

Supporting Students' Disciplinary Writing in Engineering Education*

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As demands for research productivity increase, engineering faculty, particularly untenured junior faculty, must efficiently expedite the development of their graduate students' disciplinary writing skills. This paper reports on the outcomes of a semester-long graduate course offered to facilitate engineering students' production of a manuscript ready, or near ready, for submission to a peer-reviewed engineering journal at the end of the semester. Course content addressed the purpose of and information included in each of four sections of a standard engineering research paper. Data generated from course participants and their faculty advisers were used to assess the extent to which course participation resulted in publication submission, textual production in each of four standard article sections, and perceived changes in student writing that was attributable to course participation. Findings suggest implications for policies and practices supporting the development of engineering students as disciplinary writers.

Keywords: academic writing; civil engineering; disciplinary writing instruction; graduate students

1. Introduction

Disciplinary writing in the form of contributions to grant proposals, peer-reviewed journal publications, and conference papers is a natural outcome of graduate engineering students' research activities and is vital to the research productivity of these students' faculty advisers. Most discussion of how to facilitate the development of written communication, however, is situated within undergraduate engineering education (e.g., [1–3]) where 'an ability to communicate effectively' is required for accrediting engineering programs [4]. The integration of writing and engineering curricula is commonly found in design courses [5], but undergraduate programs that include writing throughout their engineering curricula (e.g. [6]) are rare. Further, students' first exposure to disciplinary writing is often circumscribed within carefully managed laboratory experiments with pre-determined outcomes [7]. Even those undergraduates who have conducted research beyond the classroom rarely couple their research efforts with disciplinary writing [8]. Thus, while students may possess depth and breadth in content knowledge and technical expertise, many enter graduate programs with limited understanding of disciplinary writing and publication processes [9].

Graduate students typically learn how to write

for their discipline through intensive hands-on guidance from their faculty mentor [8, 10]. Yet, while graduate mentoring is prized among many engineering faculty, individual guidance in the basic structure of and process for generating disciplinary writing is laborious and can greatly slow faculty research productivity. Other challenges await faculty who seek to support their students' development as disciplinary writers. Faculty may lack appropriate pedagogical training, as many attended research-intensive doctoral programs [11, 12]. They may struggle to translate their own expertise as a writer into pedagogical guidance that students can follow, as writing expertise is often automated [13]. Candid discussions about pedagogical practices supporting students as disciplinary writers are usually rare within departments, institutions, and even disciplines. Finally, while institutions of higher education may expect faculty to facilitate students' scholarly writing and include it within faculty reward structures, sustained institutional-level support for student writing is usually quite limited.

In response to the above challenges, a semester-long graduate course was offered within the Department of Civil and Environmental Engineering at the University of South Carolina, USA, for the first time in 2012. The desired course outcome was for each student to prepare a manuscript ready, or near ready, for submission to a peer-reviewed engineer-

ing journal at semester's end. The course, *Writing for Publication*, was offered to graduate students on a voluntary basis and was attended weekly for 1.5 hours, with course sessions structured as writing workshops supplemented with presentations and group discussions. The course had three instructors: one was the instructor of record from the Department of Civil and Environmental Engineering and the other two were from the University's College of Education and Office of Research and Graduate Education. Several additional faculty from the Civil and Environmental Engineering Department with student advisees enrolled in the course attended course meetings throughout the semester. Grading was Pass/Fail and based on attendance and class participation.

When course registration opened, the course immediately filled to capacity. Twenty-two graduate students (1 master's degree, 21 doctoral) enrolled in the course, representing the research efforts of nine separate civil engineering professors across four diverse areas of civil engineering (environmental engineering, structural engineering, transportation engineering, and water resources engineering). Mirroring the departments' graduate student population, students in this course were drawn from a broad band of nationalities and demonstrated varying degrees of proficiency with the English language. Six students (27%) were female, with the lower number of females than males reflecting the reality that females are under-represented in STEM disciplines [14]. At the semester's start, students provided self-descriptions of prior writing activities. Responses revealed that 12 students (55%) had coauthored a published or submitted scholarly journal paper, with 10 of these indicating that they had written about half to 'almost the whole thing.' Fifteen (68%) had coauthored a conference paper, while six (27%) reported they had never contributed to either a published/ submitted journal paper or a conference paper.

This study draws on triangulated data sources to report on key student performance outcomes. Specifically, the study investigates: (i) the rate of student progress toward a manuscript ready, or near ready, for submission to a peer-reviewed engineering journal; (ii) the pattern of student progress within each of four common engineering manuscript subsections (Introduction, Methods, Results/Discussion and Conclusions) and (iii) the changes in student writing knowledge and skills perceived to be attributable to class participation. Courses dedicated to writing for publication, although perhaps needed, are relatively rare within the standard graduate engineering education curriculum. Thus, the broader study purpose is to explore the extent to which a semester-long graduate course of this

nature can in fact notably expedite engineering students' development as disciplinary writers.

2. Methods

2.1 Course content, activities, and logistics

To situate the study's methods and results transparently, a description of course content and activities, as well as course logistics, is offered.

Course content addressed the purpose of and information included in each of the four sections of a standard engineering research article (Introduction, Method, Results/Discussion, and Conclusions). Course activities were selected based on available research regarding graduate student developmental trajectories and included locating relevant primary literature [15], creating literature concept maps to organize disciplinary knowledge and identify areas for investigation (e.g., [16]), iteratively honing writing skills through the creation of successively more advanced manuscript drafts [17], creating and presenting meaningful figures (e.g., [18]), and applying rubrics to solicit and provide valuable peer-to-peer feedback [19]. The three co-instructors shared responsibility for presenting material and then facilitating the students' use of this material. Thus, in the first half of each course session, the co-instructors presented an interactive lecture. In the second half, instructors facilitated an informal workshop in which students incorporated the new material into their existing writing practices. Faculty guest speakers were also present at course sessions to offer insight and advice from their own writing experiences. Occasionally, group-based discussions on writing within a specific engineering area were facilitated by students' faculty advisers.

Close attention to logistical coordination between the three co-instructors and the students' faculty advisers was essential to the success of the class. Students selected their topics in consultation with their faculty adviser, and were provided with disciplinary-specific feedback on their writing progress via two mechanisms. First, students were expected to meet regularly with their faculty advisers to discuss their writing progress. Second, each student received peer feedback throughout the semester. As there were multiple students in each disciplinary specialty, students met in specialty groups to provide each other with feedback using a writing rubric [20]. The most senior graduate student in the group was tasked with identifying progress produced from the last workshop session and identifying goals for subsequent writing for each group member. Leveraging the expertise and time of peers in regular workshop sessions, strongly encouraging faculty adviser–student discussion

about writing progress, and welcoming faculty advisers as guest speakers into the classroom allowed the three co-instructors to ensure that an adequate level of technical expertise was available for student efforts across various specialties.

2.2 Data instruments

To address the above areas of investigation, relevant data from following three sources were collected and analyzed: student-generated manuscripts, pre- and post-course student surveys, and post-course faculty surveys.

2.2.1 Student-generated manuscripts

As noted above, for each student, the expected culminating course assignment was a manuscript ready, or near ready, for submission to a peer-reviewed engineering journal at semester's end. Students selected their manuscript topics in consultation with their research advisers. Thus, the topics were related to the research efforts of nine separate civil engineering professors spanning the diverse areas of environmental engineering, structural engineering, transportation engineering and water resources engineering. Course assignments due at regular intervals throughout the semester supported manuscript development. For example, early in the course, students identified and summarized articles relevant to their topic; this assignment facilitated progress on their manuscripts' Introduction section, as well as enhancing their ability to engage with primary literature in their discipline. Similar assignments supported the development of the Methods, Results/Discussion and Conclusion sections. As manuscript drafts evolved, students received instructor and peer feedback, and some received faculty adviser feedback.

Upon the conclusion of the course, all 22 students submitted a manuscript to the instructors to satisfy course requirements. Each student uploaded their manuscript into *SafeAssign*TM plagiarism software. Use of this software allowed verification that manuscripts reflected students' authentic writing progress. The content of each manuscript was analyzed for overall completeness and a basic level of quality. Both quantity and quality were assessed through percentage completed. Word counts were conducted to quantify the amount of content within each subsection (Introduction, Method, Results/Discussion and Conclusions). In terms of quality, manuscripts deemed as requiring significant revisions from a faculty adviser were rated with a lower percentage completion; manuscripts deemed to require fewer faculty adviser revisions were rated with a high percentage completion. Additional descriptions of percent completion and associated quantity are described in following sections.

2.2.2 Student surveys

Students responded to surveys before, during, and after class participation. Six weeks prior to the start of the course, instructors offered an informal course information session for prospective students. Course schedule, expectations and assignments were detailed. Those intending to enroll completed a brief survey in which they described the type and extent of their experience with writing for publication and presentation at professional conferences. At the course mid-term, students completed a brief survey that doubled as a formative class assessment, identifying topics addressed to date in the course that they perceived that they understood well and those with which they still struggled. Upon course conclusion, students completed an in-depth survey in which they responded to open-ended questions about their writing progress throughout the semester and perceptions of changes in writing knowledge and skills attributable to class participation. Finally, students who reported that they had not submitted their manuscript to a peer-reviewed journal at course completion responded to a follow-up inquiry about manuscript status six months after course completion.

2.2.3 Faculty survey

Faculty advisers responded to a survey administered at course conclusion. The open-ended survey items elicited perceived changes in students' writing knowledge and skills that could be attributed to participation in the course. Faculty advisers of students who did not submit their manuscript to a peer-reviewed journal at course completion responded to a follow-up inquiry about their student's manuscript status six months after course completion.

2.3 Analytic methods

All survey items were open-ended. Student and faculty adviser open-ended survey responses were analyzed in a three-step process. First, responses were categorized according to their relevance to each of the three areas of investigation guiding this study (rate of progress toward manuscript completion, extent of progress in each of four common manuscript sections, and perceived changes in student writing knowledge and skills that could be attributed to course participation). Second, open-ended data were quantified when appropriate to compare the rate and extent of student progress. Third, to provide deeper insight into quantitative results, qualitative analysis of open-ended survey data was achieved through application of a constant comparison approach

[21] in which responses were constantly compared and contrasted to identify emergent themes.

3. Results

The analytic results derived to respond to the overarching question: 'To what extent can a semester-long graduate course about disciplinary writing notably expedite engineering students' development as disciplinary writers?' are presented in this section, specifically targeting the rate of student progress toward manuscript submission, the extent of student progress in each of four sections common in engineering articles, and changes in student writing knowledge and skills perceived to be attributable to class participation.

3.1 What is the rate of progress toward a manuscript ready or near ready for submission undertaken as a course assignment?

The rate of students' progress toward manuscript submission was evaluated at three points in time: upon the start of the course, upon conclusion of the course, and six months after the course conclusion. The progress rate for each of the 22 students at each point in time is displayed in Fig. 1.

At the start of the course, 9 of 22 students (41%) reported no progress toward manuscript completion, while the remainder (13 of 22, 59%) reported limited initial progress, such as completing all

experiments or analysis, formulating an outline, performing the literature review, or writing the Introduction. To quantify these self-reports of initial progress, the first author assigned each a percentage of completion. As examples, a self report of having an outline for the paper was deemed to represent that 5% of the manuscript was completed, one of completing the outline and starting one or two sections (e.g., the Introduction and/or Methods) represented 10 to 15% completed, while one of an outline and solid draft of at least one section (i.e. the Introduction and/or Methods) represented 20% completed.

Upon conclusion of the course, one student had submitted a manuscript for publication; this student's self report of initial progress had been evaluated at 20% completion rate. To quantify all other students' progress toward manuscript completion upon course conclusion, an aggregate percentage for each was derived based on the student's self-reported progress and progress as reported by that student's faculty adviser. In a few cases, the first author adjusted percentages slightly up or down, based on word count and coherence of manuscripts submitted at course-end to provide a consistent basis for comparison.

Of the remaining 21 students who had not submitted a manuscript for publication upon conclusion of the course, three had developed manuscripts evaluated as 'near ready' (75–95% complete) for

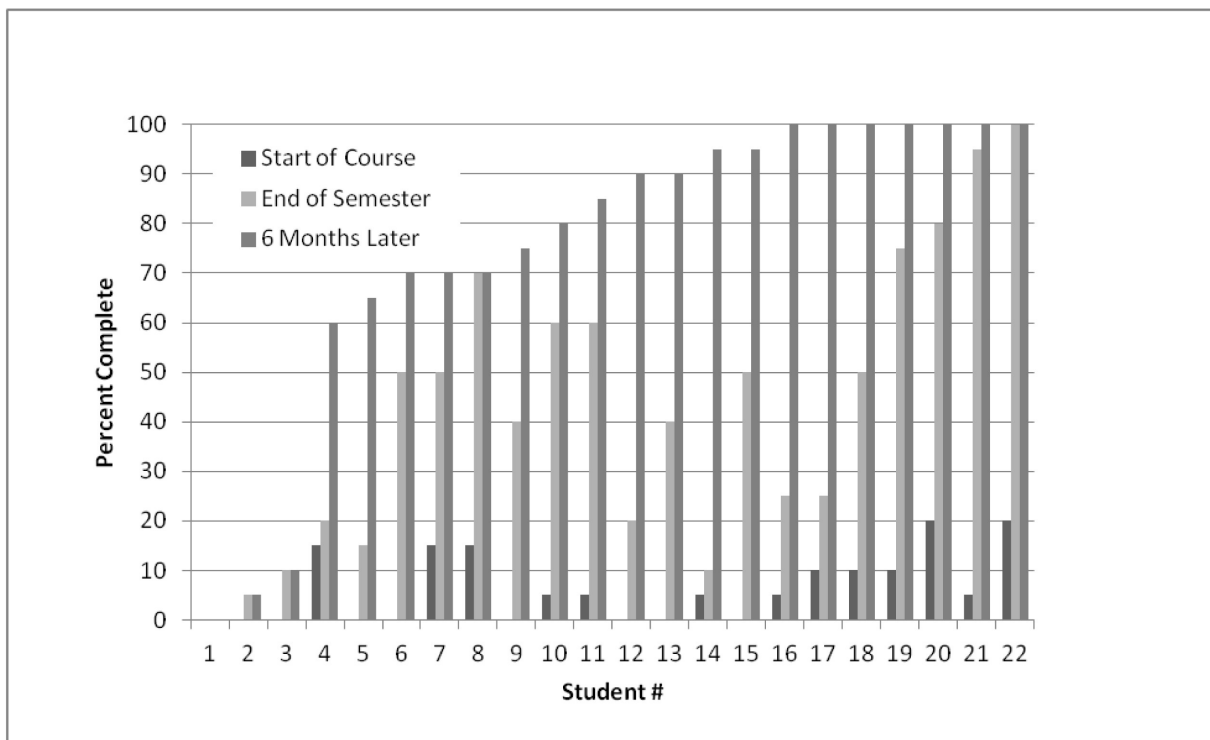


Fig. 1. Progress rate for each student at three points in time: the start of the course, the end of the semester and six months later.

submittal. Here 75% was defined as a paper with an outline, two complete sections (usually the Introduction and Methods) and partial drafts of the remaining sections and 95% was defined as a paper with all sections complete, minor edits or final review from the students faculty adviser needed. Seven students submitted manuscripts evaluated as ‘making good progress’ (50–70% complete), with 50% representing a paper with an outline and a full draft of two sections (usually the Introduction and Methods sections) and 70% representing a paper with two nearly complete sections and partial drafts of one or more remaining sections. Eight students submitted manuscripts evaluated as ‘low to moderate progress’ (10–40%), 10% again representing the completion of an outline and at least one section started, and 40% defined as a paper with an outline and near complete drafts of two sections. The remaining three students made limited to no progress toward manuscript completion upon conclusion of the course.

Six months after the course ended, a query was sent to the 21 students who had reported that they had not submitted a manuscript for publication upon course completion, and another to their faculty advisers to see if students had made additional progress on their manuscripts during the summer months when most could focus solely on their research. Varying degrees of *changes* in progress were seen (e.g., one student made no change in progress from May to October, while another increased progress by 85%). Six additional students had submitted a manuscript for publication, and seven students had produced manuscripts that were evaluated as near ready (75–95% complete) for submittal. Of the remaining 8 students, 5 students had made good progress (50–70% completion). The same three students, as before, continued to make limited to no progress. One of these three students was the only master’s degree student in the class, who appeared to waiver on commitment to continue to a doctoral program. The other two, as will be discussed more fully later, were newly admitted doctoral students and were not expected by their adviser to write prior to completion of experimental research.

3.2 In which manuscript sections did student progress occur, to what extent, and why?

A review of the 22 manuscripts submitted upon course completion revealed textual content in the following sections: Introduction ($n = 20$), Methods ($n = 16$), Results/Discussion ($n = 14$), and Conclusion ($n = 7$). To measure the extent of student progress by section, word counts for each of four manuscript sections were compiled (see Table 1). Total word count, which includes the words in the

Table 1. Word count in each of four manuscript sections

Section	Word count per section		
	Maximum	Average	Median
Introduction	2281	839	724
Methods	3597	1016	635
Results/Discussion	2506	597	283
Conclusions	670	93	0
Total	6544	2463	2356

four tabulated sections as well as additional words in sections not tallied, ranged from 0 to 6544 with a median of 2356 and an average of 2463. The minimum count is 0 for all sections.

The data in Table 1 are textual word counts only and do not include the equivalent word count associated with tables and figures. Note that it is common for journal papers in the field of civil and environmental engineering to have 10 000 maximum word equivalents (includes text, figures and tables) such as the premier journals in the field published by the American Society of Civil Engineers [22]. These papers are about ten pages in length. Certainly, however, manuscript length does vary (e.g., *Environmental Science and Technology* [23] has a maximum word equivalent of 7000 (~7 pages) and *Water Resources Research* [24] publishes manuscripts up to ~15 pages in length.

To obtain an intra-individual view of the extent of student progress, Fig. 2 details word count by total and by section for each student manuscript submitted at semester’s end. The word count for the Introduction section includes the word count for the Background section (often an extended literature review) if presented. Four students had separate Introduction and Background sections, while the remaining included their background information in the Introduction. Further, the Results and Discussion sections were combined in Fig. 2, as, in keeping with the convention that in many engineering journals, Discussion is often a subheading under the main heading Results. Students who presented discussion of their results did so within the Results section. Typical word count for each section varies by discipline and journal. In general, however, within most civil engineering journals, the Results/Discussion section typically contains the most text, while the Conclusion section contains the least text. Not surprisingly, students with higher total word counts were associated with higher percent completion (e.g., students 21 and 22 had approximately 6500 total words for manuscripts that were 95 and 100% complete, respectively, at the end of the semester).

Upon course conclusion, students responded to the questions, ‘Which parts of the paper do you feel are easier to write? Which are harder? Why?’ All but one student responded to these questions, with

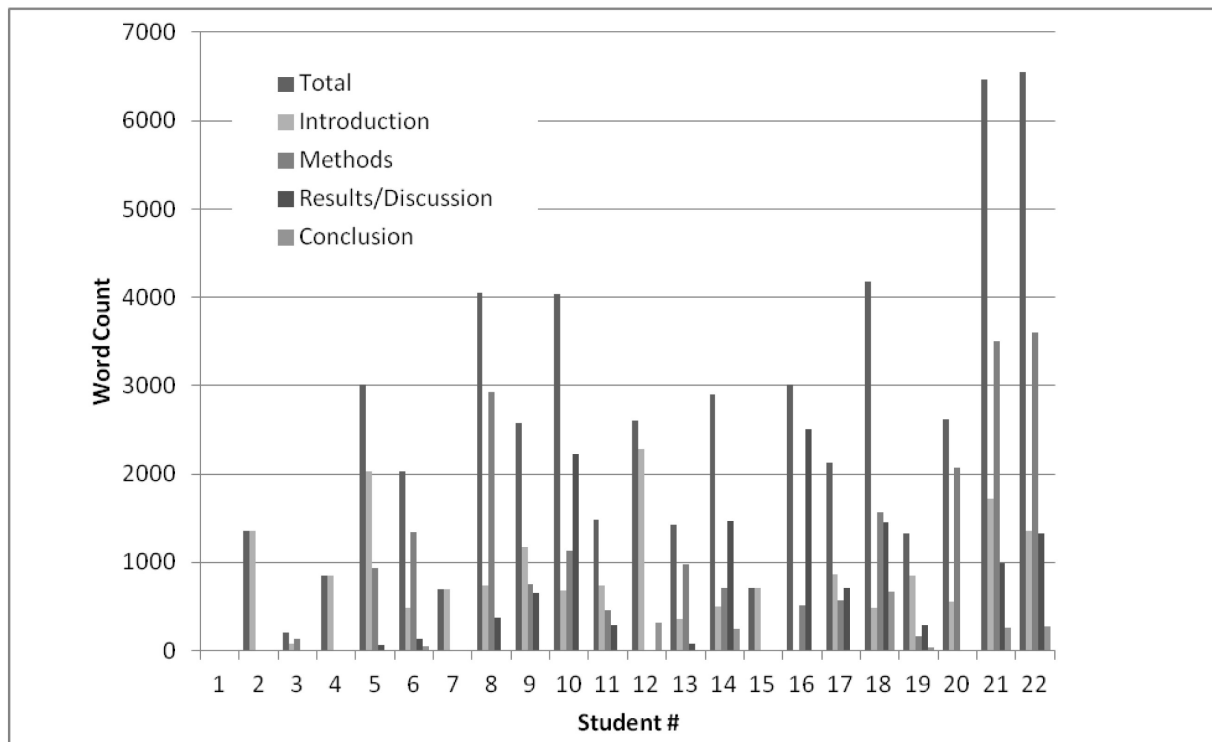


Fig. 2. Word count by total and by section for each student.

many providing extensive commentary. Response patterns were readily apparent, and provide insight into word count variation. With few exceptions, students identified the Introduction section as difficult to write. A common reason offered for this difficulty was the need to conduct an extensive literature review: 'Introduction is difficult because we need to do extensive literature review'; 'Introduction part is harder as it is full of referred works'; 'The introduction . . . is harder because I need to do research on the background of the subject and find out how other people have done in this area'; 'The introduction is harder . . . I need to use a lot of literature for my introduction.' Additionally, many perceived that writing the Introduction posed difficulty because it was, in the words of one student, 'The first contact with the reader.' Another elaborated:

The introduction is the most difficult portion to write . . . this section must be as near to perfect as possible so that a reader will continue with the paper. This is also the most artistic portion of a paper, that isn't always easy for an engineer.

However, one student summarized his perception of writing by saying, 'The hardest [part of writing the paper] is the Introduction, but it is also the most fun.'

Conversely, students almost unanimously identified the Methods section as the easiest to write because it is, in the words of one student, 'my

work.' Others agreed: 'I think methodology part is easier . . . I just need to write what I did for my research'; 'The methodology section is easier . . . because we have done those steps to get our results'; 'The easier part to write is Materials and Methods, because it is describing a procedure that you applied and you know perfectly'; 'The method part is relatively easier to write because once I do the experiments, I will have a pretty good idea on the method of the experiment.'

The Results/Discussion section received mixed reviews from students in terms of ease of writing. Some perceived this section to be relatively easy because, as with Methods, the section contained 'the results of my work' according to one student. Others offered, 'The result part will be difficult if we do not see what information to convey from our experiments' and 'Some irrational results can be difficult to explain, which requires profound understanding about the study.' Few students provided any comments regarding the Conclusion section, with the exception of one who noted, 'The discussion of results and conclusion is still hard.' Finally, one student offered, 'Still all parts [of writing the paper] are hard for me.'

3.3 What are the changes in student writing skills perceived to be attributable to class participation?

Upon course conclusion, students and their faculty advisers independently described changes in student

writing knowledge and skills perceived to be attributed to course participation. Fifteen students (68%) provided clear statements indicating their perception that course participation had improved their writing knowledge and/or skills. Many students perceived they were more skilled at writing a paper's introductory section; however, they still recounted their difficulty in writing other sections:

I have more clear structure on introduction now. But results and discussion is still challenging.

I feel easier when I start writing. The challenges: How to organize data and results and how to make discussion easier for me.

Additionally, several students perceived that they had a clearer sense of the process of disciplinary writing:

I feel more confident. I have learned the standard procedure and where and how to begin. I have also received very useful comments on how to improve the results presented in tables and figures. I think I still need to work on sentence structure and word choice. It is still challenging for me.

Writing is still challenging but following the procedure learned in the class is easing the way.

I think it is much easier now because of the format we learned this semester.

I have better ideas about how I should structure and revise my paper. The process of writing became easier.

Other students perceived that they had improved as disciplinary writers but offered more general comments:

I feel that I have improved during the course of this semester, yet it is definitely challenging as it is my first experience with technical writing.

Writing will always be challenging like anything else as you become a better writer. I believe the class has helped to improve my skills. The more I write and talk about writing, including bouncing ideas off others, [this] will help the writing improve.

My writing skills improved slightly. Still now the writing is challenging because I feel that one paper is not enough to gain all knowledge about writing skills.

Finally, a few students offered responses reflecting ambivalence toward perceived writing improvement attributable to course participation:

I don't feel that my writing has improved. It's no surprise because in my opinion, writing isn't a thing which can be changed merely taking one course in a semester.

I am still working on my first paper so I cannot say anything about improving my writing skills.

Upon course conclusion, faculty advisers were also asked to describe changes in their students' writing that they thought could be attributed to course participation. Their responses generally aligned with those of students, as they suggest that faculty

believed most students (but not all) benefited from course participation in some (but not all) areas needing improvement:

All three [of my students who took the course] appear to have a better understanding of how a paper should be structured and how to write well organized paragraphs. For example, I recently reviewed a draft of a manuscript that [student's name] is working on and it was much better than writing I have seen from him in the past . . . I was impressed with the improvement that I saw in this first draft of his second paper and believe that it can be at least partly attributed to this writing course.

[Student name] and I wrote a paper near the end of last semester and are currently in the process of writing another paper. I see distinct changes. Her ability to write an outline has improved tremendously, as has her organization of the introduction. However, she still needs to work on determining what information to include in the introduction. In addition, her knowledge on the different components of a paper has improved. When writing our last paper, she had a difficult time determining what to include in the methods section. She did not have the same difficulty with the paper we are writing now. She still suffers from a lack of organization in certain areas, such as the results and discussion section. Her results and discussion section has little organization; rather, it is a dump of information, written in a stream of consciousness.

He [student] recalls some of the concepts/tips that were discussed in class. Sometimes he acts upon them before I actually recommend relevant adjustments. In other instances, he realizes he needs help on specific parts.

For [student's name], I have seen that his technical writing has improved significantly. I am currently reviewing his first paper that is almost ready to submit. I believe that the writing class was helpful . . . Since his writing has improved, we have focused on more technical findings compared to previous semesters. For [a second student's name], unfortunately, I haven't seen any noticeable changes. This is presumably because she hasn't been motivated for writing.

Yes. I have definitely seeing an improvement on my students' writing and I believe that they are attributed to the class. I have notice the biggest difference in [student's name]. Now he is not 'afraid of writing', as he was at the beginning of the semester. I attribute this to the class because he now understands that writing is a process and that the final product that one reads in journal publications takes months. He also understands that authors do not write final papers from start to end without editing. In other words writing is different to reading.

4. Discussion

As noted earlier, courses dedicated to writing for publication, although perhaps needed, are relatively rare within the standard graduate engineering education curriculum. Thus, the broad study purpose was to explore the extent to which a semester-long graduate course on writing for publication can in fact notably expedite engineering students' devel-

opment as disciplinary writers. The primary course outcome was for each student to prepare a manuscript ready, or near ready, for submission to a peer-reviewed engineering journal at semester's end. Upon course conclusion, four of 22 students had achieved this outcome. Six months later, an additional ten students were judged to have met this goal. Thus, a total of 14 of 22 (64%) had achieved the primary course outcome six months after course completion. Because the study did not include a control group, it is impossible to know how many of these students would have reached this goal without course participation, although the student and adviser survey responses strongly suggest that it is likely that fewer would have done so.

Whether or not students were ready to submit their manuscript for review at course completion, almost all students achieved some progress. Within six months of the conclusion of the course, over half had made considerable manuscript progress. For many, the Introduction section was the most fully developed, followed by the Methods section; conversely, progress on Results/Discussion and Conclusion sections lagged. In part, these findings may be an artifact of course structure. Material on the purpose and use of primary literature and citations, coupled with instruction on avoiding plagiarism, dominated the first half of the course sessions. Additionally, students were strongly encouraged to have completed data collection prior to course initiation, so many appeared comfortable with describing their data instruments, as well as data collection and analysis techniques. In addition, many conducted research in areas closely related to that of their adviser; as such, a template for describing parts of the Method sections may have existed from previous articles written by the student's adviser. Results and Discussion and the Conclusion sections were consistently the least developed among student manuscripts. Some students did experience experimental difficulty and felt unready to write these sections; others may have simply devoted too much time to polishing the first part of their papers and may have been reluctant to move forward into unfamiliar manuscript territory. Some faculty also suggested that, as student papers were coauthored with them, these sections were the ones on which they (not the students) undertook the majority of the writing.

Although surprisingly scant literature exists on the developmental trajectory of disciplinary writing skills, inquiry into the development of research skills, a closely related area, suggests the existence of a threshold framework. The threshold framework [25] posits that learning occurs when a conceptual threshold is crossed. Once crossed, a student conceptualizes a phenomenon in a new, previously

inaccessible way. Empirical investigations of the pattern of research skill development [15] among graduate students suggest that the ability to situate work in context using primary literature generating testable hypotheses develop relatively early in students' careers. Conversely, other skills, such as forming conclusions from data, appear to form later. Thus, for novice disciplinary writers, such as the majority of students enrolled in this course, it is perhaps not surprising that extended time and effort was spent mastering how to write the Introduction and Method sections, while mastery of other sections lagged.

5. Implications

The results described above directly confront key questions for disciplinary writing courses such as the one under investigation. Is it realistic to expect students to develop a manuscript ready or near ready for submission by semester's end? If not, what are realistic expectations for students' writing progress and development within the structure of a semester-long course? In part, it is difficult to respond to these questions because graduate students are often expected to know how to write before they begin their graduate training. As such, very few graduate-level courses dedicated to writing are offered, outside of those portrayed as remedial courses [26]. Therefore, it is difficult to state with any surety the expectations for outcomes of courses of this nature. On one hand, similar courses have been offered in the humanities; their processes and expected outcomes are showcased in books such as Belcher's *Writing Your Journal Article in 12 Weeks* [17]. Further, writing for publication is a primary goal for engineering graduate students and their advisers. Therefore, one would assume that a course of this nature would only accelerate the already intense faculty adviser–graduate student efforts toward publication already in place.

On the other hand, even Belcher [27], in reflecting on a decade of teaching a writing course for graduate students and junior faculty, acknowledges:

Despite my best efforts to organize the course in the time frame allotted . . . under the heat of strenuous revision, some drafts evaporated, with some students discovering there was no *there* there [emphasis in original] . . . some needed to redo complicated statistical analyses, some couldn't proceed without the input of an AWOL adviser. Others had competing demands on their time—exams, care giving responsibilities, jobs . . . I often found that the 'experiment' of my course had a two- or three-year delay in results.

Student experiences throughout the semester in which they were enrolled in the course aligned with Belcher's above observations. One student

gave birth, while others noted competing obligations for writing time:

I feel like I should stop working in the lab and just focus on reading/writing of a paper. However, in reality it's not possible.

Due to some difficulties in the experiment, I haven't got enough results for the paper.

My research is not ready to write a paper for publishing. This is only my second semester. I need more time to get my data for writing.

Additionally, as noted earlier, one faculty stated that he had observed no notable changes in his student's writing because, he presumed, ' . . . she hasn't been motivated for writing.' Finally, not every student in the course was expected by their adviser to regularly produce written text, perhaps because the adviser believed that writing follows, but does not accompany, research. For example, upon course conclusion, one adviser offered:

I haven't seen too much [writing from my two students enrolled in the class]; they are just starting their research, so until they have produced something, they don't write.

Study findings invite consideration of factors influencing the pace of development as a disciplinary writer. First, like faculty members who struggle to balance an ever expanding workload of teaching, research and service responsibilities with writing productivity [28], a fair number of graduate students struggled to find time to write within their already full schedule. As one student memorably stated upon course conclusion, 'Trying to forcefully compel the students to write in the middle of an ongoing semester with loads of classes tasted bitter.' However, if students do not learn how to turn, in Murray and Newton's words, 'mainstream writing into workload and careers' (p. 552) during graduate school years, it is unlikely that they will be prepared to do so after graduation, regardless of professional path followed [28]. The consequences of low publication productivity are well documented for those who choose the professorial path [29]. However, professional writing knowledge and skills are becoming increasingly critical to career success in engineering, regardless of path followed [30].

Second, these results suggest that enrollment in a disciplinary writing course is perhaps most beneficial for students who are regularly involved in the writing process both in and out of the classroom. For students whose advisers expected them to simultaneously engage in research and writing, the course did appear to expedite writing skill development. For students whose advisers expected them to first engage in research, and then write, the course appeared to offer little benefit. As one student who met the latter criterion noted upon course conclu-

sion, 'Still all parts [of writing the paper] are hard for me.' Additionally, it is questionable if more advanced students with considerable experience publishing and presenting prior to course enrollment benefited as fully as those with less prior experience. Thus, some consideration of the most appropriate timing for course participation within a student's graduate career appears appropriate.

Third, the course was designed to target broader issues, such as the purpose of and information included in each of the four sections of a standard engineering research article, the use of primary literature, and the avoidance of plagiarism. However, a fair number of students expected—and were disappointed not to find—a targeted focus on more limited issues, such as receiving extensive individual assistance with grammatical usage. This raises questions for those who anticipate offering a similar course and for those who study their processes and outcomes. These questions include, 'What is the appropriate course content?'; 'What is the appropriate division of instructional duties between faculty who teach a course on writing and faculty who advise course participants?' and, even, 'At the graduate level, is instruction about disciplinary writing most appropriately situated in a classroom, in a faculty–student mentoring relationship, in a university-sponsored writing center, or somewhere else?' As noted earlier, when guidance in disciplinary writing is only offered at the individual engineering faculty adviser–student level, it can greatly slow faculty research productivity. Thus, if a department wishes to expedite faculty research productivity, a disciplinary writing course, which at least partially eases the burden of individually providing writing guidance and feedback may be an answer, but it comes with attending questions.

6. Limitations

As most faculty who support graduate students' disciplinary writing efforts can attest, 'writing is not a quick fix enterprise' [31, p. 31]. Study results suggest a dedicated course may provide a structured avenue through which disciplinary writing skills can be learned and successively honed. However, while these results are, in general, promising, they should be interpreted with caution. A single administration of a single course cannot provide evidence, no matter how compelling, upon which to base a wholesale change to engineering education curriculum. Instead, the results should be interpreted as a preliminary consideration of how disciplinary writing instruction might be best integrated into engineering departments and programs with unique characteristics and constituencies. A dedicated formal course might be an option for some, while,

for example, a more informal writers' workshop series might provide adequate writing support for others. Further, not all environments can support a class with multiple instructors with differing areas of expertise, and not all can provide a platform around which instructors and faculty advisers have the time or inclination for close and constant dialogue around the topic of student writing. To the extent that the operational conditions underpinning the course described in this study are present, the findings can be used as invitations to invent opportunities to support students' disciplinary writing.

7. Conclusions

Given the link between successful student development as a scholar and faculty research productivity, an efficient means to facilitate the development of graduate engineering students' disciplinary writing skills deserve closer attention. To that end, data generated from participants enrolled in a semester-long writing course were analyzed to better understand the processes and outcomes of graduate-level writing courses for engineering students. The extent to which course participation resulted in publication submission, textual production in each of four standard article sections, and perceived changes in student writing attributable to course participation were assessed. The findings from these three objectives are summarized as follows:

1. Upon course conclusion, four of the 22 students had achieved the outcome of preparing a manuscript that was ready, or near ready, for submission. Six months later, an additional ten students were judged to have met this goal. Thus, a total of 14 of the 22 (64%) had achieved the primary course outcome six months after course completion. But, as noted earlier, because the study did not include a control group, it is not known how many of these students would have reached this goal without course participation, although the student and faculty adviser survey responses strongly suggest that it is likely that fewer would have done so.
2. Tallies of textual production in each of four standard article sections indicated that the Introduction section was the most fully developed, followed by the Methods section; whereas, progress on the Results/Discussion and Conclusion sections lagged. While typical word count for each section is discipline and journal specific, it was found that higher total word counts were associated with higher percent completion. Tallies of total word count of student manuscripts ranged from 0 to 6544 with

a median of 2356 and an average of 2463. Manuscripts with approximately 6500 total words were associated with 95 to 100% completion rates at the end of the semester.

3. In general, students perceived the Introduction to be the hardest to write and the Methodology to be the easiest to write. The Results/Discussion section was perceived to be easy by some and hard by others. At the end of the course, many students perceived they were more skilled at writing a paper's introductory section, which they attributed to class participation. Further, 15 students (68%) provided clear statements indicating their perception that course participation had improved their writing knowledge and/or skills and several students perceived that they had a clearer sense of the disciplinary writing process. Faculty adviser responses generally aligned with those of students and suggested that faculty believed most students benefited from course participation.

Based on the above, for departments willing to offer a dedicated course to expedite the development of graduate students' writing skills, analysis suggests tangible benefits accrue for both student and their faculty advisers. Not every student completed and submitted a manuscript for peer review by the end of the semester, the hope-for goal. However, from a broader perspective, the course jump started most students' efforts toward publication in a systematic way and created a supportive environment for meaningful dialogue about disciplinary writing between student as peers and between students and their faculty advisers.

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