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Redesigning Writing Instruction Within a Lab-Based Civil Engineering Course: Reporting on the Evolution Across Several Semesters

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Abstract

Development of effective communication skills in engineering students is critical, yet challenging. As engineering programs are technically rigorous, work-intensive, and challenged by their high enrollment numbers, methods to improve students' writing skills must be cost-effective and scalable. This paper describes pedagogical changes and shares course materials designed to integrate core concepts from writing studies into an advanced laboratory-based civil engineering course. We incorporate language units developed by the Civil Engineering Writing Project that provide strong connections to professional engineers' writing. Specific concepts that guided the redesign are genre awareness and flexibility, process orientation to writing, and global, prioritized feedback. Several semesters into the iterative implementation of these changes, teaching assistants observe greater student engagement, without an increase in teaching workload.

Introduction

The development of effective communication skills in engineering students is critical [1]-[3]. This objective will always be a difficult one, given the inherent complexity of communication and the many ways our expectations and practices are shaped by our disciplinary cultures. However, the difficulty is currently compounded by additional challenges, including the separation of engineering and writing studies and the implicit nature of many of our expectations around communication. These challenges present opportunities for progress. Although different forms of communication are inevitably intertwined, we focus here on writing in engineering and science curricula.

Our perspective is grounded in on-going transdisciplinary action research conducted by the Writing Across Engineering and Science (WAES) team, with writing studies, engineering, and science faculty and students working together in an iterative approach that blends practical interventions and research [4]-[6]. Due to the large size of our university, we have adopted a faculty development model, investing in and empowering our engineering and science faculty to more effectively incorporate writing in their classes. In the course of our interventions and research, we have repeatedly observed both the value that core concepts from writing studies can bring to our courses and curricula and, at the same time, the difficulty associated with applying these core concepts in an engineering context. While research in the field of writing studies has historically prioritized and studied small classes of at most 15-20 students, in many cases our engineering classes are large, sometimes enrolling hundreds of students each semester. Our students also may not realize the importance of communication in engineering, and our courses are already densely packed with learning objectives. There is a need for more pedagogies and course materials related to engineering communication, and they need to be evidence-based, easily incorporated into existing classes and curricula, scalable to courses with large populations, and aligned with disciplinary conventions and values.

Laboratory courses provide an important opportunity to develop writing skills, as has frequently been noted in ASEE conference papers (e.g. [7]-[12]). Advantages of laboratory courses for writing instruction include their well-recognized importance in engineering curricula, the fact that they already include written reports and sometimes also other formats, such as executive summaries and/or presentations, and the professional relevance of communicating lab results and design decisions. While previous writing instruction can be useful to students, they need writing instruction within laboratory classes [10],[12]. Individual instructors of laboratory courses have developed a variety of course materials and strategies to support students' ability to meet their expectations, always working within the constraints of their courses and available resources. In some cases, writing expectations have also been scaffolded across courses within a curriculum [7],[11],[13]. More widespread incorporation and adaptation of core concepts from writing studies has the potential to more effectively leverage laboratory courses for the development of students' writing skills. Importantly, we believe this can be done without increasing the on-going workload of instructors and teaching assistants (TAs).

Our efforts to improve writing instruction in the engineering classroom are rooted in several core concepts that emerge from writing studies literature. First, writing is a complex, nonlinear, recursive process rather than a product [14]. We promote pedagogical changes that encourage drafting, global prioritized feedback, revision, and frequent interstitial writing activities over an emphasis on final deliverables as the sole representatives of the writing process. Second, our program highlights the importance of genre awareness and flexibility in writing rather than viewing writing as a skill or a style that can be practiced without disciplinary context [15]-[17]. In other words, we characterize writing as effective or ineffective only when referring to the conventions of a particular genre. Third, writing is a powerful metacognitive process [18], a means of better understanding and retaining complex technical concepts. Our program therefore also encourages pedagogical changes that encourage writing-to-learn [19]-[21]. Writing assists with critical thinking [22].

This work also builds on Conrad's Civil Engineering (CE) Writing Project [23]-[24]. The CE Writing Project uses corpus linguistics to investigate the differences between writing from practicing civil engineers and from students, as well as interviews exploring why these writers made the choices they did [23]. They have developed educational materials targeting key differences, such as language units focused on precision and accuracy in word choices [24]. For maximum flexibility, these materials are designed so that they can be used within courses or studied independently. Importantly, significant improvements are seen in student writing after adoption of these course materials; they are effective [25]-[26].

This paper discusses the pedagogical changes made to our focal laboratory course, *Properties of Materials*, integrating technical communication concepts from writing studies and units from the CE Writing Project. The upcoming sections include course materials developed by our transdisciplinary team introducing instruction on genre awareness and flexibility, a process orientation to writing, and global, prioritized feedback. In addition to optimizing student instruction, training provided to the TAs considers cost effectiveness in terms of time spent grading and providing clear, targeted feedback.

Description of focal course and course materials

The focal course described in this paper, Civil and Environmental Engineering 300 – Behavior of Materials, includes weekly lectures and laboratory sessions. The laboratory sessions are

accompanied by substantial technical writing, and thus the course fulfills our university's level two (advanced composition) writing requirement. The course is mostly taken by civil engineering juniors and seniors, although students from other years and areas of study do enroll each semester, and has an enrollment of around 100 students per semester. Prior to our redesign, the students wrote weekly reports, collaboratively in pairs, based on the data from each lab, and submitted the reports for evaluation the following week. The assignments focused on writing as a product: the deliverable from each lab was a report that was submitted and graded once. Summative feedback was provided by graduate TAs using a standard grading rubric. In both the original and the redesigned course, the reports cycle through three genres: formal reports, letter reports, and technical presentations – each with distinctive requirements and conventions.

Over the past three years, our transdisciplinary WAES program has supported course redesign in a way that preserves the lab sessions, reports and technical content while enriching the writing instruction, scaffolding the assignment structure across multiple weeks, and encouraging thoughtful self-assessment. The three key changes characterizing this redesign are a decrease in the number of assigned reports, the incorporation of language units developed by the CE Writing project [24], and a switch to individual submissions of all assignments. The decrease in number of required report submissions allowed space for scaffolding and focused assignments, including self- and peer-review, to be added to the curriculum. Additionally, due to assignments being submitted individually rather than collaboratively, the reduction in reports submitted maintains the TAs workload. The language units developed by the CE Writing Project provide a framework for a process orientation to writing and impart a strong connection to professional civil engineers' writing [23]. Design of rubrics that are aligned with core concepts, course-specific training for TAs, and feedback from TAs were crucial in developing and implementing the changes.

The redesigned assignment schedule is shown in Table 1. Before the course redesign, laboratory reports, across three genres, were assigned for each weekly lab experiment. The weekly lab experiments remain the same, but after the redesign those laboratory sessions feed into different types of assignments. In the Lab 0 formal report, which is due in the 2nd week of the course, students write a report using provided data with the writing experiences and techniques that they started class with; this report was assigned both before and after the course redesign. However, in the redesign, the Lab 0 report becomes a base product from which students evaluate and rework their own writing. Subsequent lower stakes, more focused writing assignments use the Lab 0 report work on objectives such as improving word choice and concision. Other writing assignments introduce more genres, such as writing an executive summary or an email for a specific audience. After the redesign, reports about collected laboratory data are required only for Labs 1&2 (combined), 8, and 9&10 (combined), while results from labs 3-7 and 11-12 are reported in worksheets. The worksheets are designed to capture the essence of the experiments in terms of data analysis and handling, data presentation, and conclusions drawn, but with a lower workload than a lab report, for both students and grading TAs. For example, the tension test worksheet requires graphing and selection of axes scales for ductile and brittle materials (Appendix A). Replacing several reports with worksheets created space for new writing assignments and more opportunities for report revision in a scaffolded process. The three genres originally present in the course have been maintained. The results from Lab 8 are presented in a Letter Report, and those from Labs 9 and 10 in a Presentation Report.

Table 1. Semester-long schedule of laboratory sessions and writing assignment tasks.

Week	Lab Topic	Assignments Due		
		Writing Assignment (WA)	Worksheet	Report
1	0_1. Writing Lab Reports			
2	0_2. Writing Lab Reports			* Lab 0 Formal Report DRAFT
3	1. Tension	* WA 1		
4	2. Compression		* Lab 1	Lab 0 Formal Report Revised
5	3. Bending & Torsion	WA 2	Lab 2	
6	4. Notch Sensitivity	WA 3	Lab 3	Labs 1 & 2 Formal Report DRAFT
7	5. Impact & 6. Fracture		Lab 4	Labs 1 & 2 Peer Review
8	Scheduled Semester Student Holidays			
9	7. Creep		Labs 5 & 6	
10	8. Heat Treatment		Lab 7	Labs 1 & 2 Formal Report
11	9. Production of Concrete			Lab 8 Letter Report
12	10. Strength of Concrete	WA 4		
13	11. Wood			Labs 9 & 10 Presentation Report
14	12. Asphalt	WA 5	Labs 11 & 12	
* These materials are provided in the appendices.				

Our course redesign aims to teach writing as a process, rather than a product, through a scaffolded revision process. After drafting the first formal lab report (Lab 0 in Table 1), the first focused writing assignment guides students through a reverse outlining process, to help the student writer evaluate and reconsider the organization of their report (WA in Table 1, Appendix B). This assignment also directs students to a language unit from the CE Writing Project, Sequence of Information [27], which provides more information and specific strategies they can use to address writing organization. Grading is based on their reverse outline and their reflections about their report, and the assignment leads into submission of their revised lab report the following week. In other writing assignments, we draw on other units from the CE Writing Project that encourage students to think about the discourse conventions within the field of civil engineering [24]. For example, students are asked to identify places in their own writing that show the desired property, such as conciseness, and to highlight opportunities for improvement. Later in the semester, students also apply these strategies in peer review. Attention to the structural characteristics of professional engineers' writing provides more explicit guidance for students and forms a stronger connection between the writing students produce in the classroom and the writing that professional civil engineers are expected to produce post-graduation [23].

As part of the course redesign, we switched to individual reports and assignments rather than students working in pairs. This change was initiated because student interviews revealed that the student pair would often split responsibilities, separately concentrating on different aspects of the report (data analysis/graphs versus writing the body of the reports) and thus missing out on learning what their partner did. In other words, one student of the pair would be well versed on the data/technical aspects of the laboratory work yet get very little out of the technical writing aspect, and vice versa. The major challenge in making this change was managing the workload, particularly for course staff, as switching to individual reports doubles the number of submissions. The reduction in the number of reports, discussed above, was key to achieving this, as were the revisions to assignments and rubrics, allowing for more focused, efficient feedback.

The grading rubrics that the TAs used to evaluate the work were modified as part of the course redesign to emphasize the key elements in the writing as process framework. In the redesigned grading scheme for Report 0 (Appendix C), 75% of the report score is based on format, writing and data presentation issues. The writing component of the grade is evaluated using a writing criteria table based on the skills and tools from the CE writing project that we emphasize throughout the course. Prior to the redesign, the grading rubric followed the "writing product" approach, where 75% of the report grade was distributed over the expected sections of the report, e.g. Introduction, Procedure, Results, etc. and the remaining score distributed over admittedly vague writing categories, e.g. Style, Organization, Spelling, etc., without guidance. As part of the weekly TA training sessions, which are required for the TAs to learn operation of the test machines for the following week, we now include time to reflect on the past week's assignment and those outcomes, and to discuss the assignments for the following week. During this session we share experiences and grades among the lab sections led by different TAs. The introduction of discussing and reflecting on the new writing assignments and worksheets during the weekly TA training meeting expands upon instruction from years prior that only provided the weekly assigned report genre. The post-assignment reflections centered on assignment effectiveness in terms of student benefits, gradeability, and complaints lodged from students or TAs guide modifications and improvements of assignments to implement in the future. The pre-assignment discussions conducted during weekly TA training meetings focus on finalizing assignments and verifying grading scheme and rubrics, whereas post-assignment discussions monitor the grade distributions across TA sections to ensure there were no average score outliers.

Feedback on and experience with course changes

Throughout the course redesign we monitored the workload and experience of the TAs who led lab sections and responded to student writing. A principal concern with the course redesign was the potential for increased workload for the TAs, who were already at a maximum workload limit with the previous course structure. Interviews of TAs who had worked under both the previous and redesigned course structures revealed that the workload was similar before and after the redesign, despite the switch to individual submissions. In general, the TAs adapted well to the modification and appreciated the work on technical writing through the focused writing assignments.

Preliminary evidence suggests that the reworked writing instruction for laboratory reports increases students' technical writing capabilities. Specifically, in semesters that scaffolded revisions and contained the new writing assignments, there has been a greater increase in average scores between the draft and revised formal reports for Lab 0 (Table 2). As our aim is to improve

writing skills, rather than a specific document, we also considered how the redesign affected students' scores on the second major assignment and changes in scores between their Lab 0 draft and their formal report for Lab 1 (before redesign) or Labs 1 & 2 (comparable assignment after redesign). There was a slight increase in scores on this second assignment, and a greater increase in scores, after the redesign (Table 2). Interestingly, the scores on the final lab report (presentation report for Labs 9&10, data not shown) have not shown a similar improvement after the course redesign. This finding is still under investigation but could reflect changes in the grading rubric that were implemented during the redesign. While we acknowledge that this is preliminary analysis, these results are encouraging, suggesting the new writing assignments and peer review process are having a positive impact on students' writing.

Table 2. Comparison of average student grades from the formal lab reports, from initial to revised submissions and from before and after course redesign.

	Lab 0 draft	Lab 0 revised	Labs 1 & 2 formal report	Improvements	
				Lab 0 (first/revised)	Lab 0 to Labs 1&2[2]
Before[1]	73.6	84.4	80	+10.8	+6.4
	74.9	85.7	81.8	+10.8	+7.0
After[1]	69.8	82.6	83.6	+12.8	+13.8
	71.5	86.7	84.7	+15.2	+13.2

[1] Before data taken from fall 2019 and spring 2020, with all of these assignments completed before the COVID pandemic disrupted instruction. After data is from fall 2021 and spring 2022.
[2] This column reports the change in scores from the first submission of Lab 0 to the final submission of Lab 1 or Labs 1&2. In the redesigned course, there is one report covering Labs 1 & 2, and there are scaffolded revisions of that report prior to the final submission.

One additional benefit that arose from the redesign is the elimination of conflict between student pairs, for example complaints of uneven work contribution to a report, which freed up TAs' time and energy. The students' experience with the redesign is more difficult to assess directly because they did not experience both course structures. Based on end-of-semester student evaluations, students appreciated the focus on technical writing and offered helpful suggestions for improvements. Anecdotally, we know that students in the redesigned course structure were aware of the previous course structure. In some cases, they lamented the fact that they could not work in pairs to write and submit their reports. At the same time, they recognized the reduced workload of the redesigned structure, which no longer required a complete report due every week. Future work for this project includes a deeper analysis of students' perceptions and writing.

Conclusions

This lab course redesign was intended to improve technical communication instruction, based in large part on core concepts from writing studies and language units from the CE Writing Project, without increasing the workload for course staff. Initial signs are that students, TAs, and the course instructors all appreciate the pedagogical changes. Advanced laboratory-based courses throughout engineering, including courses with large populations, can apply these approaches to integrate core concepts from writing studies: genre awareness and flexibility, a process orientation to writing, and global, prioritized feedback. Through the cost-effective implementation of these concepts to

engineering lab-based courses, students will be more prepared for the writing demands of the professional workforce or higher academia.

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Couse: Civil and Environmental Engineering 300 – Behavior of Materials
Instructor: Professor John Popovics, PE

Appendix A: Lab 1 – Tension Test Worksheet

Construct a diagram of engineering stress vs. strain for each of the materials tested using plotting software, e.g. Excel, MATLAB, OriginPro, etc. The tab-delimited ASCII data files contain, in order, the crosshead position, the load, the strain, and the time. (For details, see lab manual Appendix B). For ductile materials, select one strain scale such that only the elastic portion of the curve is emphasized; use the data in this range to determine modulus of elasticity. Then select a second strain scale that allows the entire curve to be included on your plot. For brittle materials, one scale is usually sufficient. Additionally, superimpose the stress-strain diagram for each material onto a single graph (with the exception of PMMA) using an appropriate strain scale.

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Instructor: Professor John Popovics, PE

Appendix B: Writing Assignment 1- Reverse Outline

Purpose
A reverse outline is just one method technical writers use to review and revise drafts of their work. Using this technique, writers and reviewers will read a condensed version of a complete draft to check for consistency in their structure and organization.

Procedure
Reverse outlining is a process whereby most of the supportive writing is temporarily set aside so that the reader may focus on the overall topics and structure. The revised draft should ideally undergo some changes in the order of its paragraphs or the organization of its sentences. Additionally, Susan Conrad's Language Unit 6, "Sequence of Information" has research-based findings about writing as a civil engineer that can help in this process [27]. Three of Conrad's techniques with examples are provided within this unit.

How to Create a Reverse Outline

1. Start with a complete draft of a report – in this case your submitted Lab 0 formal report.
2. Read the entire draft from start to finish without taking any notes. Process the writing as though it is your first time reading this text (even if it is not).
3. Read the text again from the beginning, but this time stop at the end of each paragraph.
   Note: Stop at the end of each paragraph – not at the end of each section. Some sections may include more than one paragraph.
4. Number each paragraph as you read through it.
   Note: You may choose to number the paragraphs by section number or by paragraphs alone (e.g., "Paragraph 1, 2, 3, 4…" or "Section 1, Paragraph 1, Paragraph 2; Section 2, Paragraph 1…)
5. On a separate document take note of two things:
   - Write down what you perceive to be the topic of each paragraph; we call this the paragraph topic sentence. If the paragraph seems to be about two or more topics, note all topics.
     Note: Ignore the section titles for now. They are not always accurately indicative of the actual content in the paragraphs.
     - If a paragraph's topic sentence provides a succinct description of the paragraph's main idea, you can paste the exact sentence into the outline as a summary for that paragraph.
     - If the paragraph's topic sentence does not provide a succinct description, compose a one-sentence summary to express what you perceive to be main point of the paragraph and highlight or make note of the topic sentence that does not adequately describe the topic.
   - Highlight any sentences in the paragraph that seem to deviate from the perceived topic.
6. Continue to construct an outline by numbering and listing the main idea of each paragraph in your new document. This outline is called a reverse outline.

How To Use Your Reverse Outline

1. Once you have a complete reverse outline that mirrors the content in the original report draft, begin reading through the relevant sections of the lab manual (how to write laboratory reports (Pg. 1-7), Sample formal lab report (Pg. 27-56)) and the formal lab report grading rubric.
2. Use the lab manual and rubric as an example of the ideal outline the report should follow.
3. Use the reverse outline you created to answer the following basic questions with feedback notes. Once the questions are answered, you can make revisions based on the observations made on the reverse outline.
    - Does the report include all the sections it should include per the lab manual?
      If the reverse outline shows that a section is missing, then it could be that another section has been mislabeled or that there are misplaced paragraphs. The missing section may also simply have been inadvertently omitted. Make a note if it needs to be added.
    - Does every paragraph relate to the section under which it appears?
      If the reverse outline shows that a paragraph appearing in one section would be better suited towards another, then that paragraph could easily be cut and pasted into the appropriate section. Now is a good time to ensure that the section titles are accurate to the topics they describe below. Note discrepancies between titles and actual content. (Refer to Technique 1 in Susan Conrad's "Sequence of Information" [27]).
    - Does every sentence relate to and adequately support the main point of each paragraph?
      Check for topic sentences that were highlighted because they did not adequately explain the topic of the paragraph. Make some light revisions at the sentence level and omit sentences that repeat information without making any new insights. (Refer to Technique 2 in Susan Conrad's "Sequence of Information" [27]).
    - As a reader, are you having any trouble following the order of the ideas?
      If the reader cannot make sense of an outline as-is, it may be time to make strategic choices for rearranging the paragraphs or adding clearer transitions between them.
    - Does more than one paragraph repeat the same information without new insight?
      If your reverse outline shows two paragraphs that make similar points, consider combining them or revising one so that it does not make too similar a point.
    - Does one paragraph try to explain too many fragmented topics?
      Check for paragraphs that had more than one topic listed on the reverse outline. Divide heavy topics into smaller concepts. Use these concepts to construct new and more focused paragraphs to ensure that your reader can follow the report. It's okay for paragraphs to have slightly uneven lengths if they facilitate understanding of the main ideas.
    - Does the end of each section stay on topic?
      Many writers find that previously unmentioned or unrelated topics appear randomly near the end of sections or at the end of the reverse outline. These topic shifts may signal a slight tangent. Generating new ideas during the writing process is completely normal and expected, but abrupt departures from the topic may require some revision. Move sentences or paragraphs around to be sure that they appear in a section where they may be more supportive. You may also be inspired to revise some of your topic sentences or add additional paragraphs to facilitate a worthy discussion.

- Does the Results section include any evaluative statements?
  Analysis and verdicts about data should be saved for the Discussion section. Adjust and move sentences that discuss data according to where they most appropriately fit into the report. Eliminate analytical language from sections that should only refer to objective data. (Refer to Technique 3 in Susan Conrad's "Sequence of Information" [27]).
- Does every figure and table appear in the correct order and section?
  Ensure that each figure and table is labeled with a number and a descriptive caption. Check for missing numbers or an incorrect sequence. Figures and tables must appear in the order they are cited in text.

Submission

1. Be sure to mark the changes in your lab 0 draft by turning on tracked changes so that your Teaching Assistant can see all your revisions.
2. Append the reverse outline to the front of your lab 0 draft (with changes marked) and submit.
3. For this writing assignment you are graded based on your reverse outline (see rubric below). Use this reverse outline and TA feedback to prepare for your Lab 0 revision submission.

Table 3. Grading rubric

Criteria (50 points total)	Exemplary	Above Average	Adequate	Inadequate	Absent
Reverse outline includes a list of numbered topics or topic descriptions. (15 points)					
Feedback notes include answers to all of the questions for review. (5 points)					
Feedback notes are clear and reasonable. (10 points)					
Feedback notes are focused and organized. (10 points)					
Feedback notes are informative and thorough. (10 points)					

Course: Civil and Environmental Engineering 300 – Behavior of Materials
Instructor: Professor John Popovics, PE

Appendix C: Laboratory Report Grade Sheet – Formal report – Lab 0

Format (25 pts.):
- Document structure (12 pts.)
  Component sections and structure
- Document appearance (13 pts.)
  Neatness, headings, font, margins

Technical content (25 pts.):
- Technical correctness – lab procedure (3pts.)
- Technical correctness – data and results (6 pts.)
- Technical correctness – calculations (3 pts.)
- Technical correctness – analysis and discussion (8 pts.)
- Conclusions (5 pts.)

Writing (25 pts.): (Table 3)
- Proofreading
  Review for mis-spelling, grammar and punctuation
- Precision
  Apply proper and consistent word selection
- Concision
  Be efficient with words
- Fluidity
  Aim for sequential presentation of content
- Clarity
  Avoid needlessly complex words and phrases

Visuals and data (25 pts.):
- Appearance of plots, tables, images and captions, for example proper axes labels, font and symbol sizing, appropriate data fits, etc.

Table 2. Writing Criteria

Topic	S+	S	U	Comments
Proofreading (7)	Thoroughly reviewed for misspellings, appropriate grammar and punctuation. (7)	Some errors with moderate impact to meaning. (4)	Several errors that interfere with meaning. (1)	
Precision / Concision (8)	Applies appropriate and consistent word selection and is efficient with words. (8)	Some errors with moderate impact to meaning. (5)	Several instances of inappropriate or incorrect word use and inefficient word selection that interfere with meaning. (1)	
Clarity / Fluidity (10)	Clear, logical and sequential presentation of content. (10)	Some problems with moderate impact to meaning. (6)	Several instances of complex or nonsequential words and phrases that interfere with meaning. (1)	
TOTAL	-	-	-	