120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7845

Embedding communication in an interdisciplinary project-based upper-level engineering design course

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Abstract

Our experience working with junior and senior students in a two-quarter, interdisciplinary project-based design course taught by teams of engineering and communication faculty suggests that providing students with instruction and coaching in communication—particularly internal, team-based communication—contributes directly to students' mastery and understanding of the design process. In the course, students receive instruction in many facets of communication: writing, presenting, interacting with experts and clients. However, one hallmark of the course is that students write and talk about design decisions beginning very early in the design process. Because the course requires our students to articulate their ideas so often and so early, the students perceive gaps in their own reasoning and design work that they must then address. When teams must communicate, critique, and then rework their own ideas, it leads to stronger, better thought-out designs.

Introduction

The growing importance of design in undergraduate engineering education,[1] the importance of communication to design,[2] and the effectiveness of an integrated approach when teaching communication and design,[3-4] have been staples of the literature on engineering communication and design education for over a decade.

It is therefore not surprising that students working on open-ended design projects in multidisciplinary teams must communicate effectively in a wide range of contexts, to a number of different audiences—and that they benefit from doing so. However, clear communication is more than a means to an end when students are learning design. Our experience working with junior and senior students in a two-quarter project-based design course taught by teams of engineering and communication faculty suggests that providing students with instruction and coaching in communication—particularly internal, team-based communication—contributes directly to students' mastery and understanding of the design process. Because students are required to articulate their ideas so often and so early, they perceive gaps in their own reasoning and design work that they must then address. Thus motivated, students better understand the value of structured process tools, including decision matrices, and detailed requirements and specifications. When teams must communicate, critique, and then rework their own ideas, it leads to more rigorous, effective design process, and stronger, better thought-out designs.

Overview of the course: a team-taught, project-based sequence

The course is a 20-week, two-quarter sequence offered by the Segal Design Institute at Northwestern University. The course is team-taught by pairs of engineering and communication faculty. Because the course sequence is required for students pursuing a design certificate, the juniors and seniors who take the course come from many different majors.
Projects for the course are sponsored by clients from industry as well as community organizations and not-for-profit organizations. These projects cover a range of engineering

domains and disciplines and are, ideally, multidisciplinary. Recent examples include devices to assist patients in post-stroke therapies at a nearby rehabilitation hospital; vehicle projects sponsored by an international educational consortium; sporting equipment concepts for a local entrepreneur, and many others. Depending on the scope of the project and the commitment of the client, projects can span several years, sometimes resulting in ongoing relationships with specific organizations; project reports and evolving prototypes are inherited by successive generations of design teams. Exceptional projects have led to award-winning designs, developing in sophistication and complexity through repeated successful handoffs from one team to the next.

All of these features of the course illustrate the importance and centrality of communication in the course and in the design process. The diversity of the students' majors and backgrounds demands that they collaborate with team members who do not always share the same perspective. The presence of two instructors from different academic backgrounds further underscores the need to communicate effectively across domains. The diversity of the projects and their sponsors requires communication across different sets of institutional and disciplinary boundaries. The complexity of the projects requires that students seek out expertise from local experts, either faculty at the engineering school or a local pool of professional designers and other industry contacts who serve as program affiliates. The scope and direction of the projects further extends the need to communicate to future designers as well as to present clients.

Communicating to learn design: creating opportunities for revision and rethinking

But what of the design process itself? How exactly does attention to communication contribute to better design? One hallmark of our course is that students begin writing and presenting about design decisions very early in the design process; and the critical thinking involved in those communication events has a positive impact on the quality of their designs. Three specific sets of examples illustrate how the necessity to draft and revise a design idea in writing or speaking can create an opportunity to develop and refine that idea: the first-quarter mid-term status reports; the design briefs written in preparation for the design review at the end of the first quarter; and the final reports. For these examples, we offer samples of student work that show how writing about ideas improved those ideas; students' statements about the value of revision; and client reactions to student work. All examples of student work are used by permission.

Mid-term status reports

Students often conceptualize a sequential relationship between the process of designing and the process of writing about design: first you design and then "write it up." As such, they do not intuitively take advantage of the power of writing to help clarify ideas. In our course, students begin writing about their design early in the design process; and the faculty begin training students to use writing and presenting to think more critically about their designs.

For example, five weeks into the design process, the teams present mid-term status reports to the class. These take the form of a presentation followed by a discussion, supplemented by a written packet of information for the instructors. These presentations and written deliverables are communication skill-builders in themselves, demanding that students organize and present their project research and design directions coherently and concisely.

However, we also use this assignment as an opportunity to teach students to use clear reasoning and evidence to support their claims about their research and design decisions. As students are making their presentations, instructors write down a list of the claims they hear the teams make, and assign this follow-up exercise:

> Below is a list of claims and generalizations made during your team's project status presentations. Each sentence could serve as a topic sentence in a written document. You have a two-part assignment with these sentences.
>
> a) Write a well-developed, well-edited paragraph for the topic sentence you are assigned, using some version of the claim/generalization as your topic sentence and expanding on it. Please feel free to change the sentence as needed to make it more accurate. If you have been assigned two sentences to develop, you may choose one but we'd prefer you do both.
>
> b) For the topic sentences of your teammates, identify the questions that the topic sentence raises in your mind and that you'd like to see your teammates' paragraphs address.

During the next class session, the teams discuss and revise the paragraphs together and with the instructors. This exercise is not only an opportunity to coach students in writing clear paragraphs, but the specific set of statements that the students produce also provide a framework for discussing their design problem and their plans for future work. The attention to specific words and their consequences forces students to clarify their thinking about their problem as they revise their statements.

Example: Mid-term status reports and claims assignment

The following example demonstrates how one team used mid-term status reports and claims assignment to make a good design decision. The goal of the team's project was to design a pressurized tank, for use by veterinarians at Shedd Aquarium. The veterinarians will use the tank, similar in function to hyperbaric chambers used for treating decompression sickness in scuba divers, to experiment with a novel approach to treating Gas Bubble Disease in sea horses. During their status report presentation, one student stated "We are considering two different ways to go about maintaining water quality." The instructors selected this statement to be used in the claims assignment, described previously.

In response to part (a) of this assignment, one team member submitted the following paragraph.

> We are considering two different ways to go about maintaining water quality, and need to evaluate the feasibility of each method. Water quality consists of elements like temperature, pH, salinity, carbon hardness, nitrate, nitrite etc. It is an important part of our design because seahorses are very sensitive to the change in their environment. In order to maintain water quality, we can either hook up our tank and pressure system to the existing water circulation system at Shedd, or develop a completely independent water quality system. There is a trade-off between the two methods. The former may to be easier to operate, since we only need to design the connection part without worrying

about the water circulation system design, which saves our time and cost. However, the latter might have a much better integration with the entire system that we designed. As we make the decision, we need to communicate with our client well enough to examine the feasibility (especially with the integration to the current system) and requirements first.

The other members of the team submitted the following questions to address part (b) of the assignment.

Teammate 1
- What are the advantages and disadvantages of the two ways?
- Which of these advantages and disadvantages are relevant in our decision-making process?
- Does the Shedd have a preference in either of these methods?

Teammate 2
- What is water quality?
- Why does it have to be maintained?
- What two different ways are you considering?
- Why are you considering them?

Teammate 3
- What are the advantages and disadvantages of the two ways?
- Which of these advantages and disadvantages are relevant in our decision-making process?

The team used this list of questions to help them consider the issues they needed to communicate about their design options, with the intent of revising the paragraph to reflect their thinking. Using the answers to the questions above, the team evaluated the trade-offs of their two design options, and came to the conclusion that one option was clearly better suited to the project than the other. The revised text is both clearer and a better statement of the team's design direction.

> The pressure tank will connect to the Shedd's water supply to ensure the water parameters are adjustable to the animals living inside. Since the Shedd always has at least one tank optimized for any species of seahorse, no additional adjustments will need to be made; the main tank will simply connect to the proper aquarium tank. The primary disadvantage to this design is that the main tank will need to be physically near a properly optimized water source.
>
> A rejected alternative to this solution is to create many subsystems to adjust and monitor temperature, pH, salinity, water hardness, and other water parameters. The main benefits of an independent system would be flexibility and extra portability of the tank. However, neither of these benefits outweighs the cost of time and money of developing independent controls, especially given the experimental nature of this project.

The requirement to state their reasons persuasively and in writing early in the process pushed them to make a well-reasoned decision at an early stage of the project. This decision enabled the team to update other aspects of the design to reflect this decision and to begin identifying new issues to address. By the end of the first quarter, they had identified, resolved, and communicated several key challenges and issues effectively.

Design brief

Approximately halfway through the project, students draft a short document called a design brief that is circulated among a small panel of reviewers who meet with the team for an hour-long design review. The timing and the audience are both crucial: at this point in the project, teams have developed one or more potential design directions and a plan for moving forward. The team must present this information for critical review by a group of experts. This is an excellent opportunity to solicit expert input for their design process, but getting the most benefit from this experience requires that the team focus their design brief on key design issues and identify the critical information they want from the reviewers. Preparing this brief is challenging, and the process of having to articulate their design for an external audience helps students think critically about their design and refine it.

Example: Design brief

The following example illustrates how preparing a design brief helped one team to refine their design. The purpose of the project was to design a product that captures and delays the release of storm water into Chicago's combined sewer system during severe rain events, which currently overwhelm the entry pipes of the sewer system, leading to sewage overflow and basement backups. The students decided to focus on capturing storm water that runs off of the roof through roof gutters and drainpipes. In a draft of their design brief, the students provided the following overview of their design:

> The design direction we will be pursuing is to implement a storage tank design. The tank will be constructed of modular units that can be assembled into various layouts to suit the customer's needs. There are two alternatives for the features of tank we are pursuing, a simple underground tank that does nothing but stores water, or a tank that is partially above ground and will include features like an above tank garden and irrigation system.

In their comments to the students, the instructors called for more information on the following elements of their design:

- rationale behind the shape and dimensions of the tank
- selected components, such as pipe fittings and valves, and the reasons for selecting them
- type of pump and why it was selected
- location of pump and rationale for that choice

As the team worked to address the instructor comments, they realized that they needed to redefine their intended design direction. The following post, recorded in the team's online project management archive, explains the change in design direction.

> While writing our design direction for our design [brief], it started to become more clear that [the differences between] our two design directions, a feature tank and a simple tank, were not actually that important. It made sense to focus our design direction on the modular tank that is the basis for our two designs. The features became secondary compared the actual module details. The modular tank is now the design direction and the features that used to be our design are now a small section of our [design brief] and presentation.

Because the first draft of the design brief was due almost two weeks prior to the actual design review, the team had enough time to discover the need to redefine their design direction and to continue to develop the details of the new design before presenting it to design professionals for feedback. The revised overview of their design reflects their increased understanding of the problem and their solution

> Our tank will be constructed out of modular units to allow for a variety of tank shapes and sizes. In Chicago there is a huge variety of lot layouts, so a single tank design would be unwieldy and possibly not fit in certain yards. The modular design allows for the tank to follow the exterior of the house or to work around existing features of the yard. The modules will be 4' x 4' x 4' cubes, which will hold roughly 475 gallons. The number of modules needed to provide appropriate capacity will be determined by roof size, and will vary per lot (see Appendix III).

The writing and revising process put the team in a better position to have an effective design review. During the session, the reviewers confirmed that modular units were a good solution to the stated needs. The reviewers gave suggestions for variations on the size and shape to account for a greater variety of use-case scenarios, and discussed some off-the-shelf components that could be considered.

Final reports

The process of writing the final report also demonstrates how the teams develop their design ideas as they state and restate them. In the second quarter of the class, the students begin working on their final report four weeks before the end of the quarter. Students often state that they are not yet ready to start writing, and the pressure to complete drafts while solving detail design problems and constructing prototypes can be intense. However, the process of outlining the overall report and drafting early versions of its sections offers three key benefits.

First, the writing process brings to light design questions that still need to be resolved. It is too easy for teams to focus just on building; they often need to be coached to examine and evaluate the decisions they make in the last weeks. Drafting the rationale for their decisions, and responding to instructor feedback on those drafts, requires them to more fully address remaining design issues.

Second, requiring the students to organize and articulate their reasoning for design decisions, and particularly trade-offs, while they are making them, reinforces the value of structured process tools, such as detailed requirements and specifications (project definition), and decision matrices. Without this writing and reasoning process, students' use of these tools often remains perfunctory, and they may not see the tools as integral to good design. The value of thoughtful application of these tools is easier to grasp when they must articulate their decisions in writing.

Finally, writing report drafts well in advance of the due date also helps the students frame their work appropriately. The teams must determine whether their final report will present a finished prototype that is ready for use, or propose a design that the client will complete, or explain why the project is not feasible, or provide some other findings or results of value to the client. Understanding both the status and the future of the project helps them better emphasize the most relevant information, and create a final design and report that are truly useful to the client.

The following example is drawn from a project for Clean Harbors (formerly Cat-Tech), a company specializing in industrial cleanup, and demonstrates how the team's final report, which they wrote while they were still designing, evolved to provide the convincing analysis that their client needed and expected The focus of the team's project was to design a breathing system to be combined with a safety helmet and suit for use by workers who are handling hazardous material in enclosed spaces. The breathing system included an inline air pressure regulator adapted from the company's existing regulator, and a simplified exhaust system for venting exhaled breath. The regulator needed to comply with requirements set by the National Institute of Occupational Safety and Health (NIOSH). The regulator also needed to be cost-effective. These requirements demanded that the students produce both a sound design and a clear explanation of their design decisions.

As the students were drafting the report, they struggled to produce a cost analysis that was both accurate and effective at persuading the audience of the efficiency of the design. The first draft of the cost analysis was simply incomplete; it included only the cost of their proposed design with no analysis showing how it was cost-effective. After writing this draft, the students realized they did not have enough information about the cost of the client's current design to make an effective comparison. After a conference call with the group that manufactures the current design, the team was able to produce a persuasive cost analysis in the final draft of the report.

> Cost Analysis
>
> Our regulator design reduces the cost by $342. The most expensive part is still the regulator housing. We were able to reduce cost of the rest of the parts by roughly $120. As mentioned previously in the manufacturing section, we reduced any tooling costs for Cat-Tech by keeping some of the most important parts the same. Table 1 contains a summary of cost information we gathered about the current regulator and our proposed design from the Cat-Tech support manual and information from the McMaster-Carr catalogue (McMaster-Carr Online).

Table 1. Cost analysis of current and proposed regulators
Source: Cat-Tech manual, McMaster-Carr catalogue

Current Regulator		Proposed Regulator	
Parts	Price	Parts	Price
Housing	158.40	Housing	1.20
Ball Plug	0.44	Ball Plug	0.44
Inlet Restrictor	5.15	Inlet Restrictor	5.15
Main Valve	22.55	Main Valve	22.55
Main Valve Retainer	14.12	Main Valve Retainer	14.12
Plate Gasket	2.75	Plate Gasket	2.75
Mounting Plate	16.37		
Pilot Valve	19.80		
Lever Screw	0.09		
Lever Assembly	32.56		
Set Screw	0.15		
Mounting Plate Screws	0.24	Screws	0.24
Diaphragm Assembly	28.77		
Diaphragm Spacer	7.22		
Primary Spring	3.96		
Cover	10.38		
Cover Screen	2.20		
Retainer Ring	6.69		
		O-Ring	0.50
Connect Socket Fittings	33.70	Rubber Check Valve	7.00
Connect Socket	15.40		
Air Inlet Manifold	132.00		
Parts	356.74	Parts	52.75
Total	515.14	Total	172.72

At the end of the project, the client expressed his satisfaction with the student work in an email.

> [The team's report] is really first-rate work….They turned a lot of information and ideas into a well-conceived prototype after making sure they really understood the existing product. The supporting thought processes, such as FMEA, and the comparative cost analysis clearly show the team's good grasp of the myriad of technical and business issues surrounding this product.

Here, the client took special note of the supporting details that the students took care to present. The well-organized, relevant, and compelling information in the report reflected the thinking that went into the prototype, and convinced the client of the overall value of the design.

Conclusion: revising and rethinking as central to design

Our experience suggests that early and repeated emphasis on revision in writing gives teams more opportunities to clarify their thinking about their design problem and its possible solutions. For student design teams, revision is not a matter of polishing what they understand, but of explaining—to themselves as much as to their coaches and reviewers—what they do not yet fully grasp. It is only through attempting to express an idea before the idea is fully understood that the idea can be made better. This process of revising written explanations—and then revising them again—is time consuming. But it is of the highest value in teaching and learning design, because it directly parallels and reinforces the same iterative process that is essential to design. When demanding that our students tackle complex ill-defined problems, we must also demand that they write before they are finished, and keep revising until the answers take shape.

References

1. Froyd, J. E., Wankat, P. C., & Smith, K. A. (2012). Five Major Shifts in 100 Years of Engineering Education. *Proceedings of the IEEE,* 100, 1344-1360.

2. Brinkman, G. W., & van der Geest, T. M. (2003). Assessment of Communication Competencies in Engineering Design Projects. *Technical Communication Quarterly*, 12 (1), 67-81.

3. Froyd, J. E., Wall, A., & Williams, J. M. (2002). Writing to Design/Designing to Write: Using the Correlations between Communication and Engineering to Improve Student Reflection. Session 2132. *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*.

4. Hirsch, P. L., & Yarnoff, C. (2011). Integrating Design and Communication in Engineering Education: A Collaboration between Northwestern University and the Rehabilitation Institute of Chicago. *Topics in Stroke Rehabilitation*, 18 (4): 361-366.