Engineering Design and Communication:
Jump-starting the Engineering Curriculum

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Abstract: A new course for Northwestern University's engineering freshmen—Engineering Design and Communication or EDC—is noteworthy for its emphasis on the user-centered nature of design and its thorough integration of design and communication. Team-taught by faculty from two schools, EDC creates a new model for integrating core courses in engineering and liberal arts, combining content and pedagogy from two different fields, and building a new program and culture of design at the McCormick School of Engineering and Applied Science.

Introduction

On any given Monday in Lecture Room 2 of the McCormick School of Engineering, 110 freshmen enrolled in Engineering Design and Communication (EDC) take part in an innovative lecture class that teaches design through a combination of presentation, simulation, and discussion.   Two faculty members—one from engineering and one from the university's Writing Program—typically begin and end the class with a PowerPoint presentation focusing on one aspect of the design process. Between these two segments, four other faculty, as members of the "NU Concepts Design Team," are seated around a table in their simulated office, modeling a design-related activity. They might brainstorm solutions to a problem, make an objectives tree, or interview their "client" for the quarter, a local bike manufacturer who has asked them to help him design a recumbent bike for campus use. At some point in the hour, students are drawn into the discussion, becoming an integral part of the NU Concepts Design Team.

Later in the week, EDC students meet in groups of 16 with pairs of the design faculty—one communication specialist and one engineer—at the new Engineering Design Studio. Drawing on what they saw and heard on Monday, student teams work on design projects for clients of their own. During the first quarter of this two-quarter course, the projects all involve designing World Wide Web sites, which might range from an on-line lottery for campus housing, to Web-based support for the university's new human resources software package, to a Web-based alternative to Northwestern's current course evaluation system. During the second quarter, projects are more broadly defined and often address community or industry needs. Students have designed new playground equipment, a new storage system for a nearby elementary school, and a toy for disabled children.

For the past three years, we have been piloting EDC to increasingly large groups of freshmen, and we will complete our scale-up in 1998-99, when we teach the course to the entire freshman engineering class (approximately 320 students). This paper describes the new course and explains why we believe it is having a profound and far-reaching effect on Northwestern's undergraduate engineering curriculum. In particular, we describe the structure of the course and then its unique features: how its integrated course content and collaborative design help us (a) break down the traditional undergraduate distinction between core engineering courses and liberal arts courses, (b) expand our knowledge of both design and communication, (c) refresh our

teaching, and (d) build a new and stronger foundation for the engineering curriculum at Northwestern.

<u>Course objectives</u>
EDC assumes that freshmen, who have limited exposure to any engineering domain, can be taught a general, user-centered process for solving complex problems and can be introduced to the crucial communication skills required in design, especially those that help them organize their thinking, work effectively in teams, and interact professionally with clients. The course was conceived as part of a larger curricular reform aimed at improving Northwestern's teaching of engineering design and better preparing engineering students for the current work environment.[1] Thus EDC was designed as a cross-school, team-taught venture that integrates content and pedagogy from engineering and communication and teaches design and communication as parallel processes. The course also responded to calls from faculty, administrators, and alumni to give undergraduates more opportunities in speaking and writing.[2] In EDC, while students learn a user-centered process of design, they simultaneously learn an audience-centered process of communication. They learn not only that good communication leads to more effective engineering but also that an engineering education can help them become more effective communicators. This is often a surprising notion to students pursuing math and science—and who sometimes assume that engineers can't write, or won't have to.

EDC owes part of its development to the national resurgence of interest in design[3-6] and draws on the strengths of innovative freshman and sophomore design courses from other institutions, such as Clive Dym's at Harvey Mudd College and the D.L. Evans sequence at Arizona State.[7] For example, EDC students work on open-ended projects tied to real-world problems. However, EDC differs from other new design courses in three ways: its overarching emphasis on a user-centered approach to the design process in engineering; its thorough integration of design and communication; and its innovative, collaborative, cross-school instruction.

Specifically, EDC is designed to accomplish the following goals:

- *introduce freshmen to a user-centered design process and provide them with essential tools for the creative solving of complex, open-ended problems.* One key course goal is to demonstrate that the ultimate judge of a device is not a teacher or manager, but the user of the product. To this end, we encourage the freshmen to learn everything they can about their "customers"—e.g., how users are segmented into different groups, the size of the segments, their needs.

- *provide students with design tools* that will aid them in
  --gathering information about users, products, and technologies
  --defining complex problems by breaking them down into manageable pieces
  --generating alternative designs that address a wide spectrum of user needs
  --selecting the best approaches based on well-defined criteria
  --managing a team project

  We strive to provide freshmen with tools they can use not only for designing, but for solving complex problems they will encounter in many academic and work situations. These tools include brainstorming, objectives trees, Duncker diagrams, pairwise comparisons,

morphological charts, and requirements matrices. We also introduce basic tools for project management, teaching freshmen how to divide responsibilities, schedule and conduct meetings, evaluate individual and team performance.

- *help students see that writing, speaking, and graphical communication are an integral part of design and are crucial to the intellectual life and practice of successful engineers.* We want students to see that design and communication are similar and related processes that approach a solution to a complex problem by iterations though well-defined steps. These steps are not generally applied in a linear sequence, but recur several times as designers or communicators proceed from a concept to a final product. In both communication and design, the individual designer or team gathers information, defines objectives, generates and evaluates alternatives. Communications proceed through several drafts, just as designs evolve from concepts, to models, mock-ups, and prototypes.

- *nurture first-year students' enthusiasm for engineering by*
  -- getting them involved in real world design projects
  -- teaching them how to benefit from working in groups
  -- introducing them to faculty from across the engineering disciplines
  -- developing *esprit de corps* within the freshman class

- *initiate a new culture of design at Northwestern from the bottom up, drawing on the design expertise of the current engineering faculty in ways that break the traditional model of undergraduate education*

Course structure
Overview. EDC is designed as a two-quarter course for two reasons: (1) to integrate material from two courses—design and communication—without sacrificing important material[8-9] and (2) to give students the opportunity to work through the design process two or three times, while faculty revisit important topics at a higher level of sophistication.

In the first quarter students are introduced to design and communication as parallel processes. EDC begins with an intense one-week assignment based on the Apollo 13 LiOH canister problem, involving teamwork and procedure writing. For the remainder of the quarter student teams work on a sustained design project. They attend a large lecture each week and two small workshop sections. They also write weekly on-line journal assignments, communicate with each other and their instructors via *FirstClass* (an electronic conferencing program), and complete an independent software lab. During the second quarter, students work on a new project for a client in the university, the community, or local industry. Most of the teaching is done through group conferences, and students attend lectures on topics such as teamwork and ethics. Both quarters culminate in a final design presentation to clients.

All projects stress a user-centered approach to design. We stress the importance of developing detailed product requirements that are tied to user needs before proceeding with detailed design. We further 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 a drawing or model of a product concept. The students determine their responses to various design features which close the loop and confirm that they have succeeded in interpreting their needs in the form of a new product.

First quarter lectures. At this stage of the EDC pilot, the "lectures," or large group sessions, are highly innovative and interactive. Students spend most of the lecture seeing "snapshots" of the "NU Concepts Design Team" at work. This simulated industry team works on a design project that parallels the students' projects and roughly follows the process that students are required to use. That is, before the students create objectives trees to better define their own design problems, in the lecture they see the NU Concepts Design Team create an objectives tree for their project—the NU recumbent bike. Before the students reverse engineer various competing or model Web pages for their projects, they see how the NU Concepts Team interviews an expert bike builder and then reverse engineers a bike. In every lecture students participate in the role-playing: when NU Concepts engages in brainstorming or wants to get user feedback, the lecturers circulate in the room using handheld mikes, asking students for their ideas and comments. Some lectures focus on engineering topics and others on communication issues, but all are delivered by both engineering and communication faculty to highlight the integral connection between communication and design.

First quarter workshops. Workshops offer students an opportunity to practice the techniques modeled in the lectures and apply the techniques to their projects. In the workshops, for example, students are coached on how to use Gantt charts, objectives trees, and requirements matrices; they get feedback on writing formatted reports that include description, analysis, graphics, and appendices; they conduct informal design reviews and practice oral presentations that depend on PowerPoint slides or World Wide Web applications.

Workshops take place at the new Engineering Design Studio, an 8000 square foot space that is being renovated to include classrooms, a design library, a machine shop, a computer lab with printers and a scanner, faculty offices, a student lounge, and client meeting space. Classrooms are configured to include four group work spaces, each equipped with a work table, chairs, and a computer.

First quarter Web-based projects. One of the pedagogical innovations of this course has been to use the World Wide Web as a model technology to introduce engineering design. All student teams design Web applications that address the needs of the campus community. This approach offers several advantages.[10] First, because students can learn the basics of Web design quickly and because the desk-top computer serves as a rapid-prototyping machine for these products, it is possible for the design teams to develop quite sophisticated prototypes (which real users can examine and test) in a short time. Second, Web pages are easy (and inexpensive) for students to reverse-engineer. Third, even modest Web-based designs present teams with interesting challenges, both as engineers and as writers. Finally, by working on Web-based projects, students learn a great deal about the Web as a communication medium. When they approach the Web as designing engineers rather than as just browsers and information gatherers, students take a more critical (and creative) attitude towards it. During this past year, for example, first-quarter students designed a Web-based alternative to Northwestern's current course evaluation system, an on-line registration system for intramural sports, and Web-based support for Northwestern's new Human Resources software package.

Second-quarter projects. During the second quarter, almost all of the work is project-centered, and students work in teams on design problems that have a real client and address a real

community or local industry need. Projects have included designs for new playground equipment for a nearby elementary school , a homecoming float for NU's residential college system, and a novel self-healing composite material. Regardless of the source of a project, student teams follow a fairly rigid framework defined by a series of communication assignments: project plans, weekly progress reports, midterm updates, final proposals or reports, and final presentations. Design mock-ups are strongly encouraged and in some cases required; prototypes are encouraged when appropriate. At the end of the course students complement their group work with a portfolio of writing about what they have learned during both quarters.

Second quarter lectures and workshops. Since almost all of the second quarter work is project-centered, most teaching is done through group conferences during the workshops. Lectures feature guest speakers on topics such as green engineering, teamwork, and ethics. An effort is made to attract well-known, dynamic speakers from industry—and to have students respond to these talks by keeping an on-line journal. In addition, students attend optional Engineering Tools laboratories for about one-third of the quarter. These provide instruction in domain-specific design tools (e.g., SolidWorks, Advanced HTML, Thermocalc), specialized machine tools available for use in the projects, and advanced research techniques.

Advantages of the new course
While EDC is still in a formative stage—and is not without its challenges—we believe it offers significant advantages to freshmen, to faculty from both disciplines, and to the undergraduate engineering curriculum:

- Improvement in engineering and communication education
  Most importantly, the user-centered approach to design and the integrated nature of the course improve the quality of students' engineering work, their understanding of how design and communication are related, and their communication skills. In both lectures and workshops, faculty stress the importance of concepts that design and communication have in common—that both are processes; that in both processes, writers and designers keep producing and refining their drafts; and that in writing, speaking, and designing, engineers need to keep thinking about their users or readers. Projects receive one grade, rather than separate grades, for writing and design; and students are constantly shown that good engineering and good communication support each other—in other words, that clear communication improves engineering, and a good report or presentation is not only well written but well designed.

  Faculty believe that this integration of design and communication distinguishes EDC from courses that are simply *communication intensive*, in which writing or speaking is taught as a skills set rather than an intellectual domain with affinities to design. While communication intensive courses are beneficial, an integrated course goes even further, we believe, toward helping students apply communication skills and strategies to assignments in other engineering courses; thus EDC will be a more useful communication requirement at Northwestern than the previous course requirement in expository writing.

- Improvements in the learning environment through teamwork and collaboration
  EDC improves the learning environment in the engineering school in a number of ways: by having students work in groups, modeling teamwork and collaboration for students, promoting inclusiveness, and fostering a positive and supportive group identity in the

freshman class. In EDC, students experience group work or teamwork on two levels: they are involved in groups of their own and they see the faculty interacting as a group across disciplines, departments, and gender. This level of interaction is highly unusual in a university setting—and beneficial to all parties concerned. The new model of group interaction is especially useful to faculty who have not had much personal contact with students and to women and under-represented minorities, who have more models in this course structure and more opportunities to speak and take leadership roles.[11-13]

- Early introduction to technical communication
  EDC is an improvement in our curriculum because it introduces technical communication to freshmen. Prior to EDC, there were no courses available that focused on oral and interpersonal communication in technical contexts, and only junior and senior engineering students were allowed to register for the few technical writing courses offered each year. EDC redresses this problem; it provides freshmen with communication skills they can use in their upper-level courses and teaches them how to design readable reports and give compelling presentations. EDC assumes that freshman can learn a great deal about technical communication, just as they can learn about design, even though they do not yet have domain specific knowledge. As they write reports, instead of the traditional freshmen essay or research paper, students learn how to structure an argument, highlight benefits, answer questions and objections, and back up assertions with evidence; they learn how to gather evidence from surveys and focus groups and how to present that evidence in text, tables, charts, and appendices. Thus they can see how the demands of college writing and speaking are different from those they have experienced in high school and how they can use writing, research, and related skills in their academic and professional careers.

- Introduction to new technologies
  Most students are already computer literate at the start of EDC; they have begun to use specialized engineering programs such as MatLab and to take advantage of Northwestern's excellent networked resources. However, by the end of the course, students have become more independent and purposeful in using computer technologies for both engineering and communications. In engineering design, they become more proficient at using a number of basic tools, including CAD programs, spreadsheets, and HTML, for visualizing their concepts and building a prototype of their design. In communication, they work with new technologies for gathering information, preparing documents, and communicating with different audiences. Students also make extensive use of Northwestern's new computer-equipped "smart" classrooms when delivering their teams' final presentations.

- *Esprit de corps* , diversity, professionalism.
  Students in EDC develop an *esprit de corps* that they did not get from taking their usual freshman courses, and which, we believe, will help them develop confidence and enthusiasm for their major.[12] The new educational environment that requires team creativity offers students more opportunities to experience the value of diversity. This is central to the principles of brainstorming that we teach from the first day of class—that on a good team, everyone contributes and everyone learns from everyone else. We have been pleased to see outstanding progress in some of our most international student teams, in which non-native English speakers from very different cultures overcame their language difficulties and shyness to perform at a particularly high level. The confidence and enthusiasm being

developed in the freshman class is reflected in excellent student reports and oral presentations, which often rival the work done by senior design students in format, structure, clarity, and general professionalism.

Challenges
Despite the significant advantages offered by EDC, we still face challenges, which we continue to address as we scale up the course.

Faculty issues
A collaborative cross-school course raises questions about how to meld faculty and methods from two different disciplines and especially how to encourage a traditional, research-oriented engineering faculty to teach an interactive non-traditional course. Related issues are how to recruit engineering faculty in the first place when they are used to working in an environment that values and rewards research over teaching, as well as how to prevent faculty burnout by making the course load and responsibilities manageable.[14]

To manage some faculty issues, we have begun in-service training for faculty development in design and communication. The engineering faculty who are new to EDC are particularly eager for advice about the "coaching" aspect of the course--for ways to work with the freshmen in small, interactive, discussion-style settings that focus as much on communication as design.[15-16] To quote one prestigious professor after he worked closely with students in the EDC pilot, "What's unique about this course is how much we've learned about teaching . . . . I wouldn't have had the courage to teach in this interactive style before."[17] While the writing faculty is familiar with collaborative pedagogy, they benefit from learning about the problem-solving methods associated with design; they also learn more than they would in other settings about the numerical and graphical dimensions of technical communication. All of the faculty—experienced and new—benefit in training about cooperative learning strategies.[18]

Evaluation and assessment
Our assessment of student progress is just in its beginning stages. We periodically solicit feedback, using on-line surveys, student journal entries, and our quarterly evaluation of student work, in addition to using the standard course evaluation required by the university. Student progress has also been qualitatively assessed by a committee of independent evaluators charged with evaluating the whole new freshman initiative at the McCormick School. Initial evaluations are positive: Students produce high quality work, and clients and visitors to our classes are impressed. Nonetheless, we need to further explore assessment methods used at peer institutions [19] and to develop objective methods to measure student progress in their sophomore, junior, and senior years.

Planning follow-up
From the pilot sections of EDC, we can already see that students who complete the course expect more from their upper-level courses than in the past, such as more access to the engineering faculty and more hands-on experience and involvement with industry. As we scale up to include the whole freshman class, we expect more students to display an interest in expanding their skills throughout their upper-class years. We are working closely with the Dean for Undergraduate

Education to explore ways to build on the freshmen's new experience and to integrate design and communication in the capstone courses.[20]

Conclusion

One of our goals in developing EDC was to create a culture of design at the engineering school that begins in the freshman year and extends beyond. A culture of design is desirable because it promotes critical thinking and creativity. It helps students understand that engineering is synthetic as well as analytic. It helps students and faculty interact with each other more frequently and fruitfully than before. It helps students see how their engineering skills will help them shape the world of the future. A culture of design is of necessity a culture of communication—and therefore fosters more effective teaching and learning. A culture of design focuses on customers, users, and readers, thereby narrowing the gap between academia and industry.

This description may sound utopian, but the success of our pilot program argues otherwise. It has led us to believe that an integrated approach to design and communication for freshmen justifies the effort and expense--and can indeed jump-start the engineering curriculum.

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