Integrating Technical Writing into a Large Lecture Course

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Abstract

Technical writing was incorporated as an integral part of a large lecture, undergraduate subject in biomedical engineering. The writing component was designed and implemented in a collaboration of technical and writing professionals at MIT, which led to a tight integration of the writing process with two research projects: an experimental project in a wet lab and a theoretical study using computer simulation. For both projects, students worked in pairs to develop a formal proposal and draft a 10-page scientific paper. After receiving substantial feedback from the technical staff, writing staff, and peers, students revised their manuscripts. Comparisons across drafts suggest that peer-review, staff critiques, and the opportunity for revision are all critical to the educational process. Although written feedback is staff intensive, we have found that teaching assistants can be taught to provide excellent feedback, and in so doing, learn an important professional development tool.

Introduction

Since the 1980's there has been substantial research on the ways writing can improve learning in science and engineering.[1] "Writing-to-learn" research has been guided by the theory that language does not merely reflect knowledge, rather knowledge is constructed through language. Perhaps because of this theoretical orientation, writing-to-learn research has focused on informal or expressive modes of communication to promote learning. However, research on the effects of teaching scientific genres of communication has been less well documented.[2] In our work, we attempt to understand how learning to write scientific genres of communication can improve the acquisition of technical material. We believe that teaching students a disciplined approach to scientific communication, which includes substantial feedback, has enormous benefits in the learning process. In this project, we describe a 10-year collaboration between MIT's Department of Electrical Engineering and Computer Science and MIT's Writing Across the Curriculum Program that has led to important insights into the value of integrating technical and written instruction. During this ten year timeframe, we have attempted various methods of collaboration, including adding a writing workshop to the class and adding an additional technical writing course in biomedical engineering. These efforts, however, were only partially successful for two reasons: (1) students' schedules are often filled with required courses, so they have little time for non-required courses, and (2) technical content and the writing instruction often do not remain in synch, so it is difficult to keep parity across the two courses. Since 1999 communication instruction has been integrated with the teaching of technical content in the course. In that time we have found that integrating technical content and communication improves student learning by (1) linking the scientific research process with the exposition of scientific findings, (2) identifying high-level misunderstandings of technical content that are only obvious when students provide a written explanation of their research results, and (3) providing students a forum for giving and receiving substantial feedback on their research writing. Finally, an unexpected result of integrating technical content and communication instruction has been its effect on teaching assistant education. By educating teaching assistants on how to integrate writing and technical content in an efficient, meaningful manner, we have found that we offer the next generation of science and engineering educators a template for best practices in science education.

Context

The site of this collaboration is a large-lecture, undergraduate course in biomedical engineering at the Massachusetts Institute of Technology. The subject, which is called Quantitative Physiology: Cells and Tissues, teaches students the principles of mass transport and electrical signal generation for biological membranes, cells, and tissues. In this course, writing is associated with two projects: an experimental project in a wet lab and a theoretical study using computer simulation. Each project lasts approximately 5 weeks and is carried out in parallel with lectures, recitations, and homework assignments.

For both projects, the technical faculty presents a lecture that describes the research goals and resources that are available. Students then work in pairs to develop a formal proposal for their project. Students may choose from existing projects or develop their own novel approach. Each proposal must provide a rationale for the research question and a proposed methodology. The proposals are then submitted for review. Lead faculty and teaching assistants work together to develop criteria for successful proposals. Initially, approximately 75% of proposals are rejected because the students' research approach is too broad or methodology is unfocused. After receiving substantial feedback, students revise and resubmit their proposals until their research approach is approved. The revision process helps students sharpen their research approach so that they make better use of their time in the lab. The revision process also helps the teaching assistants to better understand the scope of a good project. As a result, the teaching assistants are better informed to coach students during the execution of the research projects.

While students are conducting their research experiments, the technical faculty and writing faculty collaboratively present a lecture on how to prepare a written report of research findings (for the first project) or how to prepare an oral presentation of research findings (for the second project).[4] Both lectures introduce a *process-based approach* (described below) that explicitly links the scientific and communications aspects of research. As students formulate technical reports, they clarify the technical issues for their readers as well as for themselves. Increasing clarity not only improves student reports, but also improves students' research processes.

The lectures introduce a specific and highly structured format for technical papers that is typical of the structure used in professional journals. We describe 5 major sections: Abstract, Introduction, Methods, Results, Discussion. In addition to describing the content of each section, we also motivate how the structure of a scientific report facilitates a specific kind of reading process used by scientific readers. This introduces the notion of *writing for an audience* (described below) which differs significantly from writing for a single individual, such as a teacher.

Students then experience what it is like to write for an audience by submitting 3 copies of their first drafts for critique. One draft is reviewed by the technical staff, one draft is reviewed by the writing staff, and one draft is reviewed by a peer student group. The critiques are then discussed at a *writing workshop* so that each pair can speak face-to-face with their critics.

Finally, students revise their work and submit a final draft of their report. The report is graded using a *multi-dimensional rubric* (described below) designed to highlight the multi-dimensional challenges of technical communication.

Process Approach to Writing

While students are working on each of the projects, the technical and writing staffs provide a joint lecture on how to formulate written and oral research reports. On-line materials are used to supplement the lectures and include a course style guide and guidelines for authors, similar to those found in professional journals.[3]

One goal of the lectures is to move beyond a simple explanation of scientific communication genres to illustrate the role of writing in the scientific research process. Rather than describing research and writing as separate activities, we outline a multi-step process that smoothly transitions from synthesizing research findings to report writing.

The first step is to define one's principal results by constructing 5 or 6 specific figures that summarize the findings. The figures can be hard copies of data obtained in an experiment or simply hand-sketched figures of expected results. The point is to assemble the 5 or 6 specific figures into a "storyboard." The storyboard is important for developing cohesion across the individual figures.

By developing a storyboard, students also focus on what information is, or is not, important in each of the figures. The storyboard thus leads to the second step in the research writing process, which is to refine the figures to focus on the major theme, that is, the "narrative" of the report. For each figure, students are asked to identify the 2 to 3 points that are most important for the audience to understand. If the list for one figure contains more than 3 important points, we suggest that the student consider whether the points might be more clearly made with more than one figure. Similarly, if there is only a single interesting point associated with a figure, it might be possible to merge figures to more meaningfully show trends in the findings. The goal in this step is to incorporate all of the interesting results into a logical and uniformly paced presentation of the research findings.

Used in this manner, the storyboard is the primary "bridge" between the research and writing efforts. The bridge runs in both directions. It becomes the technical outline for further work in drafting the manuscript. It also explicitly clarifies the research findings, often exposing problems or insights in the research. After constructing a storyboard, students often make significant changes to their research approach and obtain new data.

With storyboard in hand, students begin the third step in the research writing process, which is drafting the manuscript. To facilitate joint authoring, we suggest pairing Methods with Results and the Introduction with the Discussion. The storyboard described above represents an outline for the Results section. Writing the Results section of the report is a relatively straightforward process of crafting text to develop the important points of the storyboard. Methodological details that are used to produce the Results are then condensed into a separate Methods section, so that these details do not interfere with the main technical exposition, which is the Results section. As such, the Methods and Results together create an organizational "unit." The storyboard also provides sufficient technical detail to craft an Introduction and Discussion. These sections can also be thought of as a unit. The Introduction should provide the necessary background to motivate interest in the project. The Discussion should explain interpretations of the results. Thus, both the Introduction and Discussion sections require a high-level appreciation for what the storyboard represents. Furthermore, it is essential that this same high-level view be contained in both sections. If the topic of discussion differs from the one that was introduced, the reader should properly feel misled.

We believe that the storyboard represents a powerful tool, allowing multiple authors to write a coherent report. However, even with a well-constructed storyboard, it is essential for each student to read the manuscript as a whole, and revise the contents for consistency and proofreading errors.

When the first drafts of the Introduction, Methods, Results, and Discussion sections are complete, students are then ready to write an Abstract. Students find it counterintuitive to write the abstract last. Inexperienced writers often try to write the sections of technical papers in their published order. However, as experienced writers know, a coherent abstract is much easier to write after the results and implications are clear.

This process-approach to teaching scientific writing illustrates the non-linear composing process used by professional researchers. This approach also shows students that scientific writing is not merely about documenting research, rather scientific writing is about actively generating meaning out of research findings. In this sense, students "construct" scientific knowledge through language. One student explained that the most valuable lesson she learned about scientific communication was as follows: "It's not about forming a hypothesis that you can prove to be right. It's about reporting what you've observed and trying to explain why [you found those observations] in the most logical way possible."

Writing for an Audience

Another goal of the communications lectures is to shift the focus of writing from writer-based prose to reader-based prose. In particular, we are interested in teaching students to write for a scientific community, not for a single teacher or for themselves. Scientific writing is a disciplined approach, much like scientific research itself, and the goal in writing a technical report is readability, not self-expression. Readability means (1) clear, simple prose that is not laden with jargon or vague expressions, (2) use of a standard format so it is easy to locate data and to compare experiments (methodology, results, etc.), (3) appropriate use of technical vocabulary, and (4) effective document design and use of figures.

Moreover, technical manuscripts are often organized in a highly constrained fashion that is not particularly easy to write, especially for beginners. To write effectively in the highly constrained fashion required by most technical journals, it helps to understand the utility derived by the constraints. Practicing scientists typically read orders of magnitude more articles than they write. Therefore, efficiency for reading outweighs efficiency for writing. Furthermore, technical literature is rarely read sequentially. Non-sequential reading is a novel concept to students whose principal experience with technical information is from textbooks. Unlike students who read in a chronological fashion, professionals read in a non-sequential fashion. Abstracts are frequently read first, because they are concise and because they are compiled into collections that are readily available, often in on-line databases. The Introduction and Methods can often be skipped if the researcher has experience in the field, so Results are usually read second. Well-designed figures can often stand alone to provide the most rapid access to content in the Results section. Meaningful figure captions are imperative for scientific readers who are skimming articles.

As students realize the utility of conventional scientific writing structures, they more readily develop an intuitive grasp of what information belongs in each section of a report. More importantly, they learn how the structured nature of scientific communication lends accessibility to a global community of technical readers. Often students have never had to truly wrestle with the notion of audience beyond their immediate professor. In the practice of using scientific communication, however, students learn that communicating scientific research results extends beyond the immediate classroom to the larger scientific community.

Critiques by technical staff, writing staff, and peers

First drafts of the students' reports undergo a parallel review by peers, technical staff, and writing staff. Each reviewer offers feedback to connect technical content with exposition of ideas. Feedback about formation of technical knowledge can be summarized as, "How can we help students clarify their understanding of technical ideas?" Writing often reveals high-level misunderstandings of technical information. As a result, feedback often includes questions to probe students into thinking about how and why they found certain results. Feedback about exposition of ideas can be summarized as, "Can we understand the rationale, process, results, and data analysis of the experiment so that there is an over-arching narrative to the report, supported by each section of the report?" Each part of a report should link together to create a "research narrative." Feedback about exposition encourages students to think not just about grammar but about the "readability" of their writing, including the synthesis of written text with equations and graphics to effectively and efficiently convey meaning to readers.

Comparisons across drafts suggest that peer-review, staff critiques, and the opportunity for revision are all critical to the educational process. The parallel review process highlights to students that readers have various interpretations and that writers must balance these interpretations in revising their manuscripts. Only through feedback from outside readers do students learn how to craft reader-based prose. This approach leads to a sense of audience-awareness, or as one student explained, "I realized what makes sense to other people."

In addition to increasing audience awareness, revising encourages students to repeatedly grapple with fuzzy technical explanations, and in the process, overturn naive misconceptions about technical concepts. Just as important, revising their work reinforces to students that scientific research is an iterative process. We repeatedly return to our research results to clarify our ideas and develop new theories and interpretations.

Giving feedback on a first draft and grading a second draft is, of course, more work than simply grading a single draft. However, offering feedback is not twice as much work. We have found the feedback can be given more quickly than grading, because fairness and grades need not be considered. When giving feedback, we try to point out all possible criticisms, without regard to whether it is "fair" to hold students accountable for the errors (although it is important to explain to students that the apparent harshness of the criticism is intended to help them craft a better final draft). Reading a second draft for grading is also easier than reading a single draft. In the second draft, students have clarified their ideas so that the written presentation of their work is much easier to follow.

Multi-dimensional Scoring Rubric

Students' revised, final manuscripts are graded using a multi-dimensional rubric that assesses technical insights, conceptual correctness, and structure and clarity of their reports. Additionally students are graded on the completeness of their first draft and on the helpfulness of their peer critique. Letter grades are assigned for each of these dimensions, and the students final report grade is a weighted average of the letter grades. The weights are given in Table 1.

Table 1: Multi-dimensional scoring rubric.

10%	Completeness of First Draft
5%	Peer Critique
15%	Report Structure
10%	Clarity and Conciseness of Exposition
10%	Clarity and Conciseness of Technical Information
20%	Conceptual Correctness
30%	Insightfulness

The multi-dimensional scoring rubric replaces traditional holistic grading in which students receive a single letter or numerical grade. The goal of this assessment approach is to draw student attention to the multi-dimensional qualities of professional writing as well as create a link between feedback style and grading. Using this multi-dimensional rubric, students can more easily identify which aspects of their work they need to improve for their second project report.

Assessment

Assessment of student learning has shown that writing two drafts of a single report (first draft and revised final draft) is far more successful for student learning than writing a single draft. When students write two drafts of a single report, the average grade from draft to final increases by approximately one letter grade. The average grade after feedback and revision is 4.52/5.0

(90%). Although we have emphasized research report writing for more than 10 years in this class, we have only offered feedback on first drafts for the past five years. In the years before we required second drafts, students wrote only a single, final report for each of two projects. Although students' second reports were marginally better than their first reports, presumably because some of the instruction carried over, their work was still often poor. However, now with required revision, the first drafts for the second experiment are much better. We believe that meaningful feedback combined with revision has led to better student writing in subsequent projects, and we are working on measures to assess that improvement in a formalized manner. From our current qualitative assessment perspective, we have found that the reports are generally better organized, include more judicious use of figures, and evidence greater attention to detail. As a result, we can focus our efforts on further clarifying and refining student understanding of concepts rather than correcting major misunderstandings in report organization and presentation of findings. In fact, because student writing has improved so dramatically through the revision process of the first report that many of these first drafts for the second project are acceptable as final drafts!

We have also found through successive iterations of the course that comments made by technical faculty and writing faculty have come to correlate more closely. This effect has been the result of clarifying our expectations for student learning. Technical and writing faculty repeatedly discuss the distinctions between various aspects of the grading rubric and the attributes of "good" writing. By clarifying the distinctions between these categories and their commonalities, we have come to better consensus about the qualities of a "good" report. In this way, assessment has become a method of faculty development for both the technical faculty and the writing faculty.

The benefit of our process approach is also apparent in student surveys. At the end of semester we ask students to assess the course curriculum (Table 2). Several of the most important findings from this assessment have been about revision, collaboration, and the value of communication instruction. Approximately 95% of students who returned this year's course survey said that we should *not* eliminate the revision process. Other survey questions revealed that students recognized the value of communication instruction in the course, and did not feel that it detracted from the technical content.

Table 2: Summary of student surveys. Left column displays suggestions and the right columns show the number of students that strongly agree (YES!), mildly agree (yes), mildly disagree (no), strongly disagree (NO!), or were ambivalent (?).

	NO!	no	?	yes	YES!
Should reduce emphasis on writing and speaking in this class	11	13	7	6	2
Should eliminate first drafts of written reports	22	16	2	0	0
Emphasis on writing detracted from technical content	8	15	9	7	1
Should eliminate lectures on writing & speaking	10	17	4	4	5
Projects should be done individually rather than with partners	24	12	3	1	0
First project reinforced the technical content of the class	5	8	9	13	5
Second project reinforced the technical content of the class	1	1	2	21	15

We also collected longitudinal assessment data regarding attitudes towards writing experience and confidence. In a pre-course survey we asked students questions about their experience and comfort levels in writing technical documentation:

- How much experience do you have writing technical documents?
- How would you describe yourself as a writer?

At the end of the semester we returned to these questions and asked students the following:

- How much experience have you gained writing technical documents?
- How would you describe yourself now as a writer?

On the pre-course survey, 52% of students said that they had "some experience" or "extensive experience" in writing technical documents (Table 3). At the end of the semester, 76% of students reported that they had "some experience" or "extensive experience" in writing technical documents.

Table 3: Students Responses to Survey on Writing Experience Levels

	none	not much	some	extensive
Pre-Course Survey (n=72) How much experience do you have writing technical documents?	13%	35%	44%	8%
Post-Course Survey (n=38)* How much experience do you feel that you have gained in writing technical documents?	0%	24%	54%	22%
* This "n" does not reflect the final course enrollment. The final survey was distributed at an optional course meeting.				

At the end of the course, students also reported that they now felt more "confident" as writers. At the beginning of the semester, 8% of students reported that they were 'weak" writers. At the end of the semester, no students reported that they were "weak" writers. This trend followed across the other categories, as well (Table 4).

Table 4: Students Responses to Survey on Writing Confidence Levels

	weak	somewhat confident	confident	very confident
Pre-Course Survey (n=72) How would you describe yourself as a writer?	8%	36%	52%	4%
Post-Course Survey (n=38)* How would you describe yourself now as a writer?	0%	8%	79%	14%
* This "n" does not reflect the final course enrollment. The final survey was distributed at an optional course meeting.				

In addition to showing that students are aware that they are gaining experience in writing technical communication, the results also show that there is a link between perceptions of experience and student writing confidence levels. Gaining experience and gaining confidence are not necessarily co-occurring variables. Students must feel ownership of the material in order to develop confidence in the material.

The pre-course/post-course surveys also serve as a way to collect data about the kinds of writing experiences that students have had at the Institute. For example, at the beginning of the semester we ask students:

- What kinds of technical communication have you written?

- What kinds of feedback have you received on your writing?
- Have you worked collaboratively with a peer or mentor before?

At the end of the semester, we ask students:

- Do you think that you learned more by working with a peer than working alone in this course? Why?

The answers to these survey questions help us shape course curriculum. For example, if many students have not worked collaboratively with a peer or mentor, then we teach collaboration skills. If students have never received feedback on drafts of their work, we teach them how to integrate comments while revising their work. One of the other advantages of this kind of assessment data is that it provides a "snapshot" of student learning at one point in their academic careers. Such data are important when making decisions for curricular changes or program review.

Teaching Assistants

Although written feedback is staff intensive, we have learned that writing instruction also makes an important professional development tool for teaching assistants. Most of the interaction with students is provided by teaching assistants, who have been explicitly trained by lead faculty on how to assess proposals, first drafts, and final manuscripts. When teaching assistants participate in the assessment of student writing, they become much more cognizant of student learning. Most importantly, by educating teaching assistants on how to integrate writing and technical content in an efficient, meaningful manner, we show our future peers a "best practice" in teaching scientific communication education.

The most compelling evidence of TA involvement comes from TA insights about teaching and learning. One TA observed:

> Communication aspects of Quantitative Physiology demonstrated a student's ability to not just understand the material but also to convey that understanding. While writing a paper/giving a presentation, students must explain their reasoning behind their statements. This was interesting from a TA perspective, as it gave us immediate feedback on how the students were picking up information/understanding of what we had explained to them earlier. When reading explanations in some of the papers, some of the confusion that students were having became clearer, so it became easier to fix that, instead of being at a general loss of where the students' reasoning was incorrect.

Conclusions

By integrating the research and writing process in undergraduate science courses, such as the course described here, students learn a variety of skills that are central to the professional scientific research process. We believe that the model presented in this paper for integrating writing into a technical subject has been an enormous success for students, faculty, and TAs. In this course, students were taught to bridge research and writing through development of a "storyboard." By giving students significant feedback from multiple readers, students had to wrestle with how to make their work readable to a wider audience. Finally, students could track their development as technical communicators through a multi-dimensional scoring rubric that has been developed over time through a close collaboration between technical faculty and writing faculty. For the student, the educational value of translating research to report transcends the value of specific knowledge gained in the subject matter. Through the act of translating information from numerical to written form, students learn how scientific knowledge is generated. Furthermore, by educating teaching assistants on how to integrate writing and technical content in an efficient, meaningful manner, we show the next generation of science and engineering educators the integral role of writing in making scientific knowledge.

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Notes

4 The methodology described in this paper was used for the first time this year with oral reports. Rather than asking students to write a written report for their second project, we asked them to give an oral presentation of their findings. Like with the written reports, we required drafts of presentation slides and scripts. Technical faculty, writing faculty, and peers provided critiques of student presentations at a "dry run" session, and then students revised their presentations into a final oral presentation. Results show that the technique that we developed for written reports clearly generalizes to oral presentations as well.

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