REENGINEERING SOONER CIVIL ENGINEERING EDUCATION

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Abstract *- By reinventing the civil engineering educational system, we will be able to produce the master integrators of tomorrow. In addition to technical skills, we will imbue graduates with technical vision, business principles, marketing savvy, communications skills, leadership and management understanding. At the University of Oklahoma we are embarking on an ambitious curricular revolution that will transform what the students in the College of Engineering learn and how they learn it. The old paradigm mandates that students attend classes to accumulate the required number of credits to obtain a degree. We will replace that old culture with one in which students gain competencies through a variety of learning experiences: design and research projects; and off-campus internships, including participation in international projects. We will develop modules so that students learn new skills as they are needed within the design or research project; thus principles of "just-in-time" learning will be ubiquitous. While going through the curriculum, students will document and reflect on the meaning of what they are learning by creating a "Learning Portfolio," which will be one of the evidences of progress. Students will be charged with managing and taking responsibility for shaping their own education through active and higher level learning, all of which will develop lifelong learning skills.*

CONTEXT FOR CHANGE

The Boyer Commission Report [7] highlighted the need for reinventing undergraduate education. According to the commission, research universities have failed the undergraduate student population. The commission recommends ten pivotal approaches to radically improve today's educational paradigm. Likewise, the Kellogg Commission on the Future of State and Land-Grant Universities recommends that we create new learning environments [12]. Both commissions indicate that major curricular innovations are needed, not minor adjustments.

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We live in a rapidly changing world influenced by change agents such as: a) the global economy; b) information explosion; c) international competition; d) cognitive revolution; e) a diverse workforce; and f) environmental sustainability. The graduate engineer must be able to function in the areas of integration, analysis, innovation and synthesis, in addition to having a contextual understanding for her work [3, 5]. Table 1 identifies six types of changes in engineering, with the major implications for the engineering curriculum.

Now is the time to revolutionize undergraduate engineering education. While the traditional educational paradigm has produced generations of competent technical engineers, it is ill suited to producing graduates who can contribute in a dynamic team-oriented environment, who have advanced critical thinking skills, who are proficient with information technology and who can communicate effectively with management and the public [2, 6, 8, 11, 14, 18]. Our traditional system is discouraging many talented engineering prospects, including women and under-represented minorities, and squandering critical resources [17, 19, 24]. We have an attrition rate in engineering that exceeds 40% at many leading institutions. Students commonly leave engineering because they fail to see relevance in introductory classes and because of a lack of early faculty mentoring [22]. It is our belief that the best way to generate excitement and improve retention is to introduce project-based, modular-aided learning that develops multiple competencies in students.

CURRICULAR REFORM

We are in the process of creating the Sooner Engineering Education Center (SEEC) for multiple competencies with the over-arching goal of creating modular-aided and project-based learning throughout the curriculum in the College of Engineering (CoE) at the University of Oklahoma (OU). Initially, concepts will be developed as a pilot project in civil engineering, and subsequently SEEC will be embraced by all units in the college. We envision that multiple competencies will be enabled by SEEC through the use of multidisciplinary engineering, appropriate technology and ubiquitous design projects.

In order to realize our long-term vision of a curriculum driven by student projects (and not by students checking courses off of a list), three essential components must converge: 1) well-defined, comprehensive, multidisciplinary projects; 2) a flexible, yet rigorous assessment tool in the form of a student learning portfolio; and 3) a protocol for delivering technical information on an as-needed basis (i.e., "just-in-time" learning). Each of these components, and their interrelation, is illustrated in Figure 1. The existing course-driven curriculum is shown at the top; the long term goal of a project-based curriculum is shown at the bottom. Our methodology to get from the current to the future scenario is shown in the middle of the figure. That is, we will develop just-in-time learning modules, inclusive learning modules, and assessment tools in parallel before merging them as a coherent curriculum.

Table 1. The Changing World of Engineering

Change Agents	Implications for Student Learning*
1. Increased use of computing.	1. Ability to use information technology appropriately
2. Globalization of business	2a. Sensitivity to other world cultures
	2b. "How to learn" a foreign language
	2c. E-Commerce
3. Greater interaction between engineers and other professionals.	3a. People skills (e.g., working on a team)
	3b. Communication skills (oral presentations, writing, team dialogue)
4. Multiple and changing organizational contexts for business	4. Business operation and management
	• Organizational know-how
	• Understanding the workplace
	• Flow of ideas in an organization
5. Change in engineering practices	5a. "Learning How to Learn"
	• Discovering and mining information for solutions to new problems
	5b. Directing personal continuing professional education
	• Defining a learning agenda
	• Constructing a program for achieving learning objectives
6. Changing career opportunities	6. Preparing for new careers.
	• Monitoring career opportunities
	• Assessing capabilities
	• Re-directing your career

* In addition to domain-specific knowledge and the ability to operate at the systems level.

Figure 2 illustrates the overall program philosophy as it relates to just-in-time learning for science and mathematics (S&M). At the left of the figure, the arrow spanning the four years represents the continuum project. Assume, for example, that the project centers around the infrastructure design for a municipality and suppose that the students are working on a surface water supply reservoir; this is indicated in the middle part of the figure, along with the disciplinary subjects involved. Finally, at the right of the figure, we show the needed S&M modules in order to have the necessary background to complete the reservoir design. This knowledge is gained on an as-needed basis to complete the task. In essence, the intellectual content of traditional courses has been identified, and each individual topic delivered in a self-contained module. Modules can be self-paced, multi-media packages; short (e.g., one- to two-week) seminars; directed study; formal peer-mentoring teams or a combination thereof. By reducing existing courses into their basic components, we will allow just-in-time learning to succeed in the context of curriculum-long projects.

In a traditional curriculum, S&M are taught by faculty in their respective disciplines with little regard for the ultimate application of the material by the students. The University of Oklahoma currently falls in this model, as do most large institutions. Also, as cited earlier, it is one of the reasons for low retention rates. An integrated S&M approach is one where students simultaneously learn chemistry, physics and mathematics in supercourses in the context of meaningful applications. While highly effective, we believe it is an unsuitable national model. First, it requires a large institutional investment to restructure the curriculum and a tremendous faculty commitment to sustain the effort. Second, it cannot easily accommodate transfer students, students with advanced placement credits or students who take courses out of sequence. Institutions that adopt an in-between model maintain the individual identity within the S&M courses, yet they try to incorporate meaningful applications to motivate student learning. Some institutions may even attempt some bridging of the courses by working on common projects. As the name implies, this model is a cost-effective strategy that takes advantage of the strengths of the first two models. Many attempts fall into this category, and, given the institutional climate at many schools, it is a good first step. But we propose to do more.

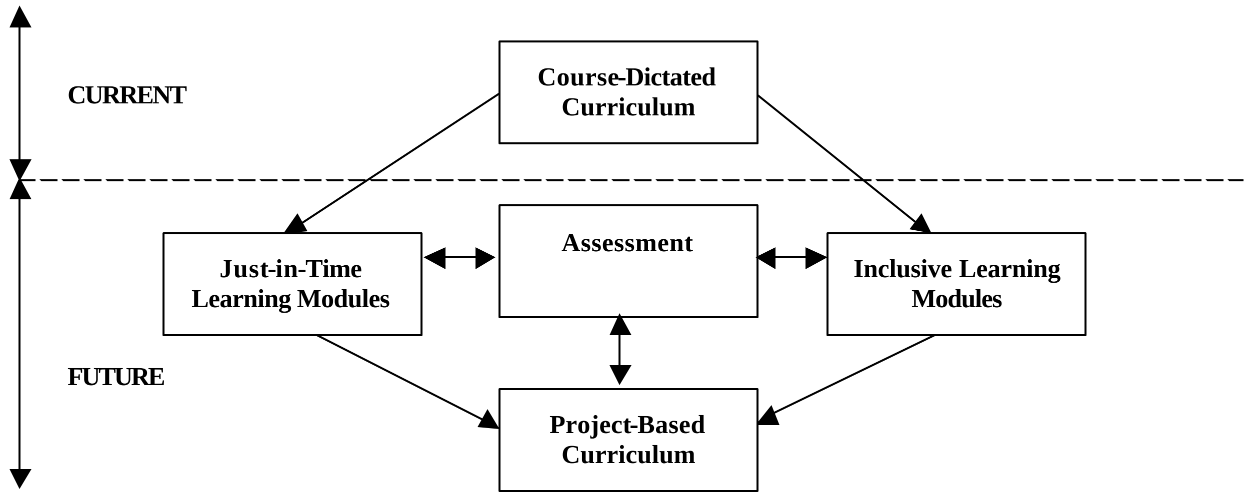

Figure 1. Transition from Course-Driven to a Project-Based Curriculum

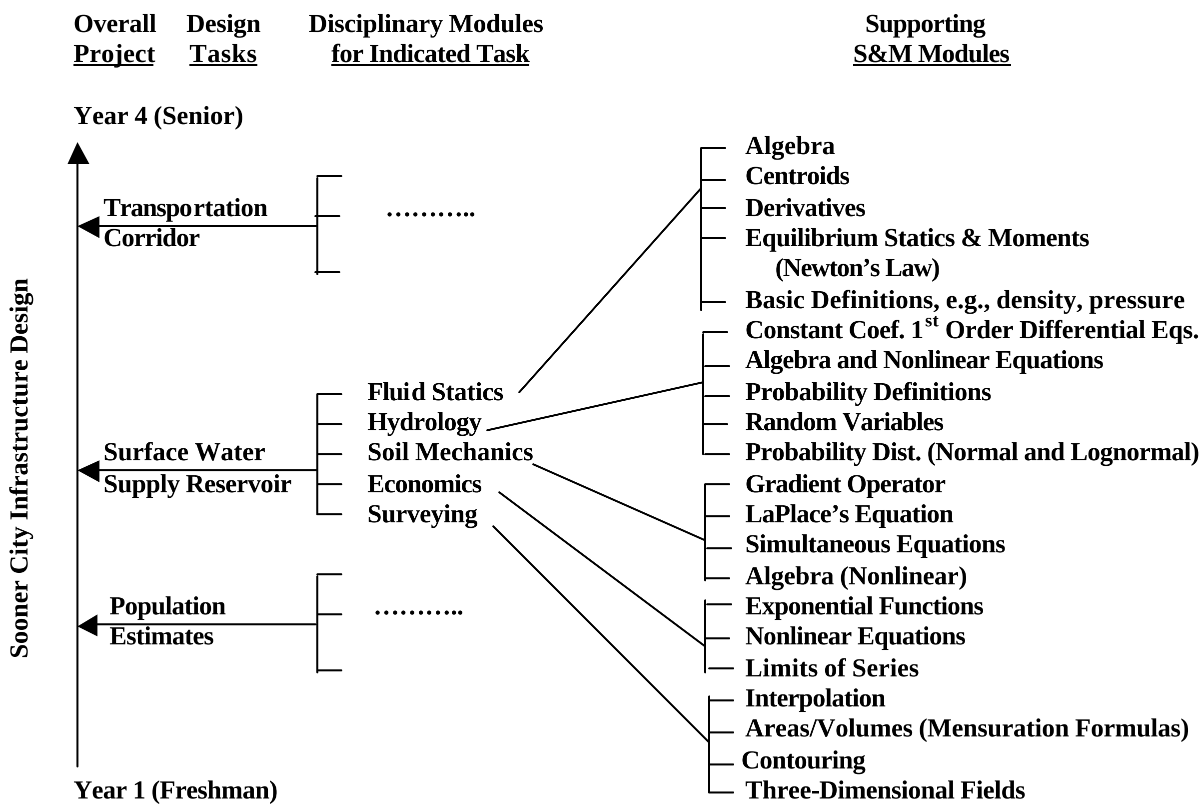

Figure 2. Just-in-Time Learning in a Project-Based Curriculum

We will institute just-in-time learning across the curriculum. Continuing with the S&M example stated above, we would eventually like to eliminate the entire S&M course sequence. Instead, students enter the engineering curriculum in the freshman year, working on multidisciplinary design projects. As they encounter tasks that require certain S&M skills, that material is presented in a self-contained module, including appropriate theory and background. We do not claim authorship of the just-in-time learning paradigm, but our experience is that where implemented, it has been implemented on a localized basis such as within a given course [16, 23]. We are not aware of its use on a curriculum-wide basis and at the level of modularization we are proposing. In those cases where it has been used, it has proven effective when it comes to issues such as higher-level learning, retention, and excitement. However, development costs are high, at least initially, and it is difficult to sustain. In fact, until the present era, we believe a full just-in-time approach was unworkable (viz, you simply cannot expect the mathematics faculty to respond quickly every time engineering summons). But with information technology, now is the time since many of the modules can be web-based and self-paced, which provides the needed flexibility to meet various timing demands. We are not proposing to replace faculty. Rather, the multimedia modules would complement faculty expertise and allow them the time to supervise group projects and offer more individual mentoring.

MULTIDISCIPLINARY PROJECTS

Pilot projects will replace discrete, independent courses with multi-semester, project-based teams learning through "inclusive learning modules" (ILM) (i.e., a composite of one or more existing courses). The project teams will be multidisciplinary, as required by project complexity, and multi-classes, with upper class students supervising entry-level colleagues.

We will initially create ILMs by exploiting the fact that we already have project-based (or design-based) courses in the freshman and senior years. Project-based courses currently exist in the freshman year to help motivate and integrate incoming students while they are primarily taking core courses (e.g., science and mathematics). The project-based capstone course that students take in their senior year helps them integrate their learning around a complex design. By coupling students in these courses, and by integrating these courses with several others in the freshman and senior year, we will develop project-based ILMs that will ultimately replace the current course-driven curriculum.

We will use a pilot project to move from our current course-driven curriculum to our desired project-based curriculum. The pilot project, which combines freshman and senior level courses in Civil Engineering, was selected based on: a) the complexity and diversity of projects in civil engineering; b) past educational initiatives; and c) faculty support and development of our proposed plan.

CIVIL ENGINEERING DESIGN PROJECT

A typical civil engineering project, such as building a shopping mall, is multifaceted and complex, requiring a combination of technical, legal, managerial, business and finance skills. While civil engineers, the master integrators, typically oversee such a project, a number of other disciplines are equally important (e.g., mechanical, electrical and industrial engineering, along with business, finance, law and management expertise). Currently the civil engineering design course at OU, which already integrates civil, mechanical and electrical engineers, is a one-semester three-credit course in the senior year. We will expand upon the existing course by: a) integrating two additional courses in the fall of the senior year and one course each semester of the freshman year: and b) including additional disciplines (e.g., industrial engineering, business and finance).

Four courses have been identified to provide a focus on a single project (i.e., the learning in each course will be motivated by, and an outgrowth of, tasks necessary to completing the project). The two freshman courses, Introduction to Engineering (a fall semester course) and Graphics and Design (a spring semester course), were selected because they naturally lend themselves to a design project. The two senior courses, Structural Design and Fundamentals of Engineering Economy, were selected because they are typically taken in the fall semester, and content is critical to the typical design project.

To achieve long-term success, educational reforms must build upon previous experience. The School of Civil Engineering and Environmental Science (CEES) has a proven track record of implementing educational reforms. Starting in 1993, the senior design class was revamped to be team-based and project-based, with projects being provided and judged by practicing engineers. The results of this course are presented in several journal articles [13, 14], and the professor was awarded a prestigious national award for the innovation. CEES also served as the pilot group for the wireless laptop program in the college (i.e., CEES courses were converted and taught in a wireless laptop environment a year before the rest of the college), and is a leader in the integration of research and education [21].

CEES is also currently implementing an NSF Action Agenda grant, Sooner City [15], to integrate a common design theme throughout courses in the civil engineering curriculum (development of a plot of land into "Sooner City."). The new curriculum is an outgrowth of this successful project, which received the 1999 Oklahoma Regents for Higher Education's "Instructional Technology Excellence Award." Whereas Sooner City seeks to integrate a common design theme throughout existing courses, the new paradigm also seeks to remove barriers between courses, and expose students to a working environment more typical in the practice of engineering. Working on Sooner City has increased the awareness and enthusiasm of CEES faculty for educational reform, making the general project-based learning project possible.

Sustainability, scalability and transferability are other key components of educational reform. No reform will have a long-term impact if it is not sustainable and easily transferred; therefore, we follow the approach of integrating existing courses. This project will develop and design features during the first year of the project, with some initial implementation, followed by a full implementation in the second year, with modifications in the third year, based on second year results.

In addition, an environmental science ILM will integrate two freshman courses with four senior-level courses. A project, such as designing a constructed wetland to treat mine wastes will provide the focus for the technical content and laboratory exercises throughout the coupled courses.

LEARNING PORTFOLIOS

Learning portfolios [20] will be used to support the new curriculum. The learning portfolio is a document that contains two sections: a narrative and an appendix of supporting materials. In the narrative, students comment and reflect on *what* they have learned and *how* they have learned. When discussing what they have learned, student comments will be organized around the six major goals of the proposed curriculum (see Table 1).

Completing a learning portfolio will help students in a number of ways. When students engage in the various research and design projects, they will be having "rich learning experiences," meaning that they will be learning several things simultaneously: content learning; how to use the content; how to work in performance groups; and developing communication skills. Consequently students need to periodically reflect on what they have learned from these experiences, what they need to learn next, and how they can broaden their education.

Going through this self-reflection exercise will also help students to develop a sense of self-direction in their own professional education. When a student finishes the engineering program under this multi-dimensional curriculum, s/he will have a portfolio to show to prospective employers that will document skills, attitudes and special learning experiences.

Creating learning portfolios will be a new experience for most students; therefore the CoE will provide the following support: 1) an initial orientation course on learning portfolios; 2) supervised and peer mentoring on reflective thinking and assembling documents; and 3) portfolio assessment by peers and faculty.

The college undergraduate advising center will coordinate and support the development of learning portfolios. Activities will also be held to orient all faculty members in the college about their role in the development of learning portfolios, and periodically orientation sessions will be held for new faculty.

INSTITUTIONAL ASSESSMENT

An institutional assessment plan is pivotal to success [1, 2, 4, 9, 10]. We anticipate that this project will generate three kinds of change: 1) enhanced student performance in a broader range of competencies, including technical competency as well as the "new" competencies that have been enumerated in the six educational goals of the project (cf, Table 1); 2) student retention; and 3) positive institutional change. These changes will be the focus of the assessment and evaluation activities.

Enhanced student performance will be assessed within the modules and courses via course evaluations, module evaluations, pre- and post-course examinations, and student learning portfolios. These formative assessments will key on the six educational goals of the curriculum, as well as the course/module specific goals. Course objectives and outcomes will be linked to both prerequisite and related courses. A content study will have a listing of specific goals or curricular student outcomes for each course and module, plus a linkage of these goals to their preceding and subsequent courses. In addition, an overall matrix will be designed that links each module/course with the six educational goals, as well as with the Accreditation Board of Engineering and Technology's Engineering Criteria 2000 student outcomes.

In preparation for the student retention measurements, we will develop assessment strategies. Criteria for retention of students will be established using a combination of factors from the cognitive and the affective learning domains. The criteria will vary based on gender, ethnicity, and socioeconomic background, as well as type of engineering discipline.

The institutionalization of the project will be measured by the success of the organizational changes that have been highlighted as necessary for the successful overhaul of the educational system. Such indicators will be changes in promotion, tenure, and review requirements, faculty reward structures, joint departmental educational projects, and faculty perceptions. Programs that recommend high levels of change are in need of change agents, which ultimately facilitate permanent change. Change agents are supported by policy changes, faculty perceptions of a successful project, and administration support. The CoE has begun the process of institutionalization by revamping new policies and procedures for annual faculty evaluations. These changes include recognition of course and educational materials development efforts and activities that promote technology transfer, industrial development, and intellectual property development. The tenure review system is the next targeted structure. Overall faculty attitudes via an annual faculty survey will be tracked during the time period of this proposal. Differences between participating faculty and "outside-of-project" faculty will be noted. Faculty interviews will be conducted within the project focusing on the perception of labor intensity/work load associated with the educational innovations proposed in this project. Measures such as the number of courses, number of different departments, number of faculty, and number of students participating in the project will be tracked, all possible indicators of positive institutional change.

SUMMARY

The School of CEES at OU will expand and build on the experience gained in "design across the curriculum," which was funded by a three-year grant from the NSF Action

Agenda Program. The school begins a pilot project in project-based learning for the College of Engineering beginning the fall semester of 2000. A series of comprehensive courses with appropriate mathematics/ science/engineering foci (i.e., Integrated Learning Modules--ILMs) that are project based will be the centerpiece of the new and flexible curriculum. This reform will begin with the expansion of the existing industry-driven senior capstone course into a two-semester ILM, with students from civil, environmental, electrical, and mechanical engineering, along with business and architecture students, working in design teams. First-year students will join the teams in this ILM and function as apprentices mentored by the seniors. In addition, fall of 2000 will see modularization of offerings such as geoinformatics, computer-aided engineering, and other topics that will be subsequently expanded to all existing courses. Planning and implementation for the comprehensive four-year curriculum will run in parallel with the first offerings. The over-arching goal is to attain module-aided, project-based learning throughout the curriculum, first in civil engineering and environmental science, and ultimately, across the entire College of Engineering at the University of Oklahoma.

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