Improving Senior Design Proposals Through Revision by Responding to Reviewer Comments

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This paper describes an instructional innovation designed to promote revision of interdisciplinary design proposals collaboratively authored by student teams participating in capstone senior design courses. Just as students from different engineering disciplines worked together to design and continually refine their projects, faculty from different disciplines worked together with industry partners to help the students see revision as an integral component of the design process.

Communication is an important workplace skill, particularly in the sciences where skilled professionals need to communicate complex information to a wide range of audiences. Engineers especially have long emphasized the need for strong communication skills and they continue to do so in the proposed ABET criteria revisions [1]. Nationwide, schools of engineering have been incorporating technical communication into engineering curricula in different ways, including the growing trend of embedding communication faculty within colleges of engineering [2]. This kind of integration promotes the application of technical communication skills to writing about disciplinary content and, in turn, contributes to thinking and learning about content [3]. Additionally, collaboration between writing instructors and engineering faculty affords opportunities to apply instructional strategies considered “best practices” in writing pedagogy directly to authentic written communication tasks focused on engineering content.

The research base on effective practices for improving students’ writing skills is extensive. The effectiveness of revision as a strategy for developing writing skills is well-documented [4]. Likewise, feedback is equally powerful in promoting student learning [5]. Yet, students do not always use feedback in productive ways [6]. The combination of feedback, modeling, and revision is an especially powerful strategy. For example, Zimmerman and Kitsantas [7] found that college students learned to persist at improving their writing when guided by feedback and modeling during revision. A recent report commissioned by the Carnegie Foundation recommends the use of formative assessment in improving writing [8]. Formative assessment provides students feedback about their writing and enables them to revise writing before the summative assessment (i.e., receiving a “final grade”). Students can also be involved in formative assessment if they are taught to use rubrics as a self-evaluation tool to evaluate writing in progress [9]. Thus, improving writing depends on the ongoing assessment of writing by instructors and students themselves. The use of formative assessment to improve engineering students’ technical communication is consistent with the paradigm shift in ABET accreditation, a shift away from reviewing what students were taught to assessing what students learned [1].

In this new ABET paradigm, students must have the skills to acquire new knowledge and apply it to their work as engineers, which includes technical communication. Requiring students to revise writing in response to specific feedback may motivate them to pay attention to feedback and apply it to improve their writing, especially when they consider the written product important to their career success. Feedback delivered within the context of professional work is especially salient to students. Some research has found that participation in engineering design projects provides opportunities for coaching and mentoring in professional skills, including
teamwork and communication [10]. Researchers concluded that feedback on professional skills helped students become enculturated into the community of engineering practice.

Clearly, the acquisition of writing skills is an ongoing process that requires effort and commitment by both instructors and students [7]. Revising writing takes time, but when viewed as an iterative design process, much like an engineering design project, the necessity of revision as a writing and thinking tool becomes clear. This descriptive study documents how engineering students revised design proposals in response to feedback from instructors and the professional community.

**Background**

At the University of New Haven, an innovative approach for developing students’ technical communication skills, PITCH (The Project to Integrate Technical Communication Habits) leverages online technology to provide instruction and common resources for students and faculty across programs [11]. With support from the Davis Educational Foundation, the engineering faculty developed three sets of online instructional resources: one that provides materials for a first-year required online course in writing short engineering reports; a second that focuses on writing lab reports and is available as an online instructional resource in third-year laboratory courses; and a third that is available to all seniors taking the two-semester long Senior Design Course sequence (see Appendix A). One critical component of PITCH is the integration of required communication products in designated courses throughout all four years of the engineering curriculum, including design proposals, reports, and posters in the Senior Design Courses. In addition to online resources, instruction and faculty support are provided by a full-time writing instructor assigned to the College of Engineering.

The context for this study was the fall semester of the Senior Design Course sequence, a requirement for seniors from all engineering disciplines. In this course, students engage in a two-semester design project in which they apply engineering principles to solve real world problems. The projects, which are proposed by industry sponsors, faculty, or students, can include actual or conceptual designs of systems, components, or processes. Most students work on projects within their particular disciplines, but some students work in interdisciplinary teams on projects that involve more than one discipline. The proposals and reports are team-authored, affording an opportunity to study how students engage in collaborative authorship.

**Methods**

The purpose of this descriptive study is to explore in-depth the revision process in which students engaged as they developed their design proposals. In particular, the study investigated three questions:

- How did students respond to feedback embedded in the revision process?
- How did interdisciplinary teams collaborate in the revision process?
- How did students use online technology to access resources and participate in virtual collaborative revision?
Study Participants

Six interdisciplinary teams whose projects were externally sponsored were selected for this study because these teams participated in an authentic “request for proposal” experience that prompted both the design project and the written proposal. Five of the teams were sponsored by companies and one was sponsored by an anonymous donor who funded the team’s entry in a robotics contest. Team members included 29 students, 6 from electrical, 11 from mechanical, 6 from system, and 6 from computer engineering. Team membership ranged from 4 to 7 students. To protect confidentiality, team projects are not described and teams are referenced by letter (Teams A through F).

Instructional Procedures and Resources

The engineering instructors required a midterm proposal draft (10% of the course grade), and a final proposal (15% of the course grade) due at the end of the fall semester. Thus, students were motivated to engage in a revision process to improve their proposal for the final grade. Instruction in technical communication was provided by the writing instructor in three ways: (1) a presentation demonstrating the Senior Design online resources; (2) facilitating team discussions of reviewers’ comments on the proposal drafts; and (3) small group instruction and ongoing feedback during the revision process.

An introductory presentation occurred in the seventh week of the 15-week semester. All students taking the Senior Design course attended a one-hour presentation, which introduced them to the online instructional resources available on their course learning management system site. The theme of the presentation, “Revision as Design” was intended to encourage students to see similarities between the iterative design process and the proposal revision. The online materials included resources for both the proposal and other communication products, including the second-semester report, presentations, and posters (see Appendix A). The fall presentation focused on the Guidelines for the Proposal, the Proposal Grading Rubric, the Project Summary, and collaborative authorship. After a review of these resources, teams engaged in revision exercises, first with a model passage, and then with a draft of their own project summaries.

Next, reviewer comments were collected and shared with teams. To simulate an actual proposal review experience, three reviewers (the Senior Design engineering instructor, the writing instructor, and the external sponsor) for each of the six teams were invited to read the proposal draft and provide qualitative feedback in response to four guiding questions: (1) How thoroughly does the proposal address the client’s needs and design criteria/constraints? (2) Is the proposal sufficiently persuasive to convince the client/sponsor that the team has a sound plan for carrying out the work, as well as the capability to succeed in that work? (3) How well is the proposal written and organized? (4) Does the proposal display a high level of professional appearance and attention to detail? These questions correspond to the Proposal Grading Rubric Criteria for “overall effectiveness” (see Appendix B).

The writing instructor met with each team to share the feedback and discuss how the comments might be used to revise the proposal. Teams were encouraged to send working drafts of revisions
to the writing instructor, who provided ongoing feedback during the revision process. Students scheduled follow-up meetings as individuals or teams to discuss revisions-in-progress or to request additional resources.

Data Collection and Analysis

Data collection began during the Senior Design Presentation when each team was asked to complete a note card in response to two prompts: (1) How is the design process like the writing process? and (2) How did the revision exercises help you think about your design project? Responses were collected anonymously, compiled in a list, and analyzed. Responses to the first prompt provided examples of students’ understanding of revision as an iterative process. Responses to the second prompt provided examples of how the writing revision process helped students rethink and refine their project designs.

Each team’s midterm draft and final proposal were collected and analyzed. First, using the compiled reviewers’ comments, the writing instructor rated each draft proposal (see Appendix B for the scoring rubric aligned with the review questions). The proposals were placed on a continuum from novice to advanced, according to stage of development at the midterm submission. Proposals that fell in the novice range were significantly underdeveloped, with sections of the proposal still in outline form. Those that fell into the intermediate range needed major revisions, while those at the advanced end of the continuum needed only minor revisions. In addition, the draft and final proposals were independently scored for overall effectiveness by the second author, using the same rubric criteria (Appendix B). To obtain a numeric score, five scoring levels were used: novice (1), novice/intermediate (2), intermediate (3), intermediate/advanced (4), and advanced (5). The second author was not involved in any of the revision interventions and did not have access to the reviewers’ comments. Additional comparison data were obtained through word counts and analyzing the number and type of revisions (using the MS Word Compare Tool).

Finally, a survey was administered to 28 of the 29 participants (One student declined to participate in the study). The response rate was 22 (79 % of those surveyed). One purpose of the survey was to assess students’ perception of the value of the different learning experiences, including the online resources, the presentation, reviewers’ comments, small group instruction, and ongoing feedback during the revision process. Students rated their experiences on a five-point Likert scale from “not at all valuable” (1) to extremely valuable” (5). Additionally, students were asked to report about the challenges and benefits of participating on interdisciplinary team projects, including collaborative authorship. On a five-point Likert scale from “strongly disagree” (1) to “strongly agree” (5), students reported their agreement with statements about their participation on interdisciplinary teams. Descriptive statistics were calculated for each item. Open-ended items assessed students’ understanding of the revision process and plans for addressing reviewers’ comments, their reported participation in collaborative authorship, and their disciplinary contributions to the team. Responses were collected anonymously but students were asked to identify their engineering discipline and team assignment so that responses could be analyzed by team and discipline. See Appendix C for the survey instrument.
Results

The findings of this study show how the senior design teams engaged in a continuous revision process, guided by ongoing feedback and a set of online resources. First, the reviewers’ comments identified unclear or incomplete descriptions of the project in the early stages of the design process, which in turn, prompted students to seek more input from clients and rethink their project design. Next, the required revision and collaborative authorship plan encouraged students to work together and consider the contributions from the different disciplines, not only to the project, but to the proposal. The results that follow provide evidence of students’ use of feedback from reviewers to engage in collaborative revision on interdisciplinary teams as well as how they perceived the learning experiences the project afforded.

Comments from three different reviewers, each with a different area of expertise (i.e., writing, engineering, and industry) provided feedback from three different perspectives. For example, comments from the external reviewers helped to clarify the client’s needs and requests. Despite differences in perspective, overall judgments were similar. For example, all three reviewers found Team Proposal D to be convincing, well-written, and responsive to client’s needs. As another example of consistency, the lack of detail in Team Proposals E, F, and C was noted by all three reviewers. Notably, these three proposals were the shortest, with word counts of, 487, 846, and 1347, respectively.

The proposal drafts that the reviewers were asked to assess were found to represent varying stages of development, based on the reviewer comments and independent assessment by the second author. Figure 1 shows a continuum that represents stages of proposal development from novice to advanced.

<table>
<thead>
<tr>
<th>Novice</th>
<th>Intermediate</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team E</td>
<td>Team C</td>
<td>Team D</td>
</tr>
<tr>
<td>Team F</td>
<td></td>
<td>Team A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Team B</td>
</tr>
</tbody>
</table>

Fig. 1: Stage of Development of First Draft

The novice proposals were underdeveloped, with many of the components still in outline form. In some cases, the proposal included “placeholder” headings noting that the sections would be written later in the project development process. Team E’s proposal was the least complete, missing several major components, including the Letter of Transmittal, Literature and Patent Searches, Project Design, and Team Qualifications. Team F’s proposal was missing a Table of Contents, Patent Search, and Schedule of Costs, and was not clearly written. The two novice teams (Team E and F) each chose to begin by writing sections that would ultimately be placed in the Appendix. For example, they developed a work plan and outlined the scope of their work. One team member on each team was assigned this work, while the other team members began to write the proposal itself. Their drafts were submitted as two separate documents with a cover sheet for each one.

The proposals in the intermediate stage of development (Team C, A, and B) were each submitted in a single document, with all the applicable components written in a narrative form, except for
Project Goals, which were listed. Team C and B submitted complete proposals, while Team A was missing only the Letter of Transmittal. Proposals in this category were judged to need major revisions, including refining the statement of problem, adding details to the project description, making a more convincing case about the proposed project would address client needs, and in some cases, correcting errors in content (e.g., Team B). These intermediate category proposals needed reorganization both within components and across components (e.g., transitions between components, reordering of components within the proposal, and moving supplementary information to the appendices, as appropriate).

One proposal (Team D) was judged as advanced. All three reviewers found this proposal in need of only minor revision such as an inclusion of standards and the extension of the timeline to two semesters. Positive feedback included such comments as “I found this proposal very persuasive in almost all aspects” and “All sections are well written and attention is paid to details.” It is notable that Team D’s external sponsor regularly communicated with the team and provided ongoing feedback about the company’s expectations for the project.

In a simulated “revise and resubmit” process, teams revised their proposals and submitted a final version to course instructors. All teams made extensive revisions. Table 1 shows the number and types of revisions made by each team. The increase in word count reflects the level of detail added to the proposal, in response to feedback from reviewers. The least number of revisions were “moves” (reorganization), possibly because the Proposal Design Guidelines outlined and described the content of each section in detail. The number of insertions and deletions reflect the manner in which teams tended to work. Most teams revised section by section, deleting unnecessary or inappropriate information and replacing it with more appropriate content. For example, Team D’s original Project Summary described how the external sponsor visited the class and proposed the project. The revision included a 4-paragraph Project Summary briefly describing the problem, the project’s objective, and the proposed solution, and a conclusion with a convincing statement appealing to the company sponsor: “The optimized [name] system will enable [The Company] to deliver a usable and reliable product to their clients.”

<table>
<thead>
<tr>
<th>Level</th>
<th>Team</th>
<th>Word Count Before Revision</th>
<th>Word Count After Revision</th>
<th>Insertions</th>
<th>Deletions</th>
<th>Moves</th>
<th>Format</th>
<th>Total Revisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice</td>
<td>E</td>
<td>487</td>
<td>1493</td>
<td>57</td>
<td>46</td>
<td>6</td>
<td>22</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>846</td>
<td>1858</td>
<td>87</td>
<td>61</td>
<td>14</td>
<td>126</td>
<td>288</td>
</tr>
<tr>
<td>Intermediate</td>
<td>C</td>
<td>1347</td>
<td>4784</td>
<td>36</td>
<td>40</td>
<td>2</td>
<td>38</td>
<td>116</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>1746</td>
<td>2397</td>
<td>179</td>
<td>157</td>
<td>2</td>
<td>228</td>
<td>566</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2380</td>
<td>2915</td>
<td>137</td>
<td>125</td>
<td>4</td>
<td>70</td>
<td>336</td>
</tr>
<tr>
<td>Advanced</td>
<td>D</td>
<td>3890</td>
<td>4229</td>
<td>186</td>
<td>204</td>
<td>2</td>
<td>416</td>
<td>808</td>
</tr>
</tbody>
</table>

Table 2 shows the proposal scores for overall effectiveness before and after revision. A five-level, multi-trait scoring rubric (see Appendix B) was used to provide a score in content and writing, with 5 representing the highest score and 1, the lowest.
Table 2: Proposal Scores for Overall Effectiveness Before and After Revision

<table>
<thead>
<tr>
<th>Level</th>
<th>Team</th>
<th>Before Revision</th>
<th>After Revision</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Content</td>
<td>Writing</td>
</tr>
<tr>
<td>Novice</td>
<td>E</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Intermediate</td>
<td>C</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Advanced</td>
<td>D</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Thus, the data show that each team progressed along the continuum, from novice to intermediate, and from intermediate to advanced, making progress as writers. Two novice teams (E & F) made substantial improvements in writing. These teams started with less complete drafts than the other teams, but worked steadily on revision, meeting once with the writing instructor to discuss external feedback and again with both the engineering and writing instructors to discuss compiled feedback. On the other hand, Team D initially submitted a complete and well-written proposal for reviewer comments; only minor revisions were recommended in the review process. This client’s review indicated how well the team had been incorporating his feedback throughout the project.

Our assessment of student learning is not based on a statistical model, as in large-scale assessments, but rather it measures how students perform on a classroom-based assessment. Pellegrino argues that classroom assessments, which depend on interpretations made by teachers using qualitative data, rather than statistical models, are not being used to their fullest potential [12]. The qualitative data that follow provide evidence for interpreting student performance, including students’ use of feedback in the revision process. These data are provided to explore possible reasons for improvement and differences among the teams.

Students’ Use of Feedback

The feedback provided by the reviewers propelled the students on a revision course. As the teams discussed the reviewers’ comments in meetings with the writing instructor, the teams identified the need to seek additional feedback from the reviewers. For example, Team F met with the industry partner and clarified that the project’s goal was not to develop a new process, but to prove with statistical significance that the proposed innovative process would perform as well or better than the existing process. Team B initiated additional meetings with the writing instructor and each team member submitted revisions of assigned sections to the writing instructor for comment during the revision process.

Student survey responses describe how teams acted upon the feedback to revise their proposals. Some students described how the team responded to specific comments from reviewers. Others cited the need for more extensive revision, including rewriting most or all of the original proposal. Some examples of students’ responses are listed below:
• We added more details to the proposal. For example, we added more details to the technical side (such) as why we chose certain parts over others (Team C student).

• My team was very successful in addressing specific comments. For example, it was originally unclear why our system needed to be made other than the fact that our sponsor wanted it, so we addressed this by discussing the system's applications and why our sponsor wanted it (Team B student).

• The whole proposal was pretty much rewritten from the ground up. We didn't have a clear understanding or help when writing the first draft so it wasn't up to standard and needed to be completely changed. (Team F student).

Students also described how their team went about revision in a planned, systematic way. Examples of responses include:

• Each person was able to look at … portions of the reviewer comments and adjust (that) section (Team B student).

• The members went through the revision comments one-by-one and made the revisions accordingly (Team E student).

Students reported that they weighed the importance of comments, choosing the feedback they thought most important. Examples of responses include:

• Comments were mostly positives, but we had to research well before accepting the recommendation about certain aspects of the proposal (Team D student).

• It's important for us to improve our proposal. For example, our sponsor thought we need to be more specific in our proposal (Team E student).

• We especially focused on revisions from (the engineering instructor) . . . as we felt that was directly affecting the grade. Secondly, we focused on the revisions of our sponsors (Team A student).

• We chose the important comments and omitted the ones that were either unimportant, or missed the proposal’s intention (Team E student).

Thus, whether or not they acted upon all or selected portions of the feedback, students apparently took the revision process seriously. For these six teams working on authentic projects, feedback from actual clients may have motivated the revision process. But there is also evidence that the opportunity to revise an engineering report was an unexpected, but welcome learning opportunity, as one student summed up the revision process: “I get it. It’s like English class, only (applied to) what we like doing.”
Taken together, students’ comments suggest that it may not have been the feedback alone that promoted their learning, but the opportunity to act upon the feedback in a revision process that was scaffolded in team meetings and writing conferences with instructors.

**Working with External Reviewers**

As noted in course catalog descriptions, senior design projects may be suggested by students, faculty or sponsored by industry. On average, 60% of senior design projects are externally sponsored each year. Some of these sponsors are alumni who own businesses and return to their alma mater for assistance in developing their product lines. Others are industry executives with established working relationships with the College and these industries are likely to sponsor one or more projects each year, some of which are continuations of previous work. Many of these sponsors, especially those in the local region attend senior design classes to observe the progress of their sponsored teams, providing guidance and feedback at every stage of the project. Teams often visit the industries and observe the existing process or product they are trying to improve.

What was unusual about the revision project described here is that external sponsors were invited to provide feedback, not only on the project, but on the written proposal. Thus, not only the design project but also the proposal writing process simulated an authentic career experience.

This authentic feedback and revision process provides an opportunity to study this instructional method, and also raises potential ethical questions that might surface during a project such as this. For example, what might happen if an external reviewer requests an addition to the proposal or project, beyond the scope of the curriculum requirements? As previously noted, students made deliberate decisions about which feedback to use (“based on research” as one Team D student explained), just as authors have an opportunity to respond to reviewer comments when they “revise and resubmit” manuscripts for publication. Moreover, the College has established collaborative working relationships with the sponsors, most of whom have sponsored projects in the past. Senior Design instructors serve as intermediaries between sponsors and students and have the responsibility of ensuring that sponsor requirements are not excessive. Although the students’ sponsors may review their work and proposals, the students’ final grade is determined solely by the faculty. Another issue is the confidential nature of some of the industry-sponsored projects. In some cases, teams will develop products or processes that may ultimately be patented. The present study provided an opportunity to address this issue with students. For example, some teams were using unsecured cloud-based applications for collaborative authorship and communication about project activities. Some of these applications were free to the students, but the hosting firm’s policies noted that all content uploaded by the students was owned by the hosting firm. Teams, especially those working on innovative industry-sponsored projects, were advised to use MS Word track change tools and/or to save their work on the secure University shared drive. Whether or not industry sponsors are invited to review proposals, it seems prudent for externally-sponsored teams to consider how to protect the confidentiality of their work, including diagrams and specifications that may ultimately be included in the final project reports. To protect the identity of the industry sponsors and maintain confidentiality, the specific nature of the projects is not described in this paper.
Collaborative Authorship on Interdisciplinary Teams

Team members provided detailed descriptions about their collaborative authorship experience. For some teams, collaborative authorship was a planned process, much like the team design process. Three teams (B, D, and E) tended to report positive experiences with collaborative authorship.

One team member described Team B’s plan as follows:

1. Individual team members would review the sections they wrote and revise as they see fit.
2. After this is done, the entire paper would be reviewed and edited by team member 1, then when they are done team member 2 would review and revise the entire paper, then team member 3 and so on and so forth.
3. Team members made their final checks.

A similar outline was reported by a Computer Engineer on Team D, the team that produced the most polished proposal at midterm:

1. Read review comments.
2. Figure out which parts of the proposal they are mentioning.
3. Review the specific sections of the proposal.
4. Discuss if changes should be applied with the team.
4. Research and fix section.

Team E also reported on a plan for sharing authorship, in which members made changes in a shared online document. This team also accommodated a member who preferred to work offline. This member reported that he “made changes and emailed (the document to) other team members for proofreading.”

Unfortunately, no one from Team A responded to the survey item on collaborative authorship, but Team F and Team C described challenges that arose in collaborative authorship. Team C, which had 7 members, reported that one member took the lead in writing and revising the proposal. The lead author reported working with 2 other team members who contributed substantially. Although the writing was apparently shared by only three Team C members, other Team C members reported meeting to discuss feedback and understand what needed to be done. Students also reported adding to or editing particular sections. It may be more practical for larger teams to assign writing to a few team members and editing and proofreading to other members.

One Team F member expressed concern that only one team member “took over the majority of the work” and that not all team members were present at the feedback discussion. The team member reported, however, that after the needed revisions were identified in the feedback discussion, “he managed to split up the work” and involve other team members from that point on. Team leader roles rotated so that more than one student had opportunities to develop leadership skills during the project, but the roles assigned to authors may have been based more on individuals’ existing skills rather than providing opportunities for developing new skills. One strong writer claimed that he wrote most of his team’s proposal because his “grade depended on
it.” Put another way, this student perceived collaborative authorship as a risk he was not willing to take. One way of encouraging collaborative authorship is to capitalize on formative assessment opportunities to promote learning in a low-risk situation. When students receive feedback during the writing process, even struggling writers can be assigned narrative proposal components and have opportunities for guidance and revision without risking a “low grade” as a summative assessment for the team. Another approach is to equip student team leaders with the same strategies instructors use when assigning “group work.” For example, holding each team member accountable for an individual contribution is an important tenet of cooperative learning [13]. Group members themselves evaluate individuals’ contributions to the group and support each other to attain a common goal. Both individuals and groups are evaluated, with group evaluation focused on accomplishment of project goals.

Given the different collaborative authorship experiences described by students, it is not surprising that they expressed widely varying opinions about collaborative authorship. Of 21 respondents, 12 (57%) agreed or strongly agreed that collaborative authorship on an interdisciplinary team is challenging, while 4 (19%) neither agreed nor disagreed, and 5 (24%) disagreed. When asked if they would choose to participate on an interdisciplinary team again, 10 (48%) agreed they would like to work on an interdisciplinary team. Only 5 (24%) responded that they would not like to work on an interdisciplinary team again, and 6 (28%) expressed no opinion. Apparently, despite the challenges encountered in senior design teams, students felt that experiences in their freshmen and sophomore engineering courses in the College’s innovative interdisciplinary “spiral” curriculum [14] prepared them for tackling the challenges of interdisciplinary work. Of the 21 respondents, 14 (67%) strongly agreed or agreed that participation in earlier interdisciplinary courses provided a foundation for interdisciplinary team collaboration and communication, while 7 (33%) expressed no opinion. Of the 21 respondents, 15 (71%) strongly agreed or agreed that participation on interdisciplinary teams enabled them to contribute their disciplinary expertise to the proposal, and only 2 (10%) disagreed that they had an opportunity to contribute disciplinary expertise, while 4 (19%) expressed no opinion. For example, one system engineer on Team F, who may not have contributed substantially to the proposal narrative, contributed an innovative schematic of the project design.

Clearly, collaborative authorship on interdisciplinary teams offers both challenges and opportunities. “Getting everyone to participate” was a challenge noted by most students, but students also cited benefits such as “gaining insight from the other disciplines in engineering.” One student summed up the challenges and benefits from a practical standpoint:

- **Benefits**: Everyone has strengths in terms formulating a proposal. Some authors are more skilled in technical writing, others are more skilled in writing research and project summaries, while others are skilled in formatting and visual representation. Additionally, it helps having many authors contribute to one work, so that no one person feels overwhelmed by all of the requirements that go into a proposal.

- **Challenges**: It can be challenging if one author is unable to satisfy the required contribution in a timely manner. Also, it can be challenging for many authors to write a single work and have that work maintain a consistent tone or voice throughout.
Disciplinary contributions to the project were not always reflected in the proposal, depending on the way in which teams divided the writing tasks. One exception was the knowledge of system engineers, who were typically responsible for developing the appendices including a “Statement of Work” (i.e., outline of project tasks) or preparing visual designs. Team C, the largest team with 7 members, drew upon the disciplinary knowledge of the computer engineers. For example, computer engineers described their disciplinary contributions to the proposal as follows:

- In programming, syntax and structure are very important. This is so that others who look at your code can easily decipher the meaning and the intent of the overall function.
- Ideas like how to fix parts from making permanent deformations in the frame of the robot.

Team B provided another example of assigning writing tasks based on disciplinary expertise. For example, the electrical engineers were assigned sections related to their discipline: “Our project consists of a control system and that is where the EEs provide their input and design. . . . I was the sole author of my proposal's Electrical System Design section.”

In at least two disciplines, interdisciplinary work facilitated collaborative authorship and provided opportunities for students to draw upon their disciplinary knowledge to contribute to both the project and the proposal. In other cases, however, collaborative authorship proved challenging for the student teams. Although students assigned roles to individuals, with the exception of the systems and computer engineers, role assignments were more often based on what individuals could contribute (e.g., a strong writer), rather than what the discipline could contribute. As previously explained, students may have been reluctant to assign meaningful roles to weaker students because their grade depended on the quality of the proposal. Although the innovative interdisciplinary foundation courses [14] prepared students for “real world” interdisciplinary work, the need for summative assessment -- a practice deeply-rooted in “school” -- appeared to limit opportunities for student learning.

Guiding the Revision Process

Throughout the proposal revision process, students were guided not only by the reviewers’ comments but also by small group instruction, ongoing feedback, and online resources.

Students were asked to rate the perceived value of learning experiences on a scale of 1 to 5, with 5 being the most valuable. Table 3 shows the means, standard deviations and medians of the student ratings ordered from the highest to the lowest means. Consistent with research on the powerful role of feedback [5] and formative assessment [8], students rated timely and specific feedback on their writing, discussion of feedback in team meetings, reviewer comments, and the grading rubric for self-evaluation as being most valuable. All of these provide opportunities for students to improve their writing and hence their grade. The grade assigned by the instructor for the midterm draft proposals was seen as being less valuable. Seeing other team members’ tracked revisions was rated as being least valuable. This may be because teams worked in different ways. For example, some teams divided writing tasks, which team members then submitted to a lead author. On these teams, members had little opportunity to see each others’ revisions. As previously suggested, the knowledge that a summative grade was forthcoming
prompted some students to take on roles that would assure a high grade for the team, but limit learning experiences for team members. The lesson here is that, when it comes to learning, the summative grade not only matters little to students, but may also impede learning.

Table 3: Student Perceptions about the Value of Learning Experiences

<table>
<thead>
<tr>
<th>Learning Experience</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing instructor’s comments on revisions</td>
<td>4.33</td>
<td>.80</td>
<td>4</td>
</tr>
<tr>
<td>Discussion of feedback (team meetings)</td>
<td>4.19</td>
<td>1.03</td>
<td>4</td>
</tr>
<tr>
<td>Reviewer comments</td>
<td>4.09</td>
<td>1.02</td>
<td>4</td>
</tr>
<tr>
<td>Grading Rubric for self-evaluation</td>
<td>4.00</td>
<td>.98</td>
<td>4</td>
</tr>
<tr>
<td>Instructor’s grade on midterm proposal</td>
<td>3.95</td>
<td>1.05</td>
<td>4</td>
</tr>
<tr>
<td>Team members’ tracked revisions</td>
<td>3.10</td>
<td>1.48</td>
<td>3</td>
</tr>
</tbody>
</table>

In addition to feedback and the writing instructor’s guidance during the revision process, online resources were available on all senior design course sites. For a description of these online resources, see Appendix A. Students were asked to rate the perceived value of these resources on a scale of 1 to 5, with 5 being the most valuable. The means, standard deviations and medians of the student ratings, ordered from highest to lowest means, are provided in Table 4.

Table 4: Student Perceptions about the Value of Learning Resources

<table>
<thead>
<tr>
<th>Learning Resources</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grading Rubric for Design Proposals (Online Module)</td>
<td>3.80</td>
<td>1.24</td>
<td>4.0</td>
</tr>
<tr>
<td>Developing the Work Plan (Online Module)</td>
<td>3.17</td>
<td>1.34</td>
<td>3.5</td>
</tr>
<tr>
<td>Writing Effective Design Proposals (Online Module)</td>
<td>3.16</td>
<td>1.21</td>
<td>4.0</td>
</tr>
<tr>
<td>Team Authoring Tutorial (Online Module)</td>
<td>3.12</td>
<td>1.27</td>
<td>3.0</td>
</tr>
<tr>
<td>Organization of the Proposal (Online Module)</td>
<td>3.11</td>
<td>1.18</td>
<td>3.0</td>
</tr>
<tr>
<td>Formal Summaries (Online Module)</td>
<td>3.06</td>
<td>1.21</td>
<td>3.0</td>
</tr>
<tr>
<td>Introduction to online resources (Presentation)</td>
<td>3.05</td>
<td>1.07</td>
<td>3.0</td>
</tr>
<tr>
<td>Presenting Team Qualifications (Online Module)</td>
<td>2.94</td>
<td>1.21</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Students rated the Grading Rubric Module as the most valuable. As previously noted, the grading rubric was viewed as an important learning experience, a self-evaluation tool that provided students non-threatening feedback and an opportunity for revision before the summative assessment. Consistent with research on formative assessment, rubrics communicate criteria for success and using a rubric as a self-evaluation tool promotes revision [15]. Moreover, a study of college students’ perceptions of rubric-driven self-assessment showed that students tended to be less anxious about writing assignments when criteria were communicated through a rubric [16].

Students reported the online module on “Presenting Team Qualifications” and the general presentation introducing the online resources as the least valuable. There is some indication that students may not have realized how these resources could support their learning until they were asked to use the resources in the revision process. For example, when students were provided a print copy of the rubric and were guided to use it to self-evaluate their proposal drafts, they
indicated they had not realized the rubric was actually available in the set of online resources. The online module, “Presenting Team Qualifications” provided models of team qualifications from actual proposals, but students may not have looked to this resource for guidance when they drafted their proposals. During team meetings, misconceptions about presenting team qualification surfaced. For example, qualifications were written in first person to describe a team member (e.g., Name: I am a Systems Engineer) and provided general background information rather than emphasizing the member’s contribution to the project. The writing instructor pointed students to the online resource, but also immediately addressed specific misconceptions during the writing conference. Thus, students were able to correct their errors, without the need to consult the online resource on team qualifications. In contrast, the need to use the rubric to self-evaluate their proposals during the revision process may have encouraged students to consult the online module that included the rubric. This suggests that students may be more likely to use online resources when they are given a specific assignment that creates a need to use the resource.

Notably, students’ perception of the value of different online resources (see Table 4) ranged from a mean of 2.94 (Presenting Team Qualifications) to a mean of 3.80 (Grading Rubrics for Design Proposals). On the other hand, students’ perceptions of different learning experiences (see Table 3) ranged from a mean of 3.10 (Team Members’ Tracked Revisions) to a mean of 4.33 (Writing Instructor’s Comments). These results suggest that students may initially perceive online resources less valuable than instruction targeted to specific learning needs. The online format ensured that all students had access to a common set of resources to support proposal writing. The data suggest, however, that students find the online resources more valuable when they are supplemented with targeted instruction and assignments that require them to use the resources (e.g., the rubric as a self-evaluation tool).

Revision as Design

As one of the engineering students noted, revision is typically a writing practice associated with “English” classes. By framing revision as a design process, however, the authors of this paper “made the strange familiar” for these engineering students. Almost immediately, students made the connection between the recursive nature of the design process and the revision cycle. After the introductory presentation, teams were asked to quickly write associations between the design process and revision. The following examples of students’ insights demonstrate their understanding of both revision and the design process:

- Both have a series of steps for completing a task.
- Both are iterative processes.
- Both are continuous improvement processes.
- Both require extensive time and critical thinking.
- Both are collaborative processes.
- You have to continually work at both; revise as you go.
- Constant feedback in both processes.
- Writing needs an outline and the design process needs a schedule.
Students also explained how writing helped them clarify their thinking about their project designs. After participating in revision activities at the introductory presentation, students were asked how revising their project summaries helped them think about the project itself. Their comments included the following:

- (Revision) made us think about components of a system, by breaking down the product.
- Revision will (allow us to see) if there is anything missing.
- We thought about our goals and outcomes and incorporated thoughts into the proposal.
- Revising the proposal lets you rethink your process and compare the design to the set restrictions.
- It helped us reinforce and verify our requirements.”
- It made us realize you improve as you go.
- It gave us a better understanding of our project because we had to articulate exactly what we were doing, using words rather than thoughts.
- I learned to think about the ‘how’ and ‘why’ of the project more.

At the end of the semester, students were asked to describe how the revision process contributed to the development of their project. Their responses provide further evidence that students were aware of the connection between writing and thinking.

- Revising the proposal gave an insight on the next step of the project.
- We are all more familiar with the rules and are going to make sure that the design of the robot fits within the constraints of the competition.
- During the revision process, our team found out that we could not answer specific questions that we needed to answer in the proposal so it made us have more of an in-depth conversation with our sponsor, which then allowed us to go back into the proposal and have a very detailed design process.
- Many times the writing portion required us to define specifically what each member is responsible for in the project.
- I think revising the proposal summary actually helps us to have a better understanding of our project objective and the process to be done.
- The revisions of the proposal got me thinking of how the robot would go through the maze efficiently while not losing power.
- When I keep revising it, I can rethink my project again and make my point very clear.

**Teaching as a Collaborative, Recursive Process**

Consistent with the proposed revisions to the ABET student outcomes, which place increased emphasis on professional growth and problem solving as well as inclusive and collaborative team work [1] students continually refined their knowledge of engineering concepts and learned to manage and negotiate roles on interdisciplinary teams, including collaborative authorship. One might argue that this type of senior design experience is not uncommon in engineering programs, but, in this research, the new ABET criteria were modeled by faculty. Like the students’ interdisciplinary projects, this revision study depended on collaboration between and among a
writing instructor, engineering faculty, and an administrator. In this study, teaching was enabled by finding similarities between the disciplines and seeing connections between writing about content and knowledge of content, consistent with the new ABET guidelines. Like the design process, this study began with a practical problem – how to improve communication skills of engineering students. Like an iterative design process, teaching depended on the continual assessment of student writing. The compiled reviewers’ comments enabled the instructors to identify and address student misconceptions.

Reviewers’ comments served an important purpose for students as well. The feedback propelled students on a course toward revision and improvement of writing. Noted educational psychologist, Lyn Corno [17] terms this an “implementation mindset” that moves students from wanting to improve (e.g., wishing they were better writers) to taking action to improve (in this case, revising their writing). Instructor guidance and discussion during team meetings supported students in overcoming challenges of revision and collaborative authorship. Feedback from students and discussions during these team meetings, in turn, enabled instructors to understand students’ needs and work toward revising instruction accordingly. Thus, both teaching and learning to write can be construed as design processes.

Summary of Instructional Components for Improving Senior Design Proposals through Revision

The findings from this revision project suggest that engineering students can be guided to view the writing revision process as seriously as they view the design project itself. The revision project reported here is an example of how faculty at one university drew upon the research base for teaching and learning to embed writing instruction into senior design in a way that highlighted similarities between the design process and revision of writing. The following summarizes the components of the instructional innovation described in this paper:

1. The design project itself was authentic. For example, each team worked on a project that was sponsored by an actual client, company, or organization. In essence, teams were responding to a “request for a proposal.”

2. The proposal writing process was authenticated by the involvement of external reviewers. Each team submitted the proposal to the client, who, in turn, provided feedback. Through feedback from these external reviewers, students not only received feedback on writing, but learned whether or not their design projects were on track to meet client needs.

3. Formative assessment was leveraged to promote revision. For example, students received non-evaluative (i.e., non-graded) feedback on proposal drafts throughout the process. Formative feedback drove the revision process, enabling students to see what needed to be improved before submitting the final proposal.

4. Revision of writing and continuous refinement of the project design were ongoing and concurrent.
5. Students had access to evaluative criteria (i.e., the proposal grading rubric) and were guided to use the rubric to self-evaluate their work. Thus, students were scaffolded toward independence. That is, students were first guided by feedback from instructors and reviewers before they moved on to self-evaluation, guided by criteria.

6. A set of general online resources was supplemented by small group instruction that targeted specific writing skills and addressed misconceptions. Formative assessments (e.g., reviewer comments) informed the content of the instruction.

7. Interdisciplinary teams provided opportunities for students to use their disciplinary knowledge to contribute to the project. For example, computer scientists wrote descriptions of programming algorithms and systems engineers wrote work plans.

8. Writing instruction was delivered in a meaningful context. Students honed their writing skills and immediately applied them to the design proposal. Writing, in this context, was not a separate task, but an integral component of the design process.

References


## Appendix A: Online Instructional Modules for Senior Design

<table>
<thead>
<tr>
<th>Module Topics</th>
<th>Resources Introduced and/or Demonstrated at Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Writing Effective Design Proposals: Understanding Components of a Design Proposal</td>
<td>PITCH Guidelines for Preparation of Senior Design Proposals (printable reference material)</td>
</tr>
<tr>
<td>3. Presenting Team Qualifications</td>
<td></td>
</tr>
<tr>
<td>5. Developing the Work Plan</td>
<td></td>
</tr>
<tr>
<td>7. Formal Summaries in Senior Design Proposals and Senior Design Papers</td>
<td>Online Tutorial: Functions of the Project and Executive Summaries Annotated Examples (demonstrated)</td>
</tr>
<tr>
<td>8. Grading Rubric for Design Proposals</td>
<td>Grading Rubric for Design Proposals (printable reference material)</td>
</tr>
<tr>
<td>9. Writing Effective Design Reports - Understanding the Components of a Design Report</td>
<td></td>
</tr>
<tr>
<td>10. Grading to Rubric for Design Reports</td>
<td></td>
</tr>
<tr>
<td>11. Constructing Effective Design Posters - Components, Format, and Presentation</td>
<td></td>
</tr>
<tr>
<td>12. Grading Rubric for Design Posters</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix B: Proposal Scoring Rubric Aligned with Reviewer Questions

### Guiding Questions for Review of Overall Effectiveness (Content)
1. How thoroughly does the proposal address the client’s needs and design criteria/constraints?
2. Is the proposal sufficiently persuasive to convince the client/sponsor that the team has a sound plan for carrying out the work, as well as the capability to succeed in that work?

<table>
<thead>
<tr>
<th>Levels of Proficiency</th>
<th>Novice (1)</th>
<th>(2)</th>
<th>Intermediate (3)</th>
<th>(4)</th>
<th>Advanced (5)</th>
</tr>
</thead>
</table>
| Overall Effectiveness (Content) | ▪ Proposal fails to address the client’s needs and design criteria/constraints.  
▪ Proposal fails to persuade client/sponsor that the team has a sound plan for carrying out the work, as well as the capability to succeed in that work. | ▪ Proposal fails to adequately address the client’s needs and design criteria/constraints.  
▪ Proposal persuades client/sponsor that the team has a sound plan for carrying out the work, as well as the capability to succeed in that work. | ▪ Proposal thoroughly addresses the client’s needs and design criteria/constraints.  
▪ Proposal strongly persuades client/sponsor that the team has a sound plan for carrying out the work, as well as the capability to succeed in that work. |

### Guiding Questions for Review of Overall Effectiveness (Writing)
1. How well is the proposal written and organized? (COPE Guidelines for Technical Writing)
2. Does the proposal display a high level of professional appearance and attention to detail?

<table>
<thead>
<tr>
<th>Levels of Proficiency</th>
<th>Novice (1)</th>
<th>(2)</th>
<th>Intermediate (3)</th>
<th>(4)</th>
<th>Advanced (5)</th>
</tr>
</thead>
</table>
| Overall Effectiveness (Writing) | ▪ Writing and organization reveal little or no application of COPE guidelines throughout the proposal.  
Proposal does not display a professional appearance or attention to detail:  
▪ Required proposal elements are missing.  
▪ Proposal does not follow a style guide (e.g., APA, Chicago).  
▪ The document has not been carefully proofread and edited for grammar and spelling. | ▪ Writing and organization reveal occasional application of COPE guidelines throughout the proposal.  
With a few exceptions, proposal displays a professional appearance and attention to detail:  
▪ Required proposal elements are only partly developed.  
▪ Proposal uses styles (e.g., APA, Chicago) inconsistently.  
▪ Some of the document has been carefully proofread and edited for grammar and spelling. | ▪ Writing and organization are at professional level and reveal application of COPE guidelines throughout the proposal.  
Proposal displays a high level of professional appearance and attention to detail:  
▪ All required proposal elements are fully developed, and organized into one document.  
▪ Proposal follows a style (e.g., APA, Chicago) appropriate for the discipline, consistently throughout the proposal.  
▪ Entire document has been carefully proofread and edited for grammar and spelling. |
Appendix C: Survey Items

Background Information

1. What is your engineering discipline?
2. What is the name of your team project?

Item Set 1: Value of Learning Experiences and Resources
Please reflect on the revision process in which you engaged. During this process, you were provided with a number of resources and opportunities to develop technical communication habits. On a scale of 1 (not at all valuable) to 5, please indicate how valuable you consider each of these learning experiences or instructional resources to be. If you did not use the resource, please circle N/A (not applicable).

3. Reviewers’ comments (compiled)
4. Instructor’s grade on midterm proposal
5. Opportunity to discuss reviewers’ comments with writing instructor
6. Use of Proposal Grading Rubric to self-evaluate proposal
7. Opportunity to see team members’ revisions in Track Changes
8. Comments provided during revision process (in MS Word Comments)
9. Presentation introducing online resources, “Written Communication in Engineering Design.”
10. Online Module 1: Writing Effective Design Proposals
11. Online Module 3: Presenting Team Qualification
12. Online Module 4: Team Authoring Tutorial
13. Online Module 5: Developing the Work Plan
14. Online Module 6: Organization (COPE Guidelines O1-O4)
15. Online Module 7: Formal Summaries
16. Online Module 8: Grading Rubric for Design Proposals

Item Set 2: Collaborative Authorship & Revision Process in Interdisciplinary Teams
Please indicate your agreement with each of the following statements, on a scale of 1 (strongly disagree) to 5 (strongly agree).

17. Collaborative authorship and revision can be facilitated by technologies such as email, Google Docs, Dropbox, or other technologies that allow virtual collaboration.
18. Collaborative authorship and revision requires face-to-face meetings.
19. Collaborative authorship and revision is best accomplished through both face-to-face meetings and virtual communications.
20. Authorship & revision within an interdisciplinary team is challenging.
21. The online module, “Team Authoring” provided excellent resources and strategies for engaging in collaborative authorship.
22. Participation in EASC interdisciplinary courses during freshmen and sophomore years provided a foundation for interdisciplinary team collaboration and communication.
23. If I had the chance again, I would like to work on an interdisciplinary team project.
24. Writing and revising an interdisciplinary proposal gave me opportunities to contribute my disciplinary expertise to the proposal.
Item Set 3: Leveraging Technology

25. Please indicate by a check (✓) which of the following tools you used to communicate and collaborate during the authoring and/or revision process. Check all that apply.

- MS Word track changes
- MS Word comment
- Google Docs
- Dropbox
- Email
- Share Point
- Blackboard (e.g., Discussion or Chat)
- Other: (Please identify)

Item Set 4: Open-ended items

26. Please describe the process (or plan) you used to revise your proposal in response to reviewers’ comments.

27. Please comment on how well you think your team addressed the reviewers’ comments. Provide specific examples whenever you can.

28. Now that you have participated in both the writing revision and the design process, please provide at least one specific example of how revising the proposal helped you clarify your thinking about the project design.

29. What do you consider to be the major contribution of your disciplinary knowledge to your team's proposal?

30. One purpose of this study is to investigate how members of different engineering disciplines contribute to writing the proposal. What do you consider to be the challenges and/or benefits involved in writing an interdisciplinary project proposal?