Integrating Engineering and Communication: A Study of Capstone Design Courses

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Abstract - This paper presents results from a study investigating the use of Problem-Based Learning (PBL) as a framework for integrating communication into engineering courses. The results of a two-year study of capstone design courses suggest that PBL provides the opportunity to develop communication assignments that enable students to understand not only particular document formats, but also the role texts play in the workplace for both writers and readers. Surveys and interview data demonstrate that students learn to use texts as tools to advance engineering work and communicate key project information to managers. The framework thus effectively helps students treat communication activities as a critical element of professional engineering practice.

Index Terms - communication, capstone design, project management, writing, problem-based learning

COMMUNICATION AS PROFESSIONAL PRACTICE IN THE PROBLEM-BASED LEARNING DESIGN COURSE

As Dorothy Winsor’s seminal study of engineering communication suggests, one of the key differences between novice engineers (typically students entering the engineering workplace) and experts is their perceptions of how texts function in the workplace and what roles readers, and more importantly, writers play with respect to those functions.[1] Novices treat texts as neutral reports of information, often completed after the fact, structured according to set formulas or rules. Experts, on the other hand, view texts as having important persuasive roles that shape how audiences receive and understand information—for instance, whether they respond positively or negatively to test results, what decisions they make with respect to those results, and how they report results to other parties within and outside organizations.

One way to frame this dichotomy is by distinguishing “good writing” from “effective communication.” Good writing, as novices understand it, is an abstract ideal marked by specific textual features—grammatical and mechanical correctness, smooth transitions between sentences, coherent paragraph structures, and the like. These features are, no doubt, important and worth teaching. But effective communication as practiced by experts involves something far more complex, as recent work in technical communication theory suggests (e.g. [2], [3], [4]). Communication is a transaction between individuals in specific contexts to accomplish particular goals. In the language of activity theory, texts are mediating artifacts that writers/speakers and readers/listeners use to accomplish external goals.

Importantly, being “good writers” does not automatically make students “effective communicators.” Texts that are elegantly written or that follow the correct document formulas may still not achieve the desired outcomes if the writer fails to take into account the needs, interests, and goals of the particular audience in the particular situation at hand. For example, a student may consider a proposal as a document that follows a specific format: an executive summary, a statement of need, a project description, a project plan, a budget, and a statement of qualifications. The “formula” is the operative identifier. However, experts treat a proposal as a tool whereby those with money to spend and goals to achieve select “worthwhile” individuals or organizations to receive the money and achieve the goals.

Within that activity system, the written proposal is often only one of multiple texts used in the transaction; phone calls, face-to-face meetings, pre-proposals, statements of qualifications, and similar texts may all play critical roles in the larger activity of earning and spending money to achieve desired outcomes. Thus an NSF proposal that follows the specific guidelines defined in the Guide to Writing Proposals must still address the broader impact in terms that matter explicitly to the program writing the solicitation. In addition, principle investigators also frequently contact program managers by phone or email, visit NSF offices prior to submitting grants, suggest proposal reviewers with particular expertise in the area in question, and thus create a whole set of written and oral texts around the individual proposal itself.

Given that communicating involves far more than grammatical correctness and readable style, then, the question for engineering educators is “How do we design and sequence instruction in communication to best prepare students for the roles they (and their texts) will play in professional contexts?” Paretti has written elsewhere about specific guidelines for designing effective assignments and grading rubrics based on solid theoretical frameworks[5]; in this paper, we concentrate on the larger pedagogical framework for fostering student learning. Specifically, within the context of problem-based learning (PBL), this paper presents Year 2 results of a four-year study concerning students’ uses of texts in capstone

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design courses. Because PBL displaces course instructors from center stage and relies instead on self-directed student learning, it provides an ideal setting for helping students understand the role of texts in professional practice. By serving as mentors, advisors, and managers, faculty in PBL settings can more readily show students how texts such as project proposals, progress reports, and team meetings serve to help all participants manage and develop design projects.

**COURSE DESCRIPTION: PROBLEM-BASED LEARNING AND CAPSTONE DESIGN**

This study investigates the viability of problem-based learning and related strategies as pedagogical tools for helping students understand and practice the ways in which texts function in the workplace, particularly with respect to the design process. It looks at two capstone design courses, one in Materials Science and Engineering (MSE) and the other in Engineering Science and Mechanics (ESM). Both courses are team-taught by an engineering faculty member and a communications faculty member (Paretti), though in Year 2 the MSE course was taught almost exclusively by Paretti. In both courses, students work in teams of two to five\(^3\) to define and complete an open-ended design project over two semesters.

Because these projects are open-ended, we have chosen to approach the course through a problem-based learning model. Students select and define their projects with the help of an advisor (typically not one of the course instructors), who supervises the technical dimension of the work. Course “lectures” focus primarily on project management and communication issues; students are expected to draw on past knowledge and (guided by their advisor) search the literature to gather the requisite technical expertise to complete the project. The course instructors position themselves as project managers; our goals are to insure that the students complete the projects on time so that they can present their work to the entire faculty at the conclusion of the spring semester.

Most of the class time is devoted to talking about the projects themselves as a class, including where the students stand, what problems they’ve encountered, what preliminary results they’ve found, and so on. The whole class is expected to comment productively on each project by, for example, offering suggestions for handling problems or critiquing design decisions. (Elsewhere Paretti has provided a more detailed discussion of this approach [6].)

In working through the design project, students complete multiple communication assignments:

- A written proposal to demonstrate 1) that the project satisfies the course goals and ABET criteria, and 2) that the students have a workable plan to complete the project.
- An oral proposal/preliminary design review, in which students present their plan to the class for critique.
- Laboratory notebooks to track experimental methods, data, design ideas, meetings, and related information.
- Formal written and oral progress updates throughout the semester (one in the fall and two in the spring) to update classmates and course instructors on the project status and solicit feedback regarding problems or challenges
- Informal biweekly reports on specific elements of the project status (e.g. budget, schedule)
- Formal written and oral reports at the conclusion of each semester to present the findings and results to the class (fall) and the whole department (spring).

In short, the document sequence reflects texts engineers typically produce in the workplace, where communication tasks range from weekly team meetings to review project status to formal presentations before clients to deliver results.

In each case, faculty frame these assignments explicitly as tools for 1) helping students manage their work and 2) helping course instructors (i.e. project managers) keep up with all the projects and ensure that students are meeting deadlines and making progress. The progress reports in particular serve as tools for assessing how well teams work together, what each team member contributes, and how effectively the teams are progressing toward their deliverables. The assignment descriptions, grading rubrics, and course handouts all emphasize the functionality of these texts within the scope of the design process. For example, the proposal assignment opens with the following explanation: “To receive approval to go ahead with your project, you need to submit a proposal to the course instructors as well as to your advisor. Note that you must receive approval before we will allocate funds … for your work.” The proposal solicitation is modeled on the NSF program solicitations, and the section describing proposal evaluation explains,

“The course instructors will evaluate proposals based on four key factors:

- Does the project successfully satisfy the relevant ABET criteria?
- Does the project address a significant need?
- Does the proposal reflect the investigators’ understanding of relevant prior research so that they can successfully proceed with the project?
- Is the project feasible? Can the investigators complete the required tasks within the allotted time and budget?”

Similarly, the grading rubrics mirror the use value of the assignments with criteria such as “Does the project description justify the importance of and need for the project, using relevant research?” and “Does the project plan effectively prove that you understand the demands of the project and have a clear plan for completing the work?” Table 1 presents part of the grading checklist for the oral proposal (additional criteria address speaking style, including talking to the audience rather than the slides, moderating tone and speed, and so on). Each criterion is checked as either Excellent, Good, Average, Poor, or Not Done, and the final grade is holistic.

\(^3\) Students in MSE who are completing an Honors Thesis may choose to work alone; in Year 1, no MSE students worked alone, but in Year 2, one student worked solo. In addition, in ESM in Year 1, four students worked alone; solo projects are no longer an option in ESM, however.
Course discussions of these assessment support this framework in which texts are useful to both writers and readers by focusing on how documents function in the workplace and directly relating formats and organizational structures to those functions. Moreover, pieces of various documents recur throughout the semester as the basis for project discussions and management. For example, students review the deliverables, Gantt charts, and budget defined in the proposal in each subsequent report, updating each as needed in light of new developments. 

Taken together, the class discussions, assignment handouts, and grading rubrics create a framework in which written and oral texts are an integral part of professional practice. The approach emphasizes the ways in which the needs of readers and writers and the functions of texts are central to the process of composing and disseminating technical information. The study thus focuses not simply on the assignments themselves, which are all often part of capstone design courses, but rather on the framework in which they operate. The assignments are considered not simply mechanisms to measure student knowledge or check adherence to certain professional formats, but rather as tools to help both student groups and faculty advisors develop and manage the design project in ways that facilitate success.

### DATA COLLECTION METHODOLOGY

Data for this study consists of anonymous student surveys conducted at the beginning and end of each capstone course, faculty comments regarding student performance, and interviews with students about their work during the design project. Year 1 involved 16 students in ESM and 17 in MSE; Year 2 involved 17 students in ESM and 16 in MSE.

The student surveys asked members of the design courses to use a 5-point Likert scale to rate both the value of the communication assignments with respect to their future careers and the usefulness of the assignments with respect to their current projects. In the survey, a value of 1 corresponded to “Not valuable/useful at all” and 5 corresponded to “Extremely valuable/useful.” In addition, students could comment on why they did or did not consider the assignments valuable or useful. For simplicity throughout this paper, we use “valuable” to refer to student perceptions regarding the role of these assignments in their future careers, and “useful” to refer to the role of the assignments with respect to the capstone project. Written and oral faculty surveys asked both project advisors and faculty attending final presentations to rate the merits of student projects.

Interviews asked students to describe their work on the communication assignments and how those did or did not impact their work on their engineering projects. Eight students participated in 30-minute interviews about the communication assignments. Because Paretti served as the course instructor, Burgoyne conducted the interviews to mitigate bias in the responses. To preserve anonymity during the academic year, and thus avoid the appearance of any influence on student grades, students knew that Burgoyne would not reveal who participated in the voluntary interviews, and that transcripts would be withheld until after the course ended.

### FINDINGS: THE VALUE OF PROJECT PLANNING AND INTERMEDIATE ANALYSIS

The findings from Year 2 confirm the Year 1 findings (2003-04 courses) reported elsewhere.[7] regarding the gains offered by the course structure.

#### Student Surveys

Surveys conducted during the first two years of the study show that students rate both the future value and the current usefulness of the communication assignments highly. Results from Year 1 show that on average, students rated the communications assignments at 3.99 in terms of current usefulness and 4.15 in terms of value. Importantly, based on student and faculty feedback from Year 1, Year 2 included several changes, including complete consistency across both MSE and ESM courses, the addition of laboratory notebooks, and the addition of informal weekly reports in the fall. On average, halfway through Year 2 (at the end of Fall 2004), students rate the usefulness of all assignments combined at 3.76 and the future value at 4.22. Figure 2 summarizes students’ perceptions of the usefulness of various assignments at the end of Year 1, the beginning of Year 2, and halfway through Year 2 [final article will include updated results for end of Year 2]. Figure 3 summarizes perceptions of future value over the same period.
Importantly, as the Year 2 – August results show, students come to the capstone course with a high level of expectation concerning both the usefulness (4.1 overall) and future value (4.11) of the assignments. Those expectations are not surprising given the scope of the communications program in both departments, the amount of writing and speaking students do in the sophomore and junior years, and the ways communication is talked about in the curriculum. In addition, given that more than half of the students in each program had co-op, internship, or other workplace experiences, their assessments of future value reflect the practices observed in their respective workplaces.

The small sample size and the addition of the oral project proposal review in Year 2 limits the conclusions that can be drawn from the slight decline in usefulness and increase in future value. Data collected over the remaining 2 years of the study should provide more information regarding those trends. However, data from both years and both courses confirm the following trends:

- Written documents are rated as both more useful and more valuable than oral presentations.
- The future value of all assignments is rated more highly than the current use.
- Planning documents (particularly the proposal) are rated more highly than summative documents (final reports).

Students’ written comments on the survey support these conclusions. In Year 2, for example, 10 of the 17 ESM students commented directly on the usefulness of the written documents in planning and tracking the project; in MSE, 13 of 16 students made similar comments. Sample remarks include:

- “Proposal – set a plan to address the project”
- “Timeline definitely motivated the team to get working”
- “Organization, organization, organization! [Microsoft] Project [software] really made you see what you’ve already done and what still needs to be completed.”

While the usefulness of these assignments regarding project planning dominated the comments, some students in each class, particularly in Year 2, also reflected on the ways the assignments helped them analyze their work as they went:

- “The lab notebook was valuable when discussing problems with our advisor”
- “All of the assignments gave us perspective on our project”
- “…these assignments helped us keep our project goals clear”
- “Most of the assignments helped in making the project, and the goals more clear”

The quantitative results and written comments suggest that students do understand the role texts play in managing projects and are, over the course of the year, using the written and oral documents to track progress, adjust plans, and stay focused.

Not all students, however, were positive. One student in particular gave universally low ratings in all categories – 1 for the current usefulness of all assignments and 2 for the future value. The comments reflected both a high level of frustration and a sharp lack of understanding about communication. In explaining the ratings, the student wrote, “I can read/examine technical papers and write in that format once I need to for a job, but it's a bad use of valuable time for busy seniors.” The time factor is significant, and the one students feel most burdened by as they try to hone their technical skills in an unfamiliar, open-ended design project.

**Faculty Response**

Importantly, faculty responses to student work suggest that not only did students perceive improvements in their ability to manage projects and communicate their findings, but that perception translated into notable results. In MSE, in particular, faculty comments were telling. The department is small enough to allow most faculty to know the students – and their abilities – quite well. In addition, several faculty have a long history with senior design projects and have seen final student presentations over the past 3-5 years, or longer in some cases. In response to these year-end presentations, the one consistent theme among these faculty was the quality of the work done by students normally at the lower end of the class. Faculty noted (often with some surprise) that all the student presentations were strong, that all speakers sounded professional, and that all groups had made significant progress and reported substantial results. That is, no one was particularly surprised that the students at the top of the class completed projects successfully and presented results professionally, but several faculty specifically noted that those students not normally considered “top performers” produced
substantial results and presented those results articulately. The faculty responses provide the most critical measure of the model’s success to date because they situate these results against prior courses operating under different pedagogical models. Planned external assessments of projects from the past several years will expand this contextualization.

Student Interview

The interview results support key aspects of the survey data, but also highlight key areas for programmatic revision. Not surprisingly, the most often noted benefit dealt with keeping the projects on track and continually reassessing progress in light of deadlines. As one student explained, “After a couple of weeks working on something, it’s easy to lose track of where exactly you stand, what you are working towards. And the progress reports helped us pin that down and get back on track.” Similar comments surfaced in almost every interview. One student in particular noted, “Not only is it a presentation or just a paper, it’s a reference for us.”

In addition, most students noted the ways in which the documents built on each other so that the reports were developed as the project progressed, giving them a chance to revise parts repeatedly and not face a daunting task at the semester’s end. Interestingly, though students found the progress reports themselves useful for staying on track, no one used the Gantt charts explicitly as a management tool; the charts were updated only because we required a current version each time.

More complicated, however, were the gains in students’ sense of audience and the functionality of these texts. In many respects, despite the PBL framework, students still perceived the course instructors as graders first, and were conscious of having their projects and the various documents graded. On being asked how the course faculty used the reports beyond grading (e.g. to manage the projects or make decisions about the course – though that example was explicitly not given in the interview), one student’s response was typical: “I am not even sure what they could do past [grading].” That same student noted, however, that the reports always came back with “a lot of input” on both the writing and the project itself. In the same way, another student noted that faculty input was geared to “making sure we knew where to improve and to help guide us toward making the project better” (emphasis mine). That is, although interviewees didn’t state it explicitly, they did recognize that the input they got on their reports involved not only the “communications” part, but also the project as a whole as they worked to achieve their deliverables.

At the same time, the interviews suggested that students’ sense of both audience and the role of documents in the workplace improve markedly as their composing processes developed over time. Even though they didn’t necessarily see the course faculty as managers, they still framed the documents in the context of management; one student noted, for example, “I learned a lot from writing the technical paper that has to be submitted to managers.” Similarly, in describing the final oral presentations, one student noted that they very explicitly took the wider faculty audience into account (the course instructors repeatedly stress this audience as the key reason for the final presentation). Based on experience, the group knew that some professors “seemed to put an effort into asking questions…some just for the sake of just asking questions and testing the people and some because they were actually interested.” In response, the students planned their presentation “to say, ‘Okay, what could they ask us here, what could we have here in case they do ask us?’” More broadly, a student noted, “…it’s not like we are just throwing [a report] together anymore. I have noticed consciously thinking, ‘All right; this is who we are talking to with this…consciously thinking who, what needs to be explained further?’”

Interview participants also commented on the way delivering multiple presentations to the same audience helped them develop an awareness of audience:

“The oral progress reports, you not only have to think how to translate what you wrote onto a PowerPoint and figure out how to present it in a way so that people you are actually working at writing to can understand it, so that when you are looking at them you can actually see a nod instead of a question on their face, a question that they might not understand.”

The same student went on to describe the way a particular point clearly caused confusion and side-tracked the audience from the key issues in their first presentation. In response, the group made a conscious decision to handle the issue differently in subsequent presentations. Importantly in terms of the growth of critical thinking, the group also consciously reshaped the issue again in the final presentation to where the audience expanded to include the entire department.

The interviews also pointed to gains in using form to support function as students commented on both the role of the checklist and the variations among projects. As we might expect, while the checklists played a key role early on, as students became familiar with the document forms, they came to really on their understanding of the audience and used the checklists as reviews to make sure they hit all the key points. More importantly, however, several interviewees commented specifically on the flexibility provided by not having to adhere to a rigid format because of differences among the projects themselves. One interviewee explained, “That [flexibility] was kind of nice because not every project was the same. And I know for ours we had a couple of things that you know other groups had that we didn’t.” Consequently, the team felt comfortable adapting their reports to reflect those differences.

Over the course of the year, students saw different groups handling the same general assignment differently based on the project itself, the work done, and the problems encountered along the way. The interview comments thus do point to important learning gains in moving from a formulaic to a more sophisticated view of communications practices.

**Future Work: Revising Classroom Practices and Assignment Designs**

The results of the first two years of this study support the potential of problem-based learning as a tool for integrating communication into capstone design courses as critical
elements of professional practice. Students in both the MSE and ESM programs come to the capstone course with high expectations regarding the usefulness and value of texts. In general, those expectations are borne out as students use the full range of texts to manage their projects, though the tension involved in meeting deadlines can make the texts a source of frustration because they require “valuable” time that students feel compelled to put towards completing the technical work.

The assignments and grading rubrics will be revised this summer based on the findings of Years 1 and 2, and tested again in Years 3 and 4 of the study using the same instruments. The decline in usefulness ratings from initial expectations (Year 2 – August) to actual experience (Year 2 – December) suggest that more work needs to be done in the course to help fulfill the potential these assignments hold for developing students as effective practicing professionals. Key revisions include the following:

- Revising the use of Gantt charts throughout the year, as these proved less helpful to students than the ongoing progress reports themselves.
- Redesigning the progress reports to lessen the workload on students and faculty while still maintaining their value as project management and analysis tools.
- Highlighting the way we as faculty use various reports to provide project-related feedback (rather than simply grading or feedback on writing/speaking style) to further develop students’ sense of texts as functional tools.
- Implement systematic external assessment of projects and reports.

In addition, students in the final two years should come to the capstone course with a stronger rhetorical base developed through revisions to the overall engineering communications program, as reported elsewhere.[8] Data from the upcoming years should thus help demonstrate if and how those changes impact students’ work with the written and oral assignments in the capstone projects.

Finally, beginning Summer 2005, alumni data gathered through both surveys and interviews should provide information regarding the actual value of the instructional approach in students’ careers.

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