

Engineering Design and Communication: The Case for Interdisciplinary Collaboration*

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This paper describes an innovative, interdisciplinary, project-based freshman course at Northwestern University—Engineering Design and Communication (EDC). The course fully integrates engineering design with freshman communication and is taught collaboratively by faculty from Engineering and from Arts and Sciences. Working on real projects for real clients, students acquire skills in communication, design, and teamwork and also come to see design and communication as complementary parts of the same iterative and creative problem-solving enterprise. We argue that this interdisciplinary approach improves the teaching of both communication and design and provides students with an exceptionally solid foundation for their future engineering courses and careers.

INTRODUCTION

THE ENGINEERING faculty at Northwestern University recently joined forces with the University's Writing Program to develop a first year core course: Engineering Design and Communication, or EDC. Over two quarters, students study design process along with the communication process, while working on conceptual design projects for real clients.

In the first quarter, teams are introduced to the design process first by working on an introductory design exercise based on the Apollo 13 lunar module problem and then by designing a variety of World Wide Web projects for clients at the university. For example, these have included a web-based alternative to Northwestern's course evaluation system, an on-line registration system for intramural sports, and web-based support for NU's new Human Resources software package. In the second quarter, students apply and adapt the process to a new project for another client from either the university, the community, or local industry. Students have designed an enhanced pager system for volunteer firemen, a wheelchair for long-distance recreational use, and a new base-station antenna for cellular phones.

At the same time that students study design process in EDC, they also study communication. They are coached in oral, written, and graphical communication as they meet with clients, interview users, run focus groups, and present design reviews. They hold team 'process checks' regularly and learn about interpersonal communication. The

deliverables in EDC are not only conceptual designs, but also well-designed documents and persuasive oral proposals.

We consider EDC a cornerstone course, which has much in common with other innovative introductory design courses that have been developed in the last ten years [1–4]. However, EDC is distinctive in the way that it foregrounds interdisciplinary collaboration, meshing content and pedagogy from two very different cultures: engineering and communication. This integration makes EDC fundamentally different from most first-year introductory design courses. Although many project-centered introductory design courses espouse the importance of clear communication and give students opportunities to develop their communication skills, communication instruction is subordinate, often taught by graduate students or writing tutors who simply help students edit final papers.

In contrast, in EDC, faculty from two very different disciplines—engineering and communication—collaborate on every aspect of the course: goal-setting, curriculum, lecture content and delivery, project selection, assignments, facility design, team coaching, and evaluation. Weekly lectures, delivered by both an engineering professor and a communications professor, cover issues from both fields. Similarly, section meetings, with 16 students in each, are run by faculty pairs who share responsibility for supervising project teams, facilitating discussion, and responding to papers. Ultimately, students receive one joint grade on every project—the grades for design and communication are never separated—and one common grade for the course, even though the course gives credit for two.

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Using EDC as an example, we argue that interdisciplinary collaboration between engineering design and communication achieves two important goals. First, the collaboration gives first-year engineering students an exceptionally solid foundation in design. Second, by studying design and communication in conjunction with real projects for real clients, students gain experience in problem-solving, communication, and teamwork that is an excellent preparation for the advanced engineering design courses they pursue later in specific domains.

COURSE OVERVIEW: EDC IN ACTION

EDC owes part of its development to innovative freshman and sophomore design courses from other institutions, such as Clive Dym's at Harvey Mudd College, Woodie Flowers' at MIT, and the D. L. Evans sequence at Arizona State, to name a few. Our students, like students in these other settings, work on open-ended projects tied to real-world problems. However, EDC differs from most other new design courses in three ways: its overarching emphasis on a user-centered approach to the design process, its thoroughgoing integration of design and communication, and its two-term format, which allows students to acquire a considerable degree of comfort with a design process and its communication components [5].

User-centered approach to design

One of the key goals of EDC is to teach a rigorous design process and a set of tools and techniques that support the process. As Table 1 illustrates, the process taught in EDC shares much in common with the processes taught in popular engineering design texts, such as those by Dym and Little, Ulrich and Eppinger, Cross, Horenstein, and Burghardt [6–10].

While students are introduced to all these tools and techniques in EDC, the main focus of the course is on *user-centered design*. The course stresses that the ultimate judge of a device is not a teacher or manager, but the user of the product.

Thus, we encourage students to learn everything they can about their 'users' or 'customers'—for example, the different segments into which users fall, the size of the segments, and their varying needs. In addition, we emphasize the role of users as final judges by asking students to get feedback on their design concepts from their target users. Feedback can take the form of interviews or focus groups where a prospective user is shown drawings or models of product concepts. These interviews allow students to determine user responses to various design features; the interviews also ensure that the designers incorporate user needs into design specifications. Focusing on user-centered design in this first-year course not only allows us to develop students' communication abilities (since interviewing and observing users is so communication-intensive), but it also allows the engineering school to pace the students' design education. Having learned these skills in their freshmen year, students are able to concentrate on learning more domain-specific design skills and approaches in their upper-level courses.

Integration of design and communication

The integrated nature of the course is apparent from the first week, when students undertake a two-week hands-on design exercise based on the Apollo 13 LiOH canister problem. This requires them to perform a number of overlapping design and communication activities. Working in teams, the students have to design a CO₂ scrubber that the Apollo 13 crew can use on the lunar module. To accomplish this task, students can use only the materials that the astronauts would have had on the spacecraft (which simulate and distribute to each team). Students sketch their ideas to share with team members, decide on a design that meets the design specifications they are given, build a prototype, test it, and then write a procedure for the crew. The procedure has to be clear enough, with just words alone, for the crew to be able to duplicate the design. After the prototypes have all been tested, students evaluate the designs to see which are the most durable and efficient.

Table 1. EDC design process

Stage in design process	Tools and techniques
Defining and structuring problems	Objectives trees
Mission statements	Requirements definitions
Functional specifications	Gathering information
Interviewing clients, users, experts	Observing users
Analyzing model and competitive products	Reverse engineering
Reading relevant literature	Generating alternatives
Brainstorming concepts	Developing morphological charts
Exploring alternative implementations	Prototyping and testing
Developing looks-like mockups	Conducting user evaluations
Developing works-like mockups	Lab testing
Evaluating and selecting designs	Holding design reviews
Analyzing user evaluations	Conducting feature/benefit analysis
Conducting technology assessments	Developing decision matrices

Following this exercise, communication remains an equal partner with design as students write problem statements, scripts for interviewing users, minutes of meetings, memos to clients and faculty, progress reports, and proposals. For oral communication experience, they conduct meetings, run focus groups, hold design reviews, and give formal presentations.

Communication—as a field—also influences the pedagogy of the course. In EDC, coaching is the primary pedagogy, rather than the ‘chalk and talk’ that characterizes most engineering classes. This is another contribution of the writing faculty, who are familiar with teaching in small sections and interacting informally with students on a regular basis.

The two term format

EDC spans two quarters so that students can work through the design process three times, revise all deliverables, and practice all presentations. In two quarters we can integrate material from both design and communication without sacrificing important material. For their first major design project, following Apollo 13, students design World Wide Web sites that address the needs of clients from the campus and local communities. Web design projects work well in an introductory course for several reasons [11]:

- Students can learn the basics of Web design quickly.
- Their desk-top computers can help them develop prototypes rapidly for real users to examine and test.
- Even modest Web-based designs present teams with interesting challenges, both as engineers and as writers.

While working on these projects, students attend a weekly lecture that introduces key aspects of the design process and provides continuity to the course. They also attend two section meetings each week, communicate with each other and their instructors through *FirstClass*, an electronic conferencing program, and complete a number of independent software labs. Finally, the quarter culminates in a partial working prototype proposal, and a final presentation to the client.

During the second quarter, students work through the design process for a third time, addressing a variety of design problems that fill a local university, community, or industry need. Again they have real clients. They design such things as playground equipment for a nearby elementary school, a new pager for volunteer fireman, a recreational wheelchair, a new container for the company that sells Bubble Tape[®], a novel self-healing composite material, and a toy for disabled children. As in the first quarter, all teams follow a fairly rigid framework defined by the stages of the design process and a series of communication assignments associated with phases of design. However, in the spring quarter,

teams adapt the design process to their project. Teams determine their own timelines for problem definition, research, user testing, and design reviews. With the help of their instructors, teams are also responsible for learning the tools necessary to complete their tasks. A team designing an antenna may have to learn how to use software that helps them calculate optimal gain. However, another team, working on a balance beam for disabled children, may have to learn how to use specialized machine tools to build their prototypes. Other teams may need to learn advanced research techniques, techniques for designing experiments, graphics programs such as Visio and SolidWorks, or other specialized computer programs such as Thermocalc and Cambridge Materials Selector.

By the time they reach the second quarter, students are much more comfortable with design process and appreciate the opportunity to apply it in creative and flexible ways. One student, who was designing a new door lock for apartments for wheelchair-bound residents, explains in a journal entry:

Because we are not struggling as much with learning the design process . . . [we can] take our projects further than before . . . Winter quarter served mainly as a time to get comfortable with the design process, while spring quarter has given us an opportunity to really utilize what we've learned in solving a real world problem.

Another student says:

This [second] quarter everything is clearer to me . . . It is much easier to anticipate the steps of the design process, and therefore our group has improved on time management.

Most of the students enjoy the second quarter more, even though they find their projects more demanding.

Second-quarter lectures provide additional information about design and a larger view of design in society, covering particular areas of engineering design, such as the role of design in specific disciplines; social and professional issues, like ethics; and practical topics such as sketching, prototyping, and the design of experiments. Again, this focus is well suited to an interdisciplinary approach. Students may be prompted to think about ethics in a lecture given by someone from industry, such as the former CEO of Bell and Howell, but they also read about difficult ethical and professional decisions described by noted writers such as Freeman Dyson and Henry Petroski.

Why teach design and communication as equal partners in a single course?

The idea of combining design and communication into one course—and requiring that engineering faculty share their instruction time with another discipline—is a controversial one [12]. As anyone who has taught a project-based design course knows, there is little enough time to teach

students all the design concepts they need, even when design is the sole focus of the course. Aside from giving students a required communication credit, then—and satisfying an ABET 2000 criterion—is this collaboration worth the cost? We contend that an interdisciplinary course in engineering design and communication offers many advantages; it is not only an excellent way to teach communication, but it is an excellent way to teach design.

As a communication course, EDC sends a strong, clear message to students: communication is an integral part of the intellectual design enterprise, not merely a superficial matter of editing. EDC demonstrates that serious communication instruction advances creative problem solving, the heart of engineering design. We do this by ensuring that every communication deliverable is grounded in the engineering design process. Students don't write essays, papers, and exams. Instead they write to communicate important information about their projects: they write and rewrite mission statements and customer requirements, report on client meetings, synthesize the results of research, prepare progress reports, and create slides for PowerPoint presentations. And students receive substantial coaching on their communications from both their communication and engineering faculty.

This is vastly different from students' experience in the more conventional writing intensive courses that surfaced in the 1970s, with the Writing Across the Curriculum Movement (WAC). In WAC courses, writing assignments tend to be more traditional, and students are likely to receive less explicit and less integrated writing instruction. Critics of writing intensive courses contend that, regardless of the field, students don't take the writing in WAC courses as seriously as they take the content area [13]. In most writing intensive courses or WAC programs, the communication faculty do not share power equally with the design faculty [14]. Typically, communication faculty do not set course goals, write assignments, influence the budget (if there is one), or determine final grades; no surprise, then, that they have little credibility with the students. While some WAC programs are successful, most fail to qualify as a cornerstone communication experience for students. Ironically, writing intensive courses can reinforce the mistaken ideas about writing that WAC was intended to dispel, that is, that writing is just a set of skills that can be taught separately from intellectual activity and has more to do with spelling and usage than with professional effectiveness.

Just as the collaboration improves the teaching of communication, our experience indicates that the interdisciplinary nature of EDC has a positive impact on the teaching of design. In part, this is because the two disciplines share much in common. Both design and communication are iterative, multi-stage processes. Both require

creative problem solving. Both work well in project-oriented courses where instructors assume the role of coach or supervisor rather than omniscient dispenser of information. Design and communication are mutually beneficial: just as reports and presentations must be well designed to achieve their goals, so must designs be clearly communicated to be understood.

The benefit to design, however, goes even deeper than this. In EDC students learn that effective communication sharpens their thinking—and can uncover flaws in their designs. For example, as students systematically describe how various design alternatives meet user needs, they may come to recognize that certain needs are being overlooked. As they prepare a persuasive argument for a design review or proposal, they may see opportunities for improving their design that they had overlooked. They also learn that effective communication helps them elicit more useful feedback from clients, users, and experts alike. By knowing the right questions to ask, by organizing those questions strategically, and by learning how to avoid defensiveness, they get much better information about their designs than if they interviewed people naively. If engineering schools seriously respond to the call from industry to help students improve their communication competencies, there is no better way than a design and communication course to show students how communication concepts and skills overlap with and enhance their analytical abilities and professional competencies.

The success of EDC—as both a design and a communication course—is validated by theories of conditionalized learning, espoused by such scholars as Mark Turner, a linguist and cognitive scientist from University of Maryland, and his colleague Francis-Noel Thomas [15]. Turner and Thomas argue that skills are most successfully taught when they are integrated with genuine (rather than contrived) activities that do three things: build on past learning, create a real need for the new skills, and offer an opportunity to learn them applying this concept to writing instruction. As Turner and Thomas explain: Writing proceeds from thinking. To achieve good prose styles, writers must work through intellectual issues, not merely acquire mechanical techniques. Although it is true that an ordinary intellectual activity like writing must lead to skills, and that skills visibly mark the performance, the activity does not come from the skills, nor does it consist of using them (p. 1).

Following this thinking, an interdisciplinary course like EDC improves students' skills in communication and design because it follows an effective cognitive model: the two disciplines provide a mutually enriching set of genuine activities that allows students to learn the skills that those activities require. Since students need the new skills for EDC projects—skills that overlap the disciplines—the students learn each discipline better together

than if they were learning design or communication alone. When students study writing in a design course, they become better communicators because they are highly motivated to do well. They know they are doing real work; hence, they want to explain their designs precisely and clearly to users, clients, and instructors.

Such authentic communication activities, situated in the discipline, give students a concrete way to understand a relatively abstract communication concept—the concept of audience. When students are coached in writing for real clients, students know they are not simply writing for a teacher under fictional circumstances. Rather, just as students are designing a product to fulfill a real need, so too they are writing and presenting to real clients and users. Moreover, the engineering faculty in an interdisciplinary, project-based course continually emphasize the importance of precise, concise, and professional writing. Their support goes a long way toward validating the communication professors' advice. Working together, both faculties show students that thinking and communication go hand in hand, and that communication in design spans a broader range than they may have realized, encompassing oral, written, graphical, interpersonal, and even numerical forms of communication.

CONCLUSION: A POSITIVE REPORT

While we have not yet studied the long-term effects of EDC—because our freshmen from the first full class are just taking their capstone design courses in 2000–2001—we do have a growing body of information to support our positive assessment of this interdisciplinary venture. According to engineering faculty at Northwestern, many EDC freshmen produce higher quality reports and presentations than do some of the design teams in the senior courses. Moreover, the senior design professors say they can see their seniors approach teamwork in a more methodical and positive way than in the past [16]. Engineering school advisors report positive feedback [17]. And EDC students themselves demonstrate an enhanced appreciation of design and the role of communication in design. As one student comments in a journal:

I have learned that the design process is not something . . . fixed and rigid. It can be approached from many different angles and molded to fit the needs and scope of the project. What is most important is that a thorough job is done with each of the steps and none . . . [is] taken for granted. With this in mind, a successful design can be achieved.

Another says:

[EDC] made me realize that engineers must be able to explain 'how' and 'why' for each and every solution. . . [E]ngineers do not just solve problems, but they communicate solutions; that is a prominent part of an engineer's work.

The course is also getting positive feedback from new faculty and administrators. Faculty say they enjoy teaching the course; some say EDC is the most rewarding teaching they've done. One faculty member with industry experience (the principal designer of the Ford Mustang) says, 'We're finally teaching design the way it should be taught' [18]. Similarly, the engineering deans, alumni, and even the trustees are great supporters of the course. The Undergraduate Dean for Student Affairs claims that EDC is 'one of the best things McCormick has going for it' [19]. The Associate Dean for the Cooperative Engineering Education Program says she 'admire[s] the work of the EDC faculty,' who 'do a great job . . . [of preparing freshmen] for the expectations to come' [20].

Both theory and our experience suggest that EDC's success is largely attributable to its interdisciplinary core. However, this core alone would not be sufficient for success. EDC has required whole-hearted support and commitment from both administration and faculty. At Northwestern, we are fortunate that this support begins at the top, with a provost who is proud of Northwestern's early leadership in interdisciplinary teaching and research [21]. With his support, and the support of the university president and our former and current engineering deans, we teach our small EDC sections in an 8000 square foot design studio, equipped with classrooms that have movable worktables and computer stations, a large computer lab, a workshop, office space for faculty, conference rooms for client meetings, etc. EDC also succeeds because a core group of dedicated faculty meet weekly to hash out assignments, plan lectures, write sections of our electronic textbook (or 'coursepack'), revise curriculum, set standards for grading, order equipment, train teaching assistants, and plan workshops for new faculty. This work by the core faculty allows new faculty to enjoy the course and become familiar with its interdisciplinary aspects without being overly burdened; new faculty can concentrate on learning unfamiliar content and on becoming accustomed to team-teaching and a coaching pedagogy that is new to many.

We concede that EDC requires a great deal of work, and we admit that interdisciplinary—and especially cross-school—classes are demanding. But based on the feedback we receive and the high quality of the work that EDC freshmen are producing, we argue that an interdisciplinary course like design and communication is a successful model worth emulating.

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REFERENCES

1. C. L. Dym, Teaching design to freshmen: style and content, *J. Eng. Educ.*, **83** (4) October 1994, pp. 303–310.
2. B. W. McNeill, D. L. Evans, D. H. Bowers, L. Bellamy and G. C. Beakley, Beginning design education with freshmen, *J. Eng. Educ.*, **80** (5) July/August 1990, pp. 548–553.
3. B. M. Olds, M. J. Pavelich and F. R. Yeatts, Teaching the design process to freshmen and sophomores, *J. Eng. Educ.*, **80** (5) July/August 1990, pp. 554–559.
4. H. West, W. Flowers and D. Gilmore, Hands-on design in engineering education: learning by doing what? *J. Eng. Educ.*, **80** (5) July/August 1990, pp. 560–564.
5. For a fuller description of EDC, see P. Hirsch, B. Shwom, J. Anderson, G. Olson, D. Kelso and J. E. Colgate, Engineering design and communication: jump-starting the engineering curriculum, *Proc. Amer. Soc. Engineering Education Annual Convention*, June 1998.
6. C. Dym and P. Little, *Engineering Design: A Project-Based Introduction*, New York: John Wiley and Sons, 2000.
7. M. D. Burghardt, *Introduction to Engineering Design and Problem Solving*, Boston: WCB McGraw-Hill, 1999.
8. M. N. Hornstein, *Concepts for Engineers*, Upper Saddle River, NJ: Prentice-Hall, 1999.
9. K. Ullrich and S. D. Eppinger, *Product Design and Development*, second edition, Boston: Irwin-McGraw-Hill, 2000.
10. N. Cross, *Engineering Design Methods: Strategies for Product Design*, second edition, New York: John Wiley & Sons, 1994.
11. J. Anderson, J. E. Colgate, P. Hirsch, D. Kelso, B. Shwom and C. Yarnoff, The Web as model technology in freshman design, *Amer. Soc. Engineering Education Annual Convention*, June 1999.
12. B. Shwom, Serving our clients, preserving our discipline: a tension in cross-disciplinary programs, *Conf. College Composition and Communication*, Milwaukee, WI, March 1996.
13. M. Munter, Whacking WAC, *Business Communication Quarterly*, March 1999, pp. 108–111.
14. A. Richards and C. David, Deconstructing collaboration: multiple levels of power, *Association of Business Communication Midwest Regional USA Conference*, Chicago, IL, April 1999.
15. F-N. Thomas and M. Turner, *Clear and Simple as the Truth: Writing Classic Prose*, Princeton, NJ: Princeton University Press, 1994.
16. M. Meshii, Materials Science and Engineering; H. Stoll, Mechanical Engineering; D. Kelso, Biomedical Engineering; Northwestern University, Evanston, IL.
17. J. Holtgreive and S. Fell, Northwestern University, Evanston, IL.
18. D. Frey, Industrial Engineering, Northwestern University, Evanston, IL.
19. S. Carr, Associate Dean for Undergraduate Affairs, McCormick School of Engineering and Applied Sciences, Northwestern University, Evanston, IL.
20. G. Garner, Associate Dean for Cooperative Engineering Education, McCormick School of Engineering and Applied Sciences, Northwestern University, Evanston, IL.
21. L. B. Dumas, Why cross-schools initiative is key, *Northwestern Observer*, November 5, 1998, p. 3.
22. P. Francuch, Engineering first: McCormick students take a practical approach to problem-solving with an innovative curriculum, *Northwestern*, Spring 2000, pp. 32–35.

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