to try to do it in one sentence. I thought it had to be so long.

Other "COPE" traits, such as organization and precision, were more difficult to apply:

- You have to be professional about it and use precise wording but we rush through it.
- Just trying to follow the COPE. We learned it in your course (SER) but that was always hard for me to follow the guidelines. That's the first time we learned this, until we had this course with you.
- (It is difficult to) take all info and put it in a memo, . . . with only a few sentences per paragraph.

As shown in the quantitative data, audience was another point of confusion for students. Students struggled to reconcile writing to an authentic workplace audience with writing to show their engineering instructors what they had learned. For example, one student claimed that he considered audience but reported that other students found it difficult to break an old habit: "Knowing it was project manager helped me write. He gave me the job so I crunch numbers and (know) he just wants the results, but some students have the habit of showing work like math." Another student's memo described the advantages of using Excel, despite the student's awareness of audience. The student reasoned: "I don't believe she (Public Relations Director) would even know what system I used, but using Excel is better than hand calculations." Other students explained that students thought it important to write detailed descriptions because they had to do these calculations in their engineering projects. A common error noted in the cell tower memo was reporting calculated population density in "fractions of people." As one student explained, the emphasis on calculations in Excel spreadsheets, paradoxically led students to ignore what they learned about significant figures and units: "We do calculations and get results with 5 decimals, so I feel like it is important since we did the calculations to put in all the numbers."

For students, one especially salient difference between technical writing and other styles of writing was the "fact-based" nature of technical reports:

- In English, there are no numbers, just proposals to present ideas to be considered by government officials, like writing an argument for something. But in engineering, you (write to) show data to your boss or engineering company.
- In writing for English, depending on what the assignment is, that could be your own thoughts and views and opinions. And you can make that into a writing piece. But for technical writing, it's more fact-based. You need data.

The need to show "data" created other challenges for students. In this case, students attributed these challenges to the lack of experience with visual communication in previous courses. As these students' comments illustrate, high school was one common source of misconceptions.

- One of the problems when I first came to this school was visual communication; it was a lack of experience; we never had to do that in high school. But tech memos must be more professional. You have to go back to format the picture, the size, and (make sure there is not) too much, too little, or irrelevant data.

- In high school science, there were no graphs, not tables, no excel, just words. You have to learn how to write what you calculated, in words, which is very difficult.

On the other hand, taking standardized tests seemed to be a source of information about visual communication. One student explained: "Referring to tables and graphs (is different). Like they'd say, if it's an article, just put brackets around it, like the author's name. But graphs you just say 'This figure …' And for some actual testing, they say like 'refer to graph # 3. Like in tests, they'd say, 'as shown in graph 3'. This confusion about the distinction between tables and figures was common among the interview participants. As the student explained, students see differing forms and styles of visual communication, including in the testing situation this student described.

Students recalled other advice they had been given in pre-college education. They articulated how they tried to reconcile old advice with new and sometimes conflicting advice about good writing habits:

- Most people (teachers) would say to keep it in your head, just write it. But that's not a good way. You have to talk about it. Bunch of teachers say write whatever comes out in your head, just don't say it out loud. I can see they meant like "Don't bother your neighbor."
- In English, they told us have someone else go back and read it and see where flaws are. You think some things sound natural but when someone else reads it, it doesn't sound right. But in other classes, they rarely asked us to read it aloud.

When students were asked about differences in technical memo structure and the typical "five-paragraph essay," their explanations revealed an incomplete understanding of the summary (or abstract) that typically serves as the memo's first paragraph, in place of the essay's "introductory" paragraph. That is, the first paragraph in a technical memo is intended to provide the reader with a summary of the entire memo, including the results. One student claimed that there was no difference between the essay and the memo: "It's just the same structure as learned in high school. The intro paragraph gives main topics and small points, and body gives details, and the conclusion wraps it up."

Clearly prior knowledge can be a boon or a blessing in acquiring technical writing habits. Even when there are similarities, students do not always understand how prior knowledge relates to new learning. We found that the interviews both revealed gaps in prior knowledge at the same time that the dynamic assessment protocol afforded opportunities for students to make connections between old and new learning and begin to rethink their old habits.

Short Cuts

The issue of time was a recurring theme in the interviews. Students noted they not only the lacked time to write and revise memo assignments but perhaps more important, they noted the need for time to synthesize and internalize the content before writing. Time constraints not only accounted for careless errors but also tended to promote approaches to writing that led to persistent errors over time.

Students cited the lack of time as a reason for producing unrevised and unedited memos. Students reported feeling "rushed" with no time to "look it over" or get a peer review. One student self-evaluated her memo, and explained that the appendix was weak because she "threw stuff in there at the last minute" and did not take the time to refer to the Appendix in the memo. One student explained how time made a difference in the quality of the writing: "I know for this one (cell tower memo) we struggled with data. That was the hardest part. It was the fact that we had more time and help with pipeline. This one was a little rushed. We started writing bits and pieces of memo while we were still doing the data." When asked about revision, one student reported: "It depends on how much time I have. If I have the time, I'd read it and make sure it makes sense, and then fix it."

The nature of engineering programs leaves little time for guided practice in writing strategies or thoughtful application of the writing process. Students typically are assigned writing for homework and encouraged to engage in peer reviews on their own time. One student described an English composition class that provided time for peer review in class. She noted, however, that some students did not take full advantage of the course structure: "We brought in rough draft writing and did peer reviews. But it wasn't actually due until a few days later. I always brought in a draft but some students did not have a draft. Some kids wouldn't do it. I'd go, 'You're supposed to have the entire essay done.' But some didn't. Maybe just an outline done. And some did not even start it until after class that day. So you have to take that in consideration, that some kids won't do it."

One interesting finding was students' use of previously written memos as templates or "short cuts." For example, students recycled memos, keeping the same headings, whether or not they applied to the memo. This may have accounted for a lower than expected mean (3.47) on the memo structure criterion, a criterion that should have been easy to master. For example, students carried over headings from lab reports written in other classes. Headings such as theory, results, or discussion, were common across all four memos and this error persisted from memo to memo. These memos were scored at 3 or below on memo structure. One student explained the reason he used "experiment" as a paragraph heading: "Yeah, I took chem class where I had to do that; it's a pattern, I guess." The recycling of headings may be a "short cut" to save time but it may also indicate a misconception about memo genre and how it differs from lab reports. Or, it may represent an unsophisticated organizational pattern that relies primarily on headings, often replacing forecast (topic) statements in paragraphs.

Students not only recycled headings but used their own writing to incorporate "sentence starters" from previous memos. For example, one student began the summary paragraph for the solids memo the same way he started the cell tower memo changing "This project required information for a cell tower location and power transmitted strength signal" to "This project required calculations to determine the accumulation of solids and water in a storage tank." In a similar way, the student recycled the first sentence of the main body in the cell tower memo, changing "This project consisted of the importance of two things" to "The project consisted of the importance of two findings" in the solids memo. Students may take this recycling short cut because they need help "getting started," as shown in this student's comment: "Usually I just write the beginning part first, just to get something down on paper, so it uses up about a quarter of the page. I think I've done something, I'm already half way there." For engineering students, writing is work to “get done” and perhaps not viewed as important as “engineering work.” This comment also shows a lingering misconception about length and the habit of writing to meet a required minimum page length or word count.

Writing Processes that Accommodate Content Integration

Engineers are pressed to communicate complex content to a variety of audiences, in clear and precise language. To do so, they must have a deep understanding of content. In addition to the common misconception about revision and editing (“Revision is checking grammar”), students held different notions about the writing process itself. Engaging in the writing process (planning, drafting, revising, and editing) or using the writing process as a recursive process proved challenging and may have led some students to invent their own strategies for accomplishing technical writing tasks.

Apparently, the press to “get started” and “finish” may have led some students to skip planning. When asked what they did first in the process, one student replied “Start writing.” Another student reported, “I did not think about writing until end of all calculations.” The complexity of content apparently pressed some students to just start writing as a way of crystalizing their ideas. That is, they may have been using writing as a tool for thinking [39]. One student explained, “It’s hard not being sure what I’m doing. I start to write the summary to see if I know what I’m doing.” Given the nature of a summary paragraph (i.e., an abstracts), it may not be appropriate to start writing the summary first, without remembering they may need to go back to revise the summary, as they understand and describe the content in the main body. This is an example of a linear approach that interferes with good revision habits.

Getting a “grip on content” first, before starting to write, was important to engineering students. One student explained, “When I first start, I think what am I doing? I have no idea. When I finally get a grip on what I am doing, I say, OK this makes sense. I make sure I do all the data first. None of the memo yet.” She continued, expressing appreciation for her engineering instructor who “made us have all the data and discuss it in class before we wrote the memo. We finished most if not all the hard work of doing the data. That way I can say, ‘Oh this makes sense. I don’t have to guess.’’

Other students took a non-linear approach, thinking about the memo to guide project work and then returning to the memo assignment to guide writing. For example, one student described the process, “I try to find what the person (audience) asks me for. After the team does the calculations, then I go back to the assignment and start the memo.” For some students, the writing process was an interactive one. One student described the process: “I do a quick interpretation of data when I finish calculations to see if numbers make sense. Then I put more thought in when I write the memo.”

Another student invented her own methods of planning: “I had no idea what I was doing, from the equations. I did not do well on the exams. But when I was taking notes in that class, I would start writing words above each cell, like what it was, like what I had done, and that transferred to other classes, and I just kept going.” As Klein and Kirkpatrick [39] argue, writing is a tool for thinking about content and engineering courses might profitably embed informal writing activities, such as requiring students to take notes by adding "textboxes" to the Excel spreadsheets. This is an example of integration of writing and content.

Although students had learned about the writing process in SER and in English composition, not all students used the process. This may be because of the time constraints students noted. Future research is needed to investigate why engineering students tend not to use the writing process – a practice that they *should* transfer to other writing situations.

One student summed up the integral relationship between content knowledge and communication of content: "Calculations and writing are both about the same in terms of difficulty and importance. If you have the right data but do not know how to relay the message, you did all that for nothing. But if you are just good at writing, you could be relaying with high confidence the wrong info. This could be disastrous."

The Writing Challenge

Students tended to view writing as more challenging than math. Repeatedly, students expressed anxiety about writing, with comments such as "getting it over with" suggesting that writing was an unpleasant experience. Engineering students, who may perform better in assessments of quantitative reasoning than on measures of verbal ability, may think of themselves as "good at math" and "poor at writing." For example, one student explained, "I cannot express it (in words); numbers mean more." Another student claimed, "It's hard to put calculations in words." Another student explained how self-concept impacts learning. "I think kids as they grow up, are just divided between math and English. They just accept that – that they're math people. That's how I grew up. I remember the first time when (an instructor) asked us to write, I was like 'ughhh.' I had no idea. I just made up something. I did not know how to tackle it. I definitely did not try in that class."

Whether students acquire these self-concepts through exposure to stereotypes or through unpleasant experiences in writing (e.g., "red pencil" comments and poor grades), they interfere with students' acquisition of technical communication habits and impede writing fluency, especially critical in a career where so much rests on the ability to communicate complex concepts accurately and clearly. As demonstrated in one review of the research on self-efficacy and writing achievement [40], self-efficacy may influence students' choice of majors and thus engineering students may enter college choosing engineering because they think of themselves as "better at science and math." Students typically enter school believing they can write but their self-confidence then declines, leading Pajares [40] to conclude that students' confidence as writers is not nurtured as students progress through the grades. Although there is considerable research on math anxiety, there is less research on self-efficacy in writing, especially among engineering students. As Pajares [40] argues, educators should pay more attentions to students' self-concepts and help them understand how self-efficacy influences achievement.

Conclusion

Understanding what students know about writing, why students make the errors they do, and why writing is cognitively challenging will help educators support students' writing development. Especially in the case of technical communication, learning to write may involve putting aside previously acquired habits and misconceptions that interfere with the acquisition of new skills. Perhaps the most damaging "misconception" engineering students bring to technical writing is the notion that engineering students are "better at math" and "poor at writing." For students who think of themselves as "better at math," learning to write (and enjoy writing) must be nurtured.

Educators who approach writing from a multi-disciplinary perspective may be better able to see writing as their students experience it, as they move from classroom to classroom. According to Graham's model [33], "As students participate in a writing community, they acquire one or more identities as a writer, learn more about their audiences and particular purposes for writing, . . . obtain typified actions for carrying out writing tasks, gain facility for using specific writing tools, learn how to work with others, and amass knowledge about how the writing community operates" [33, p.274]. The same model applies to educators from different disciplines who work together to understand each other's perspectives and writing communities. Graham [33] also cautions, however, that some writing skills are situation-specific and cannot be transferred. Our study confirms that idea as students repeatedly explained that writing based on "facts" or their own calculations (i.e., empirical data) was much different than writing arguments based on opinions or secondary sources. These findings support the integration of writing into engineering coursework, especially when the writing "assignments" are cast in a workplace context and supported by instruction and time to improve both writing skills and self-concept.

An integrated approach to teaching writing to engineering students can bring both students and faculty into writing communities where individuals might learn from each other. In particular, this approach may afford opportunities for further study of which particular skills are transferable and which skills are context-bound and potentially change writing pedagogy in both English and engineering courses. For example, more research on how engineering students use or adapt the writing process to accommodate time constraints might lead to recommendations for teaching students to adapt their writing process for particular disciplinary contexts and situations. Similarly, collaborative research may lead disciplinary faculty to an understanding of the need to allow extended time for writing and the thoughtful integration of empirical data into writing products. Interdisciplinary work, together with the integration of writing into engineering courses has the potential to strengthen both understanding of content and the acquisition and application of technical writing skills.

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APPENDIX A: SCORING RUBRIC

<table>
<tr><th></th><th>Novice

(1)</th><th>(2)</th><th>Apprentice

(3)</th><th>(4)</th><th>Practitioner

(5)</th></tr>
<tr><td>I. Technical Memo Genre</td><td><u>Memo structure</u> is not evident</td><td></td><td>Basic <u>memo structure</u> is evident but some elements of the memo are incomplete, and/or improperly formatted:
Heading
Summary Paragraph
Main Body
Conclusion</td><td></td><td><u>All</u> structural elements of the technical memo are included and properly formatted:
Heading includes TO, FROM, DATE, and SUBJECT lines.
Subject Line focuses the reader's attention on the specific topic of the memo.</td></tr>
<tr><td></td><td><u>Summary Paragraph</u> is inappropriate for a technical memo (e.g., reads like an "essay")</td><td></td><td><u>Summary Paragraph</u> does not include sufficient information:
to orient the reader to the purpose of the memo
to provide major results, in numeric data, as appropriate.</td><td></td><td><u>Summary Paragraph</u> includes:
overview of the project that orients the reader to the purpose of the memo
major results, expressed in numeric data as appropriate.</td></tr>
<tr><td></td><td><u>Conclusion</u> is missing or not appropriate for a professional written technical memo (e.g., conclusion reads like a "student" assignment).</td><td></td><td><u>Conclusion</u> summarizes the results but does not provide any additional information useful for the client.</td><td></td><td><u>Conclusion</u> summarizes the results and provides information useful to the audience or client, such as recommendations, implications, or qualifications of the results.</td></tr>
</table>

<table>
<tr><td>II. Response to Requests</td><td>Memo does not fully address client requests.</td><td></td><td>Memo addresses client requests (e.g., provides the results the client requested) but does not explain the problem and/or provide details and assumptions needed to support the solution or results.</td><td></td><td>Memo explains the problem and provides details and assumptions needed to support the solution to the problem or answer the questions that the memo addresses.</td></tr>
</table>

Note: When used as a feedback rubric, three score points, novice, apprentice, and proficient (with descriptors) are assigned. When used as research rubric, memos are scored on a 5-point scale, with score points 2 and 4 allowing for scoring that falls between the novice and apprentice, or apprentice and proficient descriptors. The research rubric provides a more precise assessment.

	Novice (1)	(2)	Apprentice (3)	(4)	Practitioner (5)
III. Audience & Style	• Discussion of technical work is inappropriate for the intended audience • Style is not appropriate for technical writing (e.g., colloquial, informal language)		• Discussion of technical work is not sufficient (e.g., too little detail for the audience to understand what was done), or discussion is too detailed • Style is generally appropriate, but includes some colloquial or informal language		• Discussion of technical work is appropriate for the intended audience • Style is appropriate throughout; maintains a professional tone and avoids the use of colloquial or informal language.
IV. Visual Communication	No data displays are included in the memo itself		Data displays are included in the memo but contain errors in one or more areas: • not selected or constructed to focus on major results • includes unnecessary displays • incorrectly referenced • not discussed or interpreted		Data displays convey important results visually and tell a "story" with the data. Data displays are: • constructed to convey important results (e.g., uses highlighting, includes only the most important part of a larger display) • correctly referenced in the memo itself • discussed or interpreted
	Data displays have not been formatted (e.g., presented in an Excel sheet format)		Data displays contain format errors, in one or more areas ; incomplete labeling interferes with audience understanding		Data displays are correctly formatted.

	Novice **(1)**	**(2)**	**Apprentice** **(3)**	**(4)**	**Practitioner** **(5)**
V. **Technical Communication** **Traits***	Clarity: • Fails to use clear and simple sentences • Constructs sentences with misplaced modifiers throughout • Uses terms inconsistently throughout		Clarity: • Attempts to use clear and simple sentences • Does not always avoid misplaced modifiers • Does not always use terms consistently		Clarity: • Uses clear and simple sentences • Avoids misplaced modifiers • Keeps subjects and verbs in proximity • Uses terms consistently
	Organization: • Fails to present information in cohesive paragraphs • Fails to group and order information • Fails to use forecast and echo strategies		Organization: • Attempts to organize information into paragraphs • Attempts to group and order information • Does not use forecast and echo strategies effectively		Organization: • Organizes information into cohesive paragraphs • Groups and orders information logically • Uses forecast and echo strategies
	Precision: • Conveys information imprecisely • Uses vague terms • Uses imprecise descriptors		Precision: • Conveys some information precisely • Does not always use exact terms • Does not always use precise modifiers		Precision: • Conveys information precisely • Uses exact terms • Uses precise modifiers
	Economy: • Contains superfluous words, phrases, and sentences. • Repeats information		Economy: • Tends to use more words than necessary to convey information		• Economy: • Is concise (brief and to the point) • Avoids unnecessary words, phrases, and sentences

*Adams, David J. (2014). *Clarity, Organization, Precision, Economy: A Technical Writing Guide for Engineers*. West Haven, CT: University of New Haven.