Design Education Across the Disciplines

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Abstract

Engineers, architects, and computer scientists all engage in design upon graduation. Yet, up to now, there has been little emphasis in post-secondary education in helping students learn the ins and outs of doing design successfully. Capstone projects provide too little design experience and come late in the curriculum. Freshman design experiences, when in place, tend to emphasize the design experience itself, often without helping students reflect on and understand what the experience is teaching them. Even when both components are in place, there is little connectivity between these early and late experiences.

Georgia Tech is taking the lead nationally in creating a design curriculum that helps students learn the skills involved in doing design and that is integrated throughout their undergraduate years. In EduTech's design focal group, faculty representing the full variety of design disciplines are working along with cognitive scientists in an attempt to list the component skills involved in design, the kinds of activities and projects that promote such learning, and based on that, to devise curricular frameworks and guidelines for making design education work. We are working towards a core curriculum in design, one that can be shared by the full variety of design disciplines.

Our work is guided by the experience and needs of those in the design disciplines, the needs of the workplace, and by what cognitive scientists know about design cognition and about learning from experience (cases). Fortunately, all point in similar directions -- toward a curriculum that provides significant collaborative hands-on experience coupled with significant reflective activities. Our knowledge of case retrieval and indexing helps in guiding the sequencing of student activities, in suggesting several kinds of technology that

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* EduTech's design education team includes a variety of faculty who teach design, from a variety of engineering units (e.g., civil, mechanical, chemical, industrial), architecture, industrial design, software engineering, and rhetoric (document design?). It also includes faculty and students in the cognitive sciences, particularly those with background in case-based reasoning, design cognition, and learning; and faculty and students specializing in educational technology, interested particularly in software-realized scaffolding and software in support of collaborative learning. Shared by all is an interest in doing better at helping students learn the principles and skills behind good design and the conviction that collaboration with this broad range of participants is essential to a quality solution to that problem. EduTech Institute, which organizes this endeavor, has as its mission to use what we know about cognition to inform us as we design educational technology and the environments in which it will be used. Design education is a major focus of EduTech's current endeavors. Thanks to Farrokh Mistree for extensive comments on this paper.

might be useful both during learning and practice, and in informing us about the sorts of reflection to promote.

Design Education: What we are aiming for

Current approaches to education throughout the disciplines tend to emphasize individual work, learning of facts, and the analysis of artifacts. While engineering curricula also include one capstone design course in which students use a design project to integrate the concepts they have learned in individual courses and some include a freshman "design experience," few, if any, emphasize integrative activities as a fundamental part of the curriculum. Thus, too many of our students graduate knowing a lot of disjoint facts and concepts without knowing how or when to use those facts in responding to complex problems. Students are not yet ready at graduate time for the workplace, where use of knowledge for problem solving, design, and project management are essential. Nor are they prepared to collaborate well, to transfer their skills from one domain to another, or to learn and consider concepts beyond those learned in school.

Students currently use their first years in the workplace to integrate and learn to use the knowledge learned in college. We claim that if college education emphasized integration and use of knowledge, then necessary skills and the principles behind them would be learned by a broader cross-section of the workforce and in ways that would promote more effective use. Rather than educating our students for just one life-long career, we need to educate them to be instrumental in contributing to and managing technological change. This requires balanced experience in several areas: analysis and synthesis, science-based and process-based knowledge, communication, and human and societal issues. The body of knowledge that supports the practice of design is evolving from an art to a science, one that is different but complementary to other engineering sciences. Thus, we believe it is necessary to shift emphasis in design classes from lectures and puzzle-like problems to team activities in which participants learn by doing, acquire hands-on experience, and learn how to draw career-sustaining lessons from those experiences.

We are therefore aiming to put into place a core curriculum in design that will produce engineers, software designers, and architects with deep understanding of technical facts and the skills and foundational principles to be able to use them flexibly and well. We want to graduate students who can

- negotiate solutions to open problems;
- reflect on what they do and articulate critical decisions;
- represent, interpret, analyze, and communicate a problem;
- generate multiple alternatives in response to proposed problems;
- evaluate options and procedures both during and after determining appropriate responses;
- use mathematical and other technical resources effectively;
- manage the resources and skills needed to carry through on projects; and
- successfully work in teams; communicating at technical and professional levels.

These skills will allow our graduates to solve problems flexibly using the technological and scientific facts they are learning. But more than skill is needed to do these tasks well. Students will also need deep understanding of their own discipline, appreciation of what several related disciplines bring to their problems; and strong collaboration skills. This combination of deep knowledge and honed skills, we believe, will allow our graduates both to perform well and to learn from their individual experiences those things that will allow them to lead their companies into the future as they take on management and leadership positions.

Educational Philosophy

Recent educational research reveals several features of a learning environment that enhance learning. Students learn most effectively and permanently when they are active participants in the learning process (e.g., Chi et al., 1984). Particularly important is having the opportunity to explore the ins and outs of new concepts as they are learning them and to use newly-acquired knowledge to solve interesting problems (Bransford, Sherwood, Vye, & Reiser, 1986). Furthermore, there is much evidence that when students work in groups with others, their learning is enhanced (e.g., Brown et al., 1993). Experience shows that skills are best learned by practicing them and reflecting on that experience (Brown & Campion, 1994).

Problem-based learning (PBL), a scheme that includes all of these components, is being used substantially at medical and business schools (Barrows, 1985; Williams, 1993). In this scheme, students learn by solving authentic real-world problems. Because the problems are complex, students work in groups, where they pool their expertise and experience and together grapple with the complexities of the issues that must be considered. Coaches guide student reflection on these experiences, facilitating learning of the cognitive skills needed for problem solving, the full range of skills needed for collaboration and articulation, and the principles behind those skills. Because students are in charge of their learning, skills needed for life-long learning are also acquired, for they must manage what they need to learn and how it will be learned as they cope with the problems set for them. Experience in medical and business schools shows that problem-based curricula serve to enhance learning facts and concepts at a range of levels and to promote the learning of critical problem solving and collaboration skills needed for the workplace (Dolmans, 1994; Hmelo, 1994; Norman & Schmidt, 1992).

Based on these studies and experiences putting these programs into place in medical and business schools, the design core curriculum we are developing is collaborative and problem-based. We hypothesize that a problem-based curriculum that focuses on collaboratively solving authentic design problems will have the same benefits for our students that it has for medical students. It will allow them to better learn the factual and conceptual knowledge in the curriculum, to learn the applicability of that knowledge, to integrate facts learned across several courses, to become better designers, to learn and practice the skills they will need when they enter the workplace, and to learn the principles behind using those skills well. These principles, we believe, will allow our graduates to effectively transfer their knowledge and skills to solving new problems in new domains and that will allow them to creatively deal with the realities of noisy, ambiguous and incomplete data.

Putting it into Practice

But we can't simply transfer the problem-based curriculum of the medical schools to an undergraduate educational institution. In medical school, students focus full time on learning medicine. Medical students are older and more mature and already have at least some learning and study skills. Undergraduate education, on the other hand, is much broader, there is less focus, and students are still learning study skills. We need to borrow the best of problem-based learning as it is used in the medical schools, but to adapt it and shape it to the needs of undergraduate education.

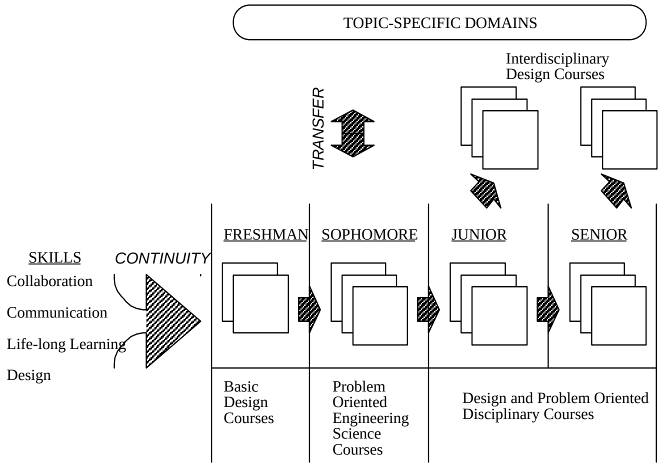
The core we are developing cuts across a large and varied set of design disciplines (the range of engineering disciplines, architecture, and computing) and focuses on several fundamental skills and principles important to the practice of design in all of those disciplines. This interdisciplinary approach is intended to expose students to differing ways of approaching design problems beyond those prescribed by their home discipline. The courses will also be available and accessible to students outside of the design disciplines (e.g., management, public policy), providing opportunities for students who will work alongside designers to learn about design.

Our effort has three parts: (1) Development of a core curriculum that fosters integrative skills necessary for analysis, synthesis, evaluation, and contextual understanding of engineering, software, and architecture problems, with an aim toward emphasizing the learning of design skills. (2) Development of problem-oriented courses as part of this curriculum that address academic and professional requirements in tandem, helping students acquire collaboration skills, communication skills, life-long learning skills, and the principles behind those skills, in addition to factual knowledge, and helping them learn how to use the facts they are learning. (3) Integration of a software environment into these courses that promotes collaboration and reflection and that provides easy access to state-of-the-art computer technologies. The software environment is intended to promote transfer of knowledge skills learned in the design curriculum to other parts of the curriculum as well.

The Core Curriculum

Faculty in EduTech's design group agree that design curricula should begin in a non-disciplinary way, move forward in each discipline addressing relatively simple problems, and gradually move toward sophisticated interdisciplinary design projects. This gives us three kinds of courses: <u>pre-disciplinary foundations courses</u> that help students learn basic problem solving skills, articulation of decisions made, collaboration among people with different expertise, and so on; <u>area-specific skills courses</u> with different gradations of complexity in which students do more and more complex design using the analytic tools of their discipline for both synthesis and evaluation, building on the foundations courses and using design skills learned in those courses to learn disciplinary facts and skills; and <u>interdisciplinary capstone courses</u> in which students work in interdisciplinary teams on a problem of real-world complexity, integrating the expertise and analysis tools of several disciplines. The core curriculum will include the foundations courses and interdisciplinary courses. Each discipline, we hope, will gradually make its curriculum more design-oriented.

Key aims in the core curriculum are <u>continuity</u> and <u>transfer</u>. Continuity refers to introducing key skills early in the curriculum and revisiting them on a regular basis while adding more complexity to the situations in which they are carried out. Transfer refers to helping students learn to use these skills in a variety of different circumstances. Our analysis so far suggests a structuring of the core curriculum as shown in the figure below.



In the freshman year, we hope to have a sequence of two courses in which the essentials of design reasoning, collaboration, and communication are learned through work on non-trivial, but non-disciplinary, collaborative design projects. Problem-oriented "engineering science" and other courses, offered in the sophomore year and shared by the disciplines, will provide an opportunity to apply key design, collaboration, and communication skills as core concepts are learned. These courses, we hope, will replace existing fact-oriented science courses. In the following two years, design-oriented and problem-oriented disciplinary courses will help students cement the learning of key disciplinary concepts with design activities. Design experiences will be used to motivate reflection on problem solving, collaborative, and communicative skills used to successfully solve problems. In addition, we'd like to see interdisciplinary design-oriented courses and capstone options, in which students at several levels of expertise solve design problems together.

Throughout, several principles and values permeate our plans: active in-class involvement, education in both facts and reflection, continuous guidance, teamwork, systems-oriented problem solving, and learning by doing on authentic design problems. We want students to learn principles of design; we also want them to learn how to learn.

Central to the proposed curriculum is a software environment that promotes reflection and collaboration, supports design decision making, makes case studies available for perusal, makes internet resources available, and provides access to relevant discipline-specific software. The software will be used throughout the design curriculum and will play a key role in providing continuity and transfer across the many design projects students will carry out in the course of their undergraduate engineering education. We hypothesize that use of a tool that helps students make their decisions explicit will help them transfer the skills they learn early on into later and more complex projects; that use of a state-of-the-art design support environment will allow students to work on more complex and challenging design projects; and that use of a state-of-the-art collaboration support environment will help students to build upon each other's skills and knowledge and to leverage their own abilities.

The Freshman-Level Courses

The freshman experience, within our core, is comprised of two quarter-length courses. The first lays foundations for design; the second allows students to focus for ten weeks on a single project. In both courses, the majority of student time is spent collaboratively solving problems. Experiences in these courses are intended to form the foundation for carrying out design activities within their chosen discipline.

It is thus important for the teacher to find problems for students to solve that are representative of problems and issues that arise in the world, to promote the creation of general knowledge by sequencing problems such that comparing and contrasting of several different situations can be productive, and to provide help with group processes, reflection, and moving productively forward, aiming to insure that students are extracting appropriate skills from their experiences.

Course 1: Foundations of design I. This pre-disciplinary foundations course will give students their first hands-on experience with design. It comes at the beginning of freshman year. Students work in interdisciplinary teams on a series of small design projects that don't require significant hard-core disciplinary knowledge. They might design and build games of various kinds, plan and cook meals, or solve simple engineering problems and construct simple artifacts (e.g., variations on the classic egg-drop activity). Students discover, in this course, the ways in which they can effectively use problem-solving skills they already have to do design. They discover how to articulate the problem solving they already do.

In particular, they learn about the importance of prioritizing constraints and framing problems, the iterative nature of design activities, the types of decisions made during design, the role evaluation plays in discovering shortcomings of designs in progress, the ingenuity required to derive evaluation criteria beyond those in a specification, the necessity of generating and exploring several alternative solutions, and general-purpose strategies for doing each of these things. They also begin to learn how to negotiate their way productively in group activities. And they have their first experiences using the collaborative software environment. At the end of this course, we want students to have the vocabulary for discussing what they do when they do design, to understand the role several key skills from their discipline play in design, and to have an understanding of design that will allow them to appreciate, in later courses, the role the knowledge learned in those courses might play in carrying out complex problem solving and design.

Students will work on three projects in this course, a very short individual project (2 to 4 days), a group project of two-weeks duration or shorter, and a larger group project of 5 to six weeks duration. In this way, students will have the opportunity to "fail" softly early in the quarter, allowing them to learn from their mistakes and be more successful in later projects. The first project, a short individual one, is intended to introduce students to the concepts of understanding a problem, proposing multiple alternative solutions, and the need for evaluation. With this in hand, students will work in groups on a second project, this time using the project to point out some of the ins and outs of collaborating, the need for clear articulation and explanation, and the role software can play in aiding collaborative efforts. In the third project, groups will put these new collaboration principles and skills to work in designing and building a simple artifact. Our intention first time through is to have students design a souvenir for the Olympics.

Central to this class will be presentations of designs and the rationale behind them to the class as a whole and discussions about the different designs that promote recognition of the reasoning and skills used in understanding problems and coming up with solutions. Thus, much class time will be spent comparing and contrasting different solutions students come up with, discussing how different solutions were derived, and examining why different students and groups came up with different solutions. Other time in class will be spent with experts, who will model design reasoning for the students by solving problems and discussing their rationale for the students and by discussing the role design plays in the discipline or workplace the expert comes from. We hope to be able to present final projects to local industry as well as to the class and to gain feedback from industrial experts on a variety of design and manufacturing issues. This course will be offered for the first time in fall, 1995.

Course 2: Foundations of Design II. In this course, students will put what they've learned in the first course to use in collaboratively solving a larger-scale design problem, though still one that doesn't require detailed disciplinary knowledge. This pre-disciplinary foundations course will be modeled after the current ME3110 (Creative Decisions in Design), taught for many years now by Professors Farrokh Mistree, Janet Allen, and David Rosen. Like ME3110, this course will reinforce the entire product realization process, from problem formulation through to design and to actually building a product, with special emphasis on planning the activities required to complete the full process. While ME3110 is taught to mechanical engineering juniors, the new course will be aimed at students in the variety of design disciplines and will be taken at the end of their freshman year. As this course is currently taught, students are introduced to an often-turbulent imaginary world. The inhabitants of that world must solve a serious problem that requires an engineered solution. Students design and build a solution to this problem. One quarter they may need to build an evacuation device, another quarter a device that will transport and drop sleeping potion in enemy territory. Important activities include problem formulation, design, construction, and testing. In this context, the students plan their activities for the quarter, allocate resources (cost, time, and so on), and have a device ready to compete near the quarter's end. Students experience the interplay inherent in meeting design requirements subject to resource constraints, selecting most-likely-to-succeed alternatives, and resolving trade-offs. Decisions are introduced as key engineering constructs to aid these tasks. Class time in this class will continue where the first class left off, helping students to further explore and understand cognitive, social, and technical skills and principles important to quality design. As in the first course, our software environment will play a key role.

Where is the Case-Based Reasoning?

This session is about case-based reasoning, but our discussion so far has neglected to mention it. CBR plays three important roles. First, an important part of the software support environment will be case-presentation software and case libraries. Case-presentation software will present the problems students will be solving, structuring the necessary background knowledge. Students will have access to libraries of cases that illustrate the issues and concepts they are exploring. Cases might provide suggestions about how to do things, but more importantly are intended to help students analyze problems to determine what their important characteristics are and where priorities should lie in devising solutions. The companion paper and presentation on Archie-2 will give more detail about this contribution.

The second contribution of case-based reasoning is more abstract. Our knowledge of case-based reasoning, especially its algorithms and heuristics for retrieval, adaptation, and indexing, suggest several insights into how we might induce learning in our students and the kinds of functionality and scaffolding our learning environments ought to have. Case-based reasoning tells us, for example, that learning happens as a result of interpreting and indexing experiences in ways that facilitate their retrieval at times when they might be useful. This suggests that we might induce reminding, and therefore transfer, by helping students to learn a vocabulary for describing design experiences and by helping them, before they are expert at using that vocabulary, to nonetheless interpret their experiences based on that vocabulary. Both the reflective discussions in class and the scaffolding provided in our collaboration environment will be designed to promote such learning and analysis. Based on case-based reasoning's premises, we are developing software for individual and collaborative use that is intended to induce skills transfer as students move through the curriculum in design-related disciplines (engineering, computing, and architecture). The paper and presentation on CaMILE explain the collaboration environment.

Finally, case-based reasoning suggests the importance of experience to learning, and the activities and materials being put together to support learning in our design courses reflect that insight. The paper and presentation on our sustainable technology course show how we are using insights from case-based reasoning and the case method of teaching to develop materials for design classes. While the sustainable technology course is not part of the design core, it is being developed with the same principles by people who are active members of EduTech's design education team.

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