Development of Integrated Technical Communication in an Undergraduate Mechanics of Materials Laboratory Course

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**Abstract**

The development of discipline-specific writing skills is important for students of all majors, but each field of study has its challenges. In engineering, frequently there is a student expectation that calculations and drawings are the primary output of their work. That expectation is, however, incorrect. Effective communication, written and graphical, is crucial for the practice of engineering. Laboratory classes provide excellent opportunities for students to apply technical skills covered in engineering lecture classes, but they also provide the opportunity to apply written communication skills covered in previous English classes.

However, to improve the disciplinary writing skills of engineering students, the several Engineering departments at the University of Detroit Mercy have selected some engineering classes to be co-taught by engineering and technical writing instructors. The courses either include engineering content or have stand-alone co-requisite engineering classes. Writing instruction content, such as lectures and writing assignments, have been added to the courses. The laboratory reports and design reports are assessed by both the engineering faculty member and the technical writing instructor.

The Mechanics of Materials Laboratory class has been co-taught by instructors from both disciplines three times. After the first class, the engineering and technical writing instructors identified several lessons-learned and places for improvement. During the second class, new lecture content and handouts were developed. For the third class, the lecture content and handouts were revised. The assessments conducted after each of the courses demonstrated that the quality of the students' reports had consistently improved each time the course was offered, and the time required for the students to write their reports decreased accordingly.

Thus far, the items that have had the largest impact are the presence of the technical writing instructor, the development of a report template, the development of a Microsoft Excel primer, and the requirement for students to revise the report prior to the final submission. Future work for this class includes further refining the lecture material and handouts, and addressing student attitudes towards the importance of writing. The real measure of success will be when the students graduate and work as engineers, demonstrating not only excellence in engineering, but in the technical writing that supports it.

## Introduction

Engineers have long been expected to possess technical competence, such as the ability to apply mathematics and science to engineering problems, the ability to design components and systems, and the ability to work with experimental data. As the availability of technology has grown over the past 30 years, and as the business of engineering has changed, engineers are expected to do more than develop ideas, perform calculations, prepare hand-sketches, and pass those sketches to others for implementation. Large drafting departments, clerical support, and technical writing staff are becoming things of the past. Engineers now prepare their own CAD drawings, write their own reports, and prepare their own presentations.

The Accreditation Board for Engineering and Technology (ABET) traditionally has held outcomes related to effective communication through Outcome g of General Criterion 3 [1]. Outcome g includes written, oral, and graphical communication. The American Society of Civil Engineers (ASCE) has proposed a more detailed criteria for writing. As part of the Body of Knowledge 2, ASCE identified 24 outcomes and listed levels of proficiency using Bloom's taxonomy that engineers should reach upon completing a baccalaureate degree, a master's degree, and the work experience required for professional licensure. ASCE proposes that students completing a baccalaureate degree should reach the Analysis level for communication and the Synthesis level upon completing the required work experience [2].

While engineering programs must meet accreditation standards, the gap between writing education and writing performance still exists. According to the Institute of Electrical and Electronics Engineers (IEEE), engineering professionals spent 44 percent of their time writing, alone or in a team [3]. The Society of Manufacturing Engineers (SME) finds "lack of communication skills among the top 'competency gaps' in engineers' education." This is significant, as the *Journal of Engineering Education* finds 64% of a typical engineer's day is spent in writing, oral presentations or meetings [4]. The problem appears to be significant.

A look at the literature provides context for the University of Detroit Mercy experience.

## Literature Review

Much has been written about teaching students effective and efficient lab report writing, but four studies have particular significance for this project. Timmerman [5], writing in 2007, outlined a universal rubric for lab reports. Her work produced a flexible grading assessment that could be tailored to the course, with portions selected or omitted as indicated. Another significant aspect of her work is that her rubric could be used across courses and departments.

Walk [6], writing in 2013, described a study undertaken to support his university's Quality Enhancement Plan, the goal of which was to improve upper-level, undergraduate disciplinary writing.

He started by reviewing Writing Across the Curriculum efforts as they applied to teaching students to write well, using writing to teach students about the discipline and, ultimately using the experience to prepare students for work in their discipline. In addition to writing instruction in class, lab report writing outside of class, team writing, and peer and instructor reviews, Walk used low-stakes prompts at the beginning of each lab session to promote in-depth thinking about the engineering principles being explored. This was a chance for students to use writing to explore their understanding of engineering.

What Walk learned was interesting. Two assignments in particular highlighted "…that students might not be ready to 'put in their own words' concepts and phenomena they have yet to contemplate outside of the standard language and discipline of use in their electrical courses to date." Despite this new finding, Walk reported that, overall, by the end of the semester, his students produced writing that was more concise, used simple sentence structure to convey complex ideas, used jargon less, proofread more effectively, and showed more confidence and persuasion in writing.

In 2016, Kim and Olson [7] described their efforts to close the gap between engineering students' writing performance as compared to peers in other majors in their Junior Writing Portfolios. After studying the approach already in use, Kim and Olson added a rhetorical component to their lab report courses. The rhetorical strategy emphasized consideration of audience, purpose and context in addition to the need for accurate engineering content. They used many of the same pedagogical tools as Walk but added a focus group and student survey. In their case, the lab class was a "gateway," the students' first exposure to writing in their discipline. A rhetorical writing approach, combined with instructor and peer feedback, led to a clear upward trend in writing performance, i.e., less use of first person, more succinct language, increased sense of context and purpose, proper choice and placement of figures and tables, and use of sources to support claims.

Conrad [8], writing in 2017, studied writing both within the discipline but also at the sentence level to learn what characterized effective workplace writing and, conversely, what type of writing students were producing. Students believed, mistakenly, that longer, more complex sentences full of multi-syllable words made them, and their work, look intelligent. Of particular concern was Conrad's finding that "students [were] using features that would have serious negative consequences in engineering practice." It is true that Conrad's study focused on a single public university. However, her recommendations were broad and included the idea that students need to be mentored by professionals in writing and in engineering.

What does this progression of study reveal?

1. Flexible rubrics are useful in assessing student performance.
2. Devoting a portion of a lab session to writing instruction and practice, particularly writing using a rhetorical strategy, helps students produce better lab reports.
3. Feedback from peers and instructors is helpful.
4. Writing in the discipline does contribute to student comprehension of the material and the engineering approach to work

5. The student tendency to prefer overly complex language and sentence structure must be re-directed.

So, what does the University of Detroit Mercy experience add to this body of knowledge? Does it support these trends, refute them, suggest new avenues of study, or something else?

This paper addresses some of these broader issues but focuses primarily on specific issues in an undergraduate Mechanics of Materials Laboratory course.

The approach to addressing the issues includes reviewing the traditional method of teaching the course, revising the course, identifying lessons learned from each offering of the course, and proposing ideas for future offerings of the course.

## Writing Experience at the University of Detroit Mercy

All students at the University of Detroit Mercy (University) take a broad core of classes, in addition to the specific courses for the student's major. The core includes freshman composition, public speaking, and humanities courses. Traditionally, engineering students and other students in the College of Engineering and Science (College) take a course in technical writing. Engineering students also take mid- and upper-level engineering courses, including those in analysis, laboratory, and design.

Engineering students take at least one laboratory course per term and multiple engineering design courses, including a senior capstone project. The laboratory courses require reports, and those reports are typically greater than 50 percent of the final grade. Design courses include projects, many of which require design reports. In the sophomore design and senior capstone, the reports are a large portion of the final grade.

Anecdotally, faculty members have expressed concern that student writing skills have not been adequate in these courses. Furthermore, employers have expressed concern that student writing skills have not been adequate for cooperative education assignments and professional practice, especially as first years are now being given the opportunity for a co-op between freshman and sophomore year. Skill-building in technical writing needed to begin sooner.

In response, faculty members in the Department of Civil, Architectural, and Environmental Engineering and in the Department of Mechanical Engineering (Departments) in the College at the University investigated strategies to improve student writing, including co-teaching that incorporated writing instruction within existing engineering courses and extensive work with the University's Writing Center, which is part of the English Department. The results of those attempts were mixed, in part because of administrative and staffing concerns around the inter-departmental teaching scheme.

Independent of these efforts, the University had been revising its core to outcomes-based learning, which includes integrating themes. One of the integrating themes is Reading, Writing, and Research across the Curriculum (IT1) – a concept not included in the old core [9]. The IT1 outcome is comparable to writing in discipline described by Kim and Olson [7]. The new core at the University makes interdisciplinary collaboration and co-teaching easier.

This theme addressed, in part, writing proficiency within specific fields to help students succeed in their professions, requiring faculty members to address both broad and specific issues.

Broad issues include:

- What does effective communication mean?
- How do students learn to communicate effectively?
- How do students learn to value effective communication?

Specific issues include:

- How do specific courses build off previous courses?
- What specific writing issues are problematic in specific courses?
- What strategies can be employed to address specific issues in a course?

With this University directive, Engineering identified several courses for the co-teaching experience. What follows here is a description of a particular course, the Mechanics of Materials Lab, as it has been traditionally taught. Later, changes to the traditional approach are discussed.

**Mechanics of Materials Courses**

ENGR 3270: Mechanics of Materials Laboratory is the first engineering laboratory course taken by students majoring in civil engineering, mechanical engineering, or architectural engineering. ENGR 3270 is a one-credit companion to the three-credit ENGR 3260: Mechanics of Materials lecture course. The courses are typically taken in the winter semester of the sophomore year or the fall semester of the junior year. By this time, most engineering students will have taken the 3-credit Technical Writing course through the English Department.

ENGR 3260 covers topics of equilibrium of forces and moments, compatibility of deformations, and concepts of stress, strain, constitutive relationships, and deformation. The general concepts are applied to axially-loaded members (statically determinate and indeterminate, forces and temperature effects), torsionally-loaded members (statically determinate and indeterminate), beams, and columns. The transformation of plane stress is also covered.

ENGR 3270 provides hands-on exploration of topics in ENGR 3260, but also addresses general issues in experimental work, data acquisition and processing, and sensors. The experiments are typically conducted after students become familiar with the underlying concepts through lectures. The experiments are:

1. Hardness testing of metals
2. Tension testing of metals
3. Tension and shear testing of plastics
4. Strength testing of wood
5. Torsion testing of metals
6. Aluminum beam bending
7. Column buckling
8. Thin-walled pressure vessel
9. Design for strength and stiffness of beams

Key details of each experiment are included in Appendix A. Experiments 8 and 9 are submitted as homework assignments and the other experiments are submitted as group reports only. Experiment 6 is performed about two-thirds of the way through the semester and Experiment 7 is the last experiment to line up with that coverage in the lecture course.

Each experiment has its own set of instruction handouts, data sheets, sample calculation sheets, and results sheets. The instruction handouts include pre-lab questions, experiment instructions, calculation and analysis requirements, and post-lab questions. All experiments with reports have the same sections; therefore, one set of report instructions is included as a stand-alone document. The report instructions include the formatting requirements, sections, and items to be addressed in each section, along with a rubric that provides points.

Traditionally, no report template was offered for student use.

## Limitations of the Traditional Laboratory Format

The first co-teaching experience was in Fall 2017, with a Civil Engineering professor and a Technical Writing instructor in place. They identified three key issues with the previous offerings of ENGR 3270:

1. Inconsistent composition within report sections,
2. Inconsistent formatting of items within reports, specifically tables and figures,
3. Inadequate details of interpretation and conclusions.

A template could potentially improve consistency; however, there were concerns that students would try to force the current assignment into the existing template without much thought into how much sense it made. A report should address the concerns of the audience and incorporate the voice of the author(s), provided that the writing is professional. Furthermore, a template would not necessarily result in better interpretation and conclusions.

The issues with the reports could be due to a lack of:

- Preparation in earlier courses
- Time between the end of the lab session and the due date of the report
- Time management

- Motivation
- Understanding that writing is important for the professional practice of engineering
- Confidence in their own writing skills

However, without a survey, it is not possible to determine how much each of these items contributes to the issues with the reports.

The last item also appears in professional practice, e.g., civil engineers in professional practice do not consider themselves to be good writers [8].

Students also started the course with varying levels of experience and confidence in Microsoft Excel, and not all had taken the 3-credit Technical Writing course.

**Development of a New Format for the Laboratory**

After identifying some limitations of the traditional offering of the laboratory course, the co-instructors focused on changes that could be made to the instruction given to students and strategies to implement those changes. These strategies included:

- Focusing on writing instruction, especially from a rhetorical perspective (audience, purpose and context)
- Developing a report checklist or a report template
- Developing a Microsoft Excel primer (focused on specific tasks for this course)
- Allowing students to submit a first draft of the report and then revise it
- Revising the grading rubric to better describe the content expected

The writing lectures cover various aspects of the report process including: audience identification, organization of ideas, clarity and conciseness, drafting and revising. Audience awareness allows students to determine the level of detail, what content is best shown in text or a visual, and what supporting information belongs in an appendix. They learn to make choices based on the reader, not their own opinions. In essence, they are learning first-hand how to write for their discipline. Co-teaching by an engineering instructor and an embedded technical writing instructor is important because students are given instruction and feedback that is relevant to this course but also to their professional preparation.

Experience supported the list generated above. A checklist was developed, based in part on an early focus group, but it proved insufficient in supporting significant improvement in the lab reports. Subsequently, a laboratory report template was developed based on existing templates within the University and those in use at other institutions. The challenge was to develop a template that was easy enough to follow, but flexible enough that it could be used for multiple experiments in multiple courses and allow students to add their own style and personality. The original goal had broadened at this point beyond a viable template for ENGR 3270 to a template that would be usable, or could be adjusted, to multiple lab courses across the engineering disciplines.

The authors of this paper found the first version of the template had too many formatting styles (fonts, line spacings, paragraph alignments, etc.), and fell somewhere between instructions and a sample report. The second and current version has fewer fonts and less text within the body, and it now includes checklists of items students might consider when writing each section of the report. The checklists are in textboxes, which the students delete when they finish the report. The items in the textboxes were drawn from the existing rubric and generic instructions, with some additions. The second version of the template will be adjusted again to reflect the lessons learned in the current lab course. These design iterations are common not only in the engineering process, but in the writing process. A key take-away from this experience is that simply providing a template is not enough to ensure good student writing performance. The template is most effective when introduced in class and discussed as the course progresses.

As listed, one of the authors developed a primer for Microsoft Excel that works from the assumption that students have no prior experience with the program. It takes students through entering numbers and formulae, fixing cell references (using $ in the reference), formatting the worksheets, creating graphs, and formatting graphs. The worksheet formatting includes overall layout, fonts, column width, etc. so that the worksheet is easy to read and looks professional when printed. The graph formatting includes font sizes, line weights, line styles, and line colors so that they are readable when printed in black and white or inserted into a Microsoft Word document and resized.

Another part of the strategy in revising the lab report writing experience is that students are now required to submit a first draft of the report for review by the writing instructor, and the students then revise the report prior to final submission. Research by others identified these as parts of effective writing [8]. When instructors give importance to reviews by non-engineers, students come to understand that clear writing is important for engineers. Additionally, repeated exposure to writing comments and writing instructors over several lab courses teaches students to regard these professionals as resources in improving writing content and delivery.

A new grading rubric was developed based on the existing one but expanded to address more items and to provide more context. The grading rubric has now entered a second iteration, becoming more simplified. The grading rubrics are made available to students at the time the lab report is assigned. In addition to the template, the grading rubric can be consulted for guidance on content, formatting, and writing style.

## Further Developments over the First Three Offerings of the Course using the New Format

As the course has been offered, the strategies for the new offering of the course have been implemented, evaluated, and refined.

The current offering dedicates thirty minutes per lab session to technical writing content. As such, the traditional English Language approach of instruction, peer review, and revision is not always feasible. Not only is time a constraint, but students have been ill-equipped to comment on another student's writing because they did not have rhetorical knowledge of the lab report as a genre, and they were unwilling to critique a classmate who was under the same resource and time constraints as themselves. In addition to time constraints and insufficient student skill sets, motivation was an issue. Labs are a one-credit class attached to a lecture. Student perceptions of too much work for too little immediate reward was an issue.

In an effort to address the above issues, writing instructors and their engineering colleagues have been stressing the importance of effective report writing in the workplace. Not only is report writing expected, but good report writing and communication skills in general are factors in advancement at work. Engineering students tend to be practical people. They understand the value of honing report writing skills while in school versus doing so at work. Student motivation was increased by strong departmental support of the Technical Writing program. Early in the course, students were presented with research on employer and industry demands for proficient engineers who distinguish themselves by their writing and presentation skills.

To help them hone those skills, a course of instruction was developed that included both group and individual report writing (see Appendix A). Prior to writing alone, each student worked with others in groups of three to four members, using the lab report template. Lab sections were rotated within the groups so that each member would write each lab section two to three times before they would undertake writing their own individual lab reports. Language issues were assessed in the submitted reports and targeted lessons on clarity, conciseness, and writing with a professional tone were given, culling the students' own sentences from their labs as examples to be corrected as a class. This approach is similar to Walk's [6] low-stake writing prompts. At University, with the time devoted to rewrites, students worked together to learn about the topic while producing more effective sentences. Lab reports with instructor comments, but minus grades, were posted on line to create a resource that students could use for subsequent labs.

As the course progressed, students continued to receive rigorously corrected and scored lab reports with extensive comments from the writing and engineering instructors and a grading rubric that gave them a numerical score for their technical writing and engineering components.

Instructors noted that although the template increased student performance, students sometimes had difficulty applying template instructions to formatting requirements. This was particularly true for the more visual learners. Additional resources, such as a completed lab report sample and a visual study of the Results and Discussion section, provided student with clearer guidance as they were writing.

Although given the opportunity to submit a first draft of lab reports for review before submittal for grading, most students did not do so or submitted work that was substandard for feedback. Students cited lack of time as a reason.

During the Fall of 2018, the third time the lab course was co-taught, a few changes were made in an attempt to meet the pedagogical goals while not overwhelming the students or the instructors. Experiments 1 through 4 were kept as group reports, Experiment 5 was made an individual report, and Experiments 6 through 9 were submitted as homework assignments (see Appendix A). For Experiments 2 through 4, each student in the report group was assigned a different material to analyze and the fourth person was responsible for assembling the Results and Discussion section. That reduced the amount of time students spent on calculations and Microsoft Excel, and it provided everyone in the group the opportunity to work with the data.

Individual lab reports were an important tool in identifying students with writing issues because their skills were the only ones on display. This knowledge allowed instructors to meet with students one-on-one and address their needs outside of class.

At the end of the last two lab courses, a confidential survey was administered to the students to determine the initiative's success. Students reported that the template was indispensable in establishing professor and professional expectations. They also reported that the group work was valuable in learning lab report requirements, in effective management of group resources and personalities, and in preparation for writing individual reports. Individual reports, although not popular with students, were identified by them as beneficial. The data collected demonstrated that the amount of time spent on the reports was two to three hours less than the time spent the previous semester, without the rubric, and students achieved better results overall. Anecdotally, students reported more confidence in their ability to produce acceptable lab reports at work.

From an instructor point of view, less time was spent on correcting formatting issues and sentence-level grammatical issues and sentence complexity, consistent with the experience reported by Kim & Olson [7] and Conrad [8].

## Conclusions and Next Steps

The preliminary results show that student report quality has improved, and the time required to write the reports has decreased. This suggests the University approach is headed in the right direction, but there is more work to do.

The assignment types for the Fall 2018 Semester changed from 7 group reports and 2 homework assignments to 5 reports (4 group and 1 individual) and 4 homework assignments. It reduced the amount of time students spent on writing, but still gave each student the opportunity to work with each section at least once, and gave the each student the opportunity to write an individual report. The quality of the individual reports was quite high, suggesting four group reports with the instructor feedback and revision may be sufficient.

Another goal is to develop a formal assessment tool and track the data to evaluate the statistical significance of the results. Anecdotal evidence provided by instructors in subsequent lab courses and feedback from co-op employers also will be useful in assessing the new approach to lab report writing. Specifically, the authors want to know whether students retain their report writing skills as they move to the next lab. (See Appendix B for a list of labs subsequent to ENGR 3270 and the semesters/years they are taken.) The ultimate goal, of course, is to retain the skills, build on them, and enter the workplace with competency in this area.

Since it is unlikely that lab course credits will rise above the one-credit/course level, another challenge is to find ways to motivate student interest and performance in report writing. The industry statistics provided at the beginning of this paper should be shared with students to reinforce the demand for engineers who are strong writers and presenters. Actual successful writing within the laboratory experience is one of those transferable skills that underpin a career in the engineering fields.

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## Appendix A: Description of the Experiments

**Table A-1: Description of each experiment, including testing and analysis**

| Experiment | Type of testing | Details of analysis and results |
|---|---|---|
| **Hardness testing of metal** (group report) | Brinell and Rockwell hardness determination<br>Three types of metal | Determine hardness values. Use published relationships to convert from one scale to another and estimate strength values. |
| **Tension testing of metals** (group report) | Tension testing<br>Cast iron and two ductile metals | Calculate strain and stress values and plot the stress – strain curve. Determine Young's modulus and strength. Calculate percent elongation and percent reduction in area. |
| **Tension and shear testing of plastics** (group report) | Tension and simple shear testing<br>Three types of plastic | Calculate strain and stress values from the tension test and plot the stress – strain curve. Determine Young's modulus and tension strength. Calculate shear stress values from the shear stress and plot the shear stress – displacement curve. Determine the shear strength. |
| **Strength testing of wood** (group report) | Flexure, compression parallel to the grain, and compression perpendicular to the grain<br>Three types of wood | Calculate strain and stress values and plot the stress – strain curve. Determine Young's modulus and strength. |
| **Torsion testing of metals** (individual report) | Torsion testing<br>One type of steel | Calculate strain and stress values and plot the stress – strain curve. Determine shear modulus and strength values |
| **Aluminum beam bending** (homework) | Measurement of strain in the beam and deflection of the beam over a sequence of loads | Calculate measured the stress from the strain gage. Calculate theoretical stresses and deflections. Compare the results. |
| **Column buckling** (homework) | Compression testing of thin steel rods with different diameters, lengths, and end conditions | Calculate experimental and theoretical buckling stresses and compare the results. |
| **Thin-walled pressure vessel** (homework) | Measurement of strain in a steel tank | Calculate the stress in the vessel. |
| **Design for strength and stiffness of beams** (homework) | Measurement of the load – deformation response of simply-supported beams loaded with a concentrated fore at mid-span | Compute moments of inertia and section moduli. Predict which section will have the highest strength and lowest deflection. Compare the theoretical and experimental results. |

## Appendix B: Laboratory Sequence by Semester and Type

**Table B-1: Engineering Laboratory Class Sequence in Civil Engineering, Architectural Engineering, and Mechanical Engineering**

| Year | Term | Program | | |
|---|---|---|---|---|
| | | **Civil Engineering** | **Architectural Engineering** | **Mechanical Engineering** |
| Sophomore | Winter | ENGR 3270 | None | ENGR 3270 |
| Junior | Fall | ENGR 3270*<br>Geotechnical engineering | ENGR 3270 | ENGR 3270* |
| | Winter | Construction materials | Fluid mechanics<br>Construction materials | Fluid mechanics |
| Senior | Fall | None | Geotechnical engineering | Manufacturing processes<br>Heat transfer |
| | Winter | Water and wastewater engineering | None | None |

* - Students in these programs typically take ENGR 3270 in the winter of the sophomore year. If students are off-track, they may take ENGR 3270 in the fall of the junior year. Reasons include not starting with adequate math skills, changing majors, transferring, or receiving a poor grade in a pre-requisite course