

IDEA: Implementing Design Throughout the Curriculum at Northwestern*

J. EDWARD COLGATE, ANN MCKENNA and BRUCE ANKENMAN

Northwestern University, Evanston, IL 60208, USA. E-mail: colgate@northwestern.edu

This paper introduces IDEA—the Institute for Design Engineering and Applications. IDEA brings together a number of Northwestern University's existing undergraduate and graduate programs in engineering design and introduces two new programs: 1) a Certificate in Engineering Design that may be earned by any engineering undergraduate; and 2) a Bachelor's in Manufacturing and Design Engineering. We review a number of our guiding philosophies and give an overview of the two new programs.

BACKGROUND: DESIGN AND INNOVATION

AT NORTHWESTERN, we seek to educate engineers who are not only technically strong, but who are innovators. Traditionally, 'one who is innovative' has been treated as synonymous with 'one who is creative,' but we maintain that *effective* innovation does not stem from creativity alone. Rather, innovation results from a design process that provides for not only creativity and the skilled application of scientific and technical know-how, but also the systematic discovery of user and stakeholder needs, as well as market understanding and effective communication. An effective design process is one through which *real problems (needs) are both identified and solved*. Rarely in today's world is such a process carried out by one person. Innovation, in its very breadth, is a team sport. Thus, skill in areas such as cross-disciplinary teamwork, writing, and interpersonal communication is critical. And rarely, one might say never, does such a process occur outside some larger societal, economic or environmental context. As such, the ability to understand context is also an important part of the design process.

This perspective is by no means ours alone. For instance, it is quite consistent with the essential skills of a graduating engineer, as outlined by ABET. Numerous educational initiatives have begun to explore the better integration of design, teamwork, communication, and context into engineering curricula. For instance, the SUCCEED Coalition has researched issues such as integrating design in the curriculum, faculty development, and teaching with technology (www.succeednow.org). Here at Northwestern, along with Vanderbilt, Texas and Harvard, the NSF-funded VaNTH ERC (www.vanth.org) has had great success in restructuring biomedical engineering courses. A main pedagogical principle within VaNTH has

been to develop *realistic* challenges for students to solve as a method for learning subject matter, and to develop core engineering competencies [1–3].

A number of leading universities have also begun to implement 'design throughout the curriculum' in recent years. For instance, the Integrated Teaching and Learning Laboratory at the University of Colorado (www.itll.colorado.edu) is both a facility and a set of courses, including a freshman-level projects course and a junior-level 'Invention and Innovation' course. In the latter, students work to develop patentable concepts. The University of Pittsburgh has established the John A. Swanson Center for Product Innovation (www.engr.pitt.edu/SITE/SCPI/index2.html), which offers students a 'Certificate in Product Realization' and bills itself as a one-stop new product development shop for industry. Michigan Tech has developed a 'Student Innovation Center' (<http://me.mtu.edu/imagesmeem/newinnovation-center.html>), including a 'Design and Creativity Center,' where senior students develop product designs, and a 'Product Realization Center,' where they can bring their designs to reality. Carnegie Mellon offers students a minor in engineering design (www.ices.cmu.edu/minor.html), and Stanford has, for many years, offered a degree in product design (<http://design.stanford.edu/PD/home.html>). Harvey Mudd offers both a freshman-level introduction to engineering design (E4) and a senior-level 'Clinic' program (www.eng.hmc.edu/clinic.asp?sidebar=clinic).

But, even among these leaders in design education, it is rare to find programs that have been embraced by entire engineering schools, let alone teams of technical and non-technical disciplines. The problems are familiar: lack of faculty know-how, interest and support; focus on engineering analysis to the near-exclusion of synthesis; lack of strong connections to non-technical disciplines; and poor articulation of the intellectual content associated with design. Overcoming these

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difficulties and integrating design synthesis throughout the curriculum is a challenge that our community must face.

ENGINEERING DESIGN EDUCATION AT NORTHWESTERN

At Northwestern, we have made an important first step. We have made design process, teamwork and communication a key part of the freshman experience. We have done this via a two-quarter sequence known as Engineering Design and Communication (EDC) [4–5]. EDC is a project-based course that is team taught by engineering and writing faculty. After a Monday lecture, students meet with their instructors twice weekly in small sections (typically 16 students). There they work on their projects and are coached in a user-centered approach to design, in which they use various engineering tools and techniques to define the problem, generate alternatives, observe and interview users, build mockups, conduct design reviews, and produce models or prototypes. Projects culminate in three deliverables: a mock-up or prototype, a written report, and an oral presentation. To stress the point that communication is an integral part of engineering, all the communication requirements in this course—memos, progress reports, proposals, drawings, and PowerPoint presentations—stem from the work in design.

In the first quarter of EDC, the projects all come from one domain, most recently modular components for automobile interiors. Students learn the basic process, but do not interact with a client. In the second quarter, however, the projects come from a variety of domains and are all submitted by actual clients. Clients include corporations, not-for-profit agencies, entrepreneurs, and individuals. Many of the projects have a social service dimension. In spring 2001, for example, EDC teams worked on designs like the following:

- an enhanced ‘spinal trainer’ for physical therapists at the Rehabilitation Institute of Chicago;
- an improved cargo carrier for a minivan;
- a device to help students with cerebral palsy play a version of basketball in their physical education class; and
- a portable massage table that is easier to set up than existing models.

EDC can be viewed in more detail on our website at www.edc.northwestern.edu; key course concepts are described in a link from that site, the EDC online textbook. In the present context, however, it is most important to understand that, on the one hand, EDC lays a strong foundation for innovation, including design process, teamwork and communication; on the other hand, EDC does not present these topics in a highly sophisticated way, nor does it introduce them in a highly technical context.

We are proud of what we have accomplished with EDC, but we recognize that one course does not make, nor remake, an entire curriculum. At present, we do very little systematic follow-up of what is taught in EDC. Of course, our students all have a capstone experience, but this generally comes some three years after taking EDC. In the interim, most students do very little to build their design, communication and teamwork skills. This is not for lack of interest. Student-initiated and student-led design competitions are popular at Northwestern as they are at many engineering schools. Many of our students are involved in a campus-wide robot design competition, while others work on national competitions such as Sunrayce, Mini-Baja and Steel Bridge.

As part of our ongoing assessment we have interviewed students to obtain feedback on our courses and programs. Our assessment data confirm that students also recognize the lack of follow-up to EDC. In addition, students express a strong desire to apply their engineering knowledge to actual problems. One common theme we hear again and again is that students yearn for more opportunities to apply their knowledge to ‘real-life’ engineering problems. The following quotes exemplify this notion:

We take all of these classes in our freshman year and never apply them to anything, then sophomore year we’ll take classes and never apply them to anything. Junior and senior year [faculty will] say, ‘Well, you’ve all taken calculus. Remember that?’ We don’t remember any of that. We never had to apply it. If we don’t have anything to apply it to and we’re just studying the book, we’re not getting to see how it relates in the real world.

Well you have to take your basic calculus and physics, which everyone’s thinking, there’s no application. We’re engineers. We want to apply.

The conclusion that we have reached is that there exists a need for a more thoroughgoing approach to design, one that provides a set of increasingly sophisticated experiences throughout the curriculum. It is for this reason that we have created IDEA.

IDEA: INSTITUTE FOR DESIGN ENGINEERING AND APPLICATIONS

IDEA, the Institute for Design Engineering and Applications (www.idea.northwestern.edu), was established in the fall of 2002, with the following mission:

Provide, sustain, and continuously improve a curriculum and environment in which students learn the process of value creation through a series of engineering design and research experiences.

‘Value creation’ means identifying and solving real problems within a social and economic context, thereby improving the quality of life on earth.

IDEA aims to build on several existing elements, including EDC, a Bachelor’s in Manufacturing

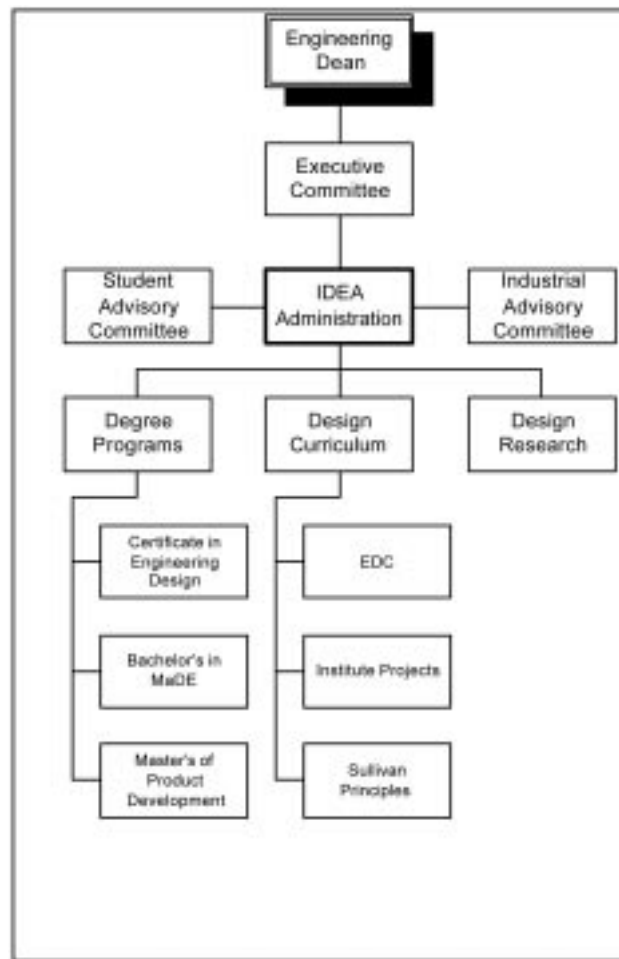


Fig. 1. IDEA organizational chart.

Engineering degree program (see the section below), and the Master's of Product Development degree program (MPD). IDEA will also develop new design curricula, focusing initially on the undergraduate engineering program. Figure 1 illustrates the relationship of these components.

As we work to develop IDEA, we are conscious of lessons learned in developing EDC and other design courses, especially with regard to pedagogy and the effective use of resources. This has led to a number of guiding philosophies:

Do not allow 10-week quarters to constrain the offerings—It is difficult to do significant design projects in only 10 weeks. Conversely, it does not necessarily require 10 weeks (or even traditional classes) to develop certain design skills, such as knowledge of CAD software or rapid prototyping techniques. In many respects, research is a better model for design education than coursework.

Archive and share information—It is ironic that, while academic research is absolutely rooted in the archiving and sharing of information (books, journals, libraries, databases . . .), academic curricula are normally designed to discourage the archiving and sharing of student

work. This is understandable in the case of static curricula (math, physics, basic engineering analysis), but it makes little sense in the teaching of design. Each new design team should be standing on the shoulders of those that came before. This is especially critical for large-scale, long-term projects in which hand-offs from team to team will be common.

Assess, iterate and improve – It is important in any curriculum to establish learning goals and metrics, and to assess against these metrics. Design curricula, however, like design problems themselves, are inherently messy. Good designers work their way through this messiness by developing clear goals and metrics ('specifications'), by assessing ('testing'), and by *iterating*. Iterating is not a sign of weakness, it is a key part of an effective process. It stands to reason, therefore, that iteration and continuous improvement must be part of an effective design curriculum. This has certainly been our experience in EDC, which continues to change as it enters its eighth year.

Establish standards for quality – This point may seem too obvious to bear mention, yet many design courses are quite *ad hoc* when it comes to grading. One never really knows what is going to

happen in a design project, and standards tend to get compromised in the heat of finishing a project at the end of a quarter or semester.

Balance cost, quality and schedule – The point above relates to a deeper lesson about project management. It is well known in industry that technical risk (quality), cost risk and schedule risk cannot all three be minimized for any one project [6]. A typical university design project eliminates schedule risk, causing students to balance cost risk (manpower, which, because bodies cannot be added, translates into all-nighters) and quality. This can be a valuable experience, but it should not be the only lens through which students see project management. Moreover, it happens all too often that faculty, upon seeing the students' Herculean efforts, compromise standards for quality. A better approach recognizes the intrinsic trade-off while maintaining high standards.

Integrate horizontally and vertically – Students benefit from working on teams that are diverse. Horizontal integration, including team members from various disciplines, encourages adaptive learning. Vertical integration, including team members of different educational levels, develops leadership and mentoring skills.

Use resources efficiently – Design projects require close monitoring and mentoring, and can consume prodigious amounts of faculty time. Part of the solution to this problem is a well-rounded teaching team, including upper-level students, support staff, and professional designers. We have found that the latter group brings especially significant pedagogical benefits [7]. Another part of the solution is the use of technology, including digital video and on-line course content. We have found that even rather complex labs can run asynchronously and without supervision in this way.

DESIGN CERTIFICATE PROGRAM

With the support of an NSF Curriculum Planning Grant (#0230547), IDEA is now developing a curriculum that any engineering student at Northwestern may follow to earn a Certificate in Engineering Design. The certificate program has been designed to build on EDC and embody the philosophies discussed above.

The program requires six courses, including four that lie beyond the normal allotment required for graduation. It also requires the development of a Design Skills Portfolio.

Coursework

At the heart of the certificate program is a set of four project-based courses. Students must take one of the following:

IDEA 306 Technology Assessment and Innovation; or

IDEA 307 Human-Centered Product Design

and both of:

IDEA 298 Interdisciplinary Design Projects I

IDEA 398 Interdisciplinary Design Projects II

All of these courses tie into a set of multi-year, interdisciplinary projects known as 'Institute Projects'. IDEA 306 and 307 may be thought of as feeder courses for Institute Projects. In these courses, projects are conceived and vetted. Only the strongest go on to be worked on in IDEA 298 and 398. 306 and 307 are similar courses, focusing on the early stages of design. 306, however, is geared toward technically sophisticated projects that have a bit more of an R&D flavor. A good example is hydrogen storage systems for automotive applications. Students working on this project are not performing basic research into storage technologies such as carbon nanotubes, but are assessing the best available technologies and developing conceptual designs around them. 307 is geared more toward traditional product development (i.e. the application of mature technology to new problems). A good example is the design of a helmet for pole-vaulters.

Class meetings in 306 and 307 intersperse lecture and student presentations/reviews. Lectures and (in some cases) associated case studies address fundamental topics such as:

- Market assessment
- Technology assessment
- Intellectual property
- Marketing
- Costs, value and pricing
- Engineering ethics
- Statistics in design

A number of guest lectures are delivered by domain experts selected for their relevance to the projects. For instance, an expert from GM may discuss design opportunities and challenges associated with hydrogen storage.

Teams of three to four students work throughout the quarter to develop design concepts. Much of their work involves concept generation followed by user needs and market assessment and technology assessment, followed by concept refinement. The teams' final deliverables are white papers, each presenting a design concept supported by detailed analyses. These white papers are then made available to 298/398 teams in subsequent quarters. Should a 298/398 team adopt a design concept, it will become an Institute Project.

In IDEA 298/398 (Interdisciplinary Design Projects), the Institute Projects are executed. 298/398 teams are interdisciplinary and also include both younger and more senior students. 298 registration is open to sophomores and juniors, while 398 registration is open to those who have previously taken 298. 398 also includes a lecture component focusing on leadership and project management skills. Each team is advised by

a faculty member and evaluated by a committee (much like a graduate research program). Teams will also receive support from several IDEA staff members, including our Operations Director, Design and Prototyping Specialist, and ultimately, we hope, a 'team leader' who is dedicated to project support.

This concept of initiating a project during one quarter, then pursuing it with different teams in subsequent quarters, is an essential part of the IDEA plan. It introduces schedule risks and allows us to set high standards for quality. It also enables our students to pursue innovative concepts to a much deeper level than would normally be the case in undergraduate design projects. In some respects, this is more like a graduate-level research endeavor (and, indeed, some graduate students will be involved), but we will foster a culture much more along the lines of a product development organization.

As a part of the infrastructure supporting these projects, we intend to create an archive of student design information. A standard, required deliverable for every design team will be a set of database entries including a report, design documentation (e.g. specifications, diagrams, programs), keywords, citations, personal contact information, and links to physical artifacts. The database will also include information about useful design resources, industry experts, design guides, FAQs, etc.

In addition to these project-based courses, three elective courses are required. These are arranged into the following categories:

- Design
- Social Sciences and 'Techmanities'
- Business and Society

As the categories suggest, many of the elective courses are taught outside the engineering school. To encourage breadth, students may not take all three electives in any one category.

Portfolio

Each student must, in conjunction with his or her IDEA faculty adviser, create and present a Design Skills Portfolio demonstrating proficiency in the following areas, as appropriate:

- Prototyping and implementation—evidence that the student has built working artifacts
- Modern software tools—evidence that the student has gained proficiency with at least one such tool
- Design analysis—use of analytical methods for decision-making and/or parameter optimization
- Project management
- Effective writing—accessible description of technical concepts; persuasion
- Effective graphical communication (preferably integrated with writing or presentation)

A plan for the portfolio must be approved by the end of the winter quarter of the student's junior

year, and the portfolio must be submitted by the end of the winter quarter of the student's senior year.

Today, it is the student's responsibility to gain the relevant experience and report on it. Eventually, we hope to offer short courses and workshops that will support the development of design skills.

BACHELOR'S IN MANUFACTURING AND DESIGN ENGINEERING (MADE)

For those students who think of their primary career goal as design engineering, we have a newly constructed Bachelor's degree program in manufacturing and design engineering (MaDE). Combining the disciplines of manufacturing and design engineering is in step with the current management policy of Integrated Product Design (IPD) that has been the new standard for managing product development in the last 10 years [8]. Under IPD, it is crucial to include the development of the processes and marketing of the product along with the actual product design. Having design engineers trained in both the design process and in manufacturing processes and systems will greatly enhance the ability of companies to implement IPD.

The MaDE degree was developed by modifying the name and course requirements of an existing degree program (previously called Manufacturing Engineering). In particular, design courses, such as 'Human Centered Product Design,' 'Manufacturing Engineering Design,' and 'Interdisciplinary Design Project,' were added to the list of required classes. Although the Manufacturing Engineering degree (started in 1995) is a fully ABET-accredited degree in manufacturing engineering, we feel that the addition of the design emphasis will make the degree even more attractive to the accreditation board, to employers, and to students. One key feature of the MaDE degree is that it is constructed so that, in only an additional quarter or two, it is possible to get a dual degree, one in MaDE and another in a more traditional engineering discipline, including Industrial Engineering and Management Sciences, Mechanical Engineering, and Electrical and Computer Engineering.

CONCLUSIONS

EDC, a course required of all engineering freshmen, has been Northwestern's first step toward an integrated curriculum in design synthesis. EDC has become an entrenched part of the culture of our engineering school. Now, with the advent of IDEA, we intend to build on EDC, creating a thoroughly integrated design curriculum and, ultimately, a 'culture of design.'

A key resource in this effort will be the Ford Motor Company Engineering Design Center. This

75,000 square foot building is scheduled to open in the winter of 2005. The Ford Design Center will house several programs, including the Computer Science Department, the Master's in Manufacturing Management program, and the Infrastructure Technology Institute. But the focal point of the Center will be its namesake: a teaching facility devoted to design education. Facilities will include:

- a large prototyping shop;
- CAD/CAM lab;
- rapid prototyping lab;
- mechatronics lab;
- automobile testing area;
- three design education classrooms modeled on the current EDC Design Studio classrooms (each room will include rugged easily moved tables, and will be equipped with computers, scanners, printers, LCD projectors, 'intelligent'

and conventional whiteboards, flipcharts, and plenty of paper and markers);

- smaller group study rooms;
- a café and student lounge area; and
- project display space.

It is our belief that IDEA's new curricula, coupled with a committed faculty and staff and a state-of-the-art facility, will allow us to offer an education that effectively teaches both technical fundamentals and innovation—the ability to both identify and solve real-world engineering problems.

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J. Edward Colgate received a Ph.D. degree in mechanical engineering in 1988 from M.I.T. He subsequently joined Northwestern University in Evanston, Illinois, where he is currently a Professor in the Department of Mechanical Engineering and the Alumnae of Northwestern Professor of Teaching Excellence. Dr Colgate's principal research interest is human-robot interaction. He has worked extensively in the areas of haptic interface and teleoperation, and he, along with collaborator Michael Peshkin, is the inventor of a class of collaborative robots known as 'cobots.' Dr Colgate is currently the Director of IDEA—the Institute for Design Engineering and Applications—that is chartered with integrating design education throughout the engineering curriculum at Northwestern University.

Ann McKenna currently holds the positions of Associate Director of Design Education in the Institute for Design Engineering and Applications (IDEA), and Research Assistant Professor in the Department of Mechanical Engineering and School of Education and Social Policy at Northwestern University. She received her B.Sc. and M.Sc. degrees in Mechanical Engineering from Drexel University in Philadelphia, Pennsylvania and a Ph.D. in Science and Mathematics Education from the University of California at Berkeley. Dr McKenna has extensive experience in engineering education research, curriculum development, and assessment.

Bruce E. Ankenman is an Associate Professor in the Department of Industrial Engineering and Management Sciences at the McCormick School of Engineering at Northwestern

University. His current research interests include response surface methodology, design of experiments, robust design, experiments involving variance components and dispersion effects, and experimental design for simulation experiments. He is a past chair of the Quality Statistics and Reliability Section of INFORMS, is on the editorial board for *IIE Transactions: Quality and Reliability Engineering*, and is an Associate Editor for *Naval Research Logistics*.