Integrating Design Throughout the Civil Engineering Curriculum - The Sooner City Project

R. L. Kolar, K. K. Muraleetharan, M. A. Mooney, B. E. Vieux, H. Gruenwald
University of Oklahoma

ABSTRACT

Evaluations of existing undergraduate engineering programs continually cite three weaknesses: graduates lack technical literacy; graduates lack oral and written communication skills; and graduates lack design experience. To address these weaknesses, the School of Civil Engineering and Environmental Science (CEES) at the University of Oklahoma, is proposing a systemic reform initiative that will incorporate four themes throughout the curriculum. The centerpiece of the initiative is a common design project, entitled "Sooner City," that will be introduced during the freshman year and continue for the entire curriculum. Design tasks range from population estimates to the water supply system. A common design project can unify the curriculum and allow material learned in early courses to carry forward. Another advantage is that the students will have a professional design portfolio that can be presented to perspective employers. Second, the design project will be taught using the just-in-time learning paradigm. By focusing on real-world applications up front, students will be interested and motivated to learn. Third, courses will be restructured to incorporate team learning and group presentations, which enhances the students' interpersonal and communication skills. Fourth, starting in Fall 1998, all incoming engineering freshman will have a laptop computer with wireless communication technology so that each classroom becomes a networked computer lab. Together, the efforts will produce graduates who are self-disciplined, responsible, computer literate, and who can communicate effectively with fellow engineers, management, and the public. Also, the reformed curriculum can serve as a template for other reform efforts around the country, with an obvious name change for the city!

INTRODUCTION

For the past five decades, undergraduate engineering education has, for the most part, followed this paradigm: class lectures on technical concepts, little or no discussion, homework consisting of numerical computations, and problem-solving exams. Furthermore, many institutions have been slow to adopt high technology (computers) into the classroom, relying instead on hand-held calculators and traditional design charts and nomographs. While this formula has produced generations of competent design engineers, it is ill-suited to producing graduates who can contribute in a dynamic, team-oriented environment, which must rely on computers to solve complex design problems, and which must be able to communicate effectively with management and the public. Articles[7,9,12,14,26,29] and interviews with our own graduates, alumni, and employers document that graduates from such programs often have poor computer and communication skills. Our four-pronged curriculum reform effort to addresses these weaknesses. The elements are as follows: 1) use a four-year design project, "Sooner City," as a common theme for all undergraduate civil engineering courses; 2) introduce an alternative classroom format that mimics the dynamic, team-oriented setting used by engineers and scientists to resolve difficult problems, problems that are too large and too complex to be tackled by individuals; 3) couple team-learning with a pedagogical approach that is primarily project- and student-driven, also referred to as “just-in-time” learning; and 4) require students to have a laptop PC, and use the laptop as the medium of instruction throughout the curriculum, including courses in other areas such as math, physics, and English.

NEED FOR THE REFORM - HISTORICAL PERSPECTIVE

The engineering educational system in the United States is discouraging many highly talented students and squandering an important national resource. We have a national attrition rate that exceeds 40% at a number of leading institutions[5]. Many nation-wide attempts have been made to address this problem, but their effectiveness remains to be seen. A related concern, is associated with the level of education acquired by the newly-graduated engineer. That is, are we as engineering educators doing an adequate job of structuring the curriculum and educating our students? We are still using the same passive lecture-style delivery mode in spite of the fact that technology has now given us the opportunity to change the paradigm for teaching and learning. As a first step in the reform effort, through round-table discussions and a review of the literature[1,2,7,8,12,14-16,21,25,28,29], we compiled a list of desirable outcomes of the undergraduate engineering education experience:

- involvement in interdisciplinary endeavors
- involvement in teamwork
- integration across age, ethnic, and experience levels
- strong oral and written communication skills
- the ability to apply knowledge in multiple settings
- experiment with design and reasons and know their synergy
- high technical literacy
- understand certainty and handle ambiguity
- a sense of social, ethical, political, and human responsibility
- a unifying and interdisciplinary view
- a culture for life-long learning
- a creative spirit, a capacity for critical judgement, and an enthusiasm for learning
- advanced knowledge of selected professional level technologies
- effective time management
- integrated team approach to product/technology development
- ability to critique one’s self, whether in work or life
- a thorough understanding of current tools
- a sense of the total industry perspective
- ability to adapt to changing emphasis in ones’ field of study

We are aware of other university’s efforts in engineering educational reform, such as Drexel’s E^4 Program which introduces design in the freshman year, and RPI’s efforts with virtual labs[6,24,30]. Other institutions, and even our own department, have implemented/experimented with technology-based education, active learning, and collaborative learning. However, we are not aware of any effort, existing or proposed, that *integrates all four reform themes listed above throughout the undergraduate engineering curriculum.*

THE PLAN

1) Sooner City

Many organizations, ABET (Accreditation Board for Engineering Technologies) included, see great value in introducing design early and often in the engineering curriculum, as the open-ended feature of such problems helps students develop critical thinking skills that are required for a successful engineering career. Furthermore, many faculty desire to generate student excitement, which usually correlates with seeing application of theory. To address these concerns, we are introducing a comprehensive project in the freshman year centered around designing Sooner City. Basically, freshman are given a plat of undeveloped land (not unlike the undeveloped expanses of prairie that greeted the early “Sooner” settlers of 1889 - hence the appropriateness of the Sooner City name) that, by the time they graduate, is turned into a (partial) design for a city, including site planning and layout, sewer and water infrastructure, water supply, wastewater treatment, buildings, transportation systems, channel design, floodplain analysis, and geotechnical work. The plan doubles as a student portfolio that can be presented to prospective employers[22]. It can also be used by the students as a valuable reference tool in their engineering career. Since Sooner City provides a unifying theme to the entire undergraduate curriculum, courses build upon one another instead of appearing as independent entities. It is our experience that, all too frequently, students fail to apply knowledge gained from previous courses to future work; Sooner City helps students not to forget what they have learned.

To implement Sooner City, little change in the course sequence is needed; however faculty must restructure their syllabi to introduce the design early, and center individual and group projects around one aspect of the design. Obviously, an entire course is not be devoted to Sooner City; rather it provides motivation for learning theory and application. Opportunities to connect the program to other departments are being explored.

2) “Just-in-Time” Learning

We believe, as do faculty at other institutions[6,14,23], that student interest, and hence learning, is maximum when they can see the application behind the theory. Sooner City was chosen precisely for this reason, i.e., to provide justification and motivation for learning design concepts. We introduce the appropriate component of Sooner City *early* in the semester, and then let the course be driven by the students’ desire (and need, in order to obtain a good grade!) to solve the proposed problem. Such a format has been used within individual courses in our curriculum on a limited basis. Student response, with regard to the design and the educational format, was very positive. A typical class contains five common components: problem statement, a student-driven syllabus, theory, application, presentations.

1) Problem Statement. The first meeting defines the specific component of Sooner City that is to be designed and pose a list of questions to be answered, the academic equivalent of an RFP (request for proposal). Empirical studies show that to maximize the success of team learning, faculty should assign groups?. Within the group, the students are responsible for organizing the design team and dividing tasks amongst themselves. Students must face the logistical problem of managing and coordinating all work; they must prepare a timetable for completion of the project, as part of the grade is based on meeting posted deadlines.

When appropriate, students are given a specialized software package early in the semester that can be used to complete the design described in the RFP. We encourage the students to try and run the program without any background information. Undoubtedly, they stumble because of a lack of understanding. Much can be learned by controlled failure, however, and the exercise captures the student's attention and provide additional motivation for the course.

2) Student-Driven Syllabus. Based on the students' review of the RFP, and based on their stumbling with the design software, the students identify what background information they need. With proper direction from the instructor, a plan of attack is outlined that would form the syllabus for the course. During the early part of the semester while the syllabus is evolving, faculty can spend time reviewing basic material and computer skills needed for the course.

3) Theory. With such a course structure, faculty are free to experiment with alternative delivery formats. One, which we believe is highly effective and which works well in a team learning environment, is a conference or seminar-type format. Rather than presenting formal lectures, the seminar meets at regular intervals, with instructors serving as facilitators responding to student's well-posed questions. Some questions may be answered directly, while for others, references to appropriate articles, web sites, or other materials are given. Students are forced to learn how to learn. Furthermore, by having the students learn more outside of the classroom, precious class time can be devoted to "bigger" issues, such as applications and implications of decisions (ethics).

4) Application. Concurrent with learning theory, students apply the material to designing the appropriate component of Sooner City, in addition to smaller textbook-type problems.

5) Presentations. With a seminar format, we require the students to document all major decisions along the way and present results to "management," i.e., the instructors, in the form of written and oral reports. In addition, each group presents a final report (oral and written) to the PI's and sometimes a panel of experts (from consulting and industry) in an effort "to get the job." In conjunction with team learning (next section), such a setup provides ample opportunity for the students to develop their communication skills.

3) Team Learning

Each class format attempts to mimic the organizational structure used in professional practice when handling complex problems, viz, project-oriented venue with work responsibilities allocated to members of an interdisciplinary design team. In this educational scheme, some members of the team, typically the stronger students, act as project managers and help guide the other members. As any instructor will attest, true understanding comes when one tries to teach material to another; hence, by naturally introducing a teaching aspect into the overall structure, student learning is maximized. Statistics presented by Professors R. Felder, K. Smith, and L. Michaelsen, demonstrate that students in a team-learning environment retain more information, make better grades, develop better attitudes toward learning, develop more self-esteem, and attend class regularly[10,11,17-20,27].

4) Mobile Computing
Over the summer of 1995, the Dean of Engineering convened a study group to examine the feasibility of a mobile computing plan, i.e., laptop computers with wireless networking. The study was borne out of the need to increase the role of high technology in education and practice, and the need to relieve the burden on existing computer labs[4]. The group, based on a thorough investigation of other institution's efforts (Virginia Polytechnic, New Jersey Institute of Technology, University of Minnesota at Crookston, and Temple University) and based on visits to the Institute of Academic Technology, recommended the mobile computing plan. At the beginning of the 1995 Fall semester, all College of Engineering School Directors embraced the plan; it will begin college-wide in the Fall of 1998.

Of course, a computer will never replace, nor should it, the personal mentoring of the professor; rather, it is used to distribute information in a very efficient manner using hypertext and interactive modules, thereby freeing the professor's time for "teaching" in the true sense of the word. Care is taken to avoid using the computer for entertainment without substance.

EXPECTED IMPACT
Curriculum reform will be rich and rewarding; this fact is abundantly clear. Entering first-year students are curious and full of questions about engineering. By providing them with a unified year-long experience in engineering design (freshman year), we mitigate their uncertainties about the field. National engineering education experience has shown that students react positively to hands-on experience at solving real-world engineering design problems[6,14]. Also, by learning high technology methods in the first year, the students are well-equipped to succeed in their subsequent three years of engineering studies. Several years ago, our department established a very strong partnership with local practitioners in restructuring our senior capstone design course; it is now a "gateway" course to the practice of civil engineering[13]. Through high technology we will be able to strengthen this cooperative arrangement that assures currency and relevancy to our curriculum. Clearly, the time is right to try a departure from the traditional lecture/problem solving format that has dominated engineering education in the past. We feel the plan detailed herein could serve as a paradigm for many engineering programs.

While group activities permeate the curriculum, we are not neglecting the value of independent study. In this respect, the laptop computer truly mobilizes resources for individual-centered education. By having computer access from across campus 24-hours a day, one can study the course content at their own pace, with as many learning loops as required to master the material. Furthermore, multimedia computing applied to higher education allows for a "multiple intelligences perspective," which provides the individual learner with more than one media so as to reach various types of learners, e.g., some people are more visual oriented, others learn better by example, and others learn best by listening.

Computer technology makes libraries and learning modules created by the best instructors more accessible, particularly benefitting disadvantaged students. The wireless network promotes not only links between the classroom and the external intellectual environment, but the use of this technology also encourages intellectual exchanges among students of various background within a classroom. Appropriately designed computer programs will make it possible to solve complex problems, like "Sooner City," by a group of students while helping "level" the abilities within a group so that less able students might take on tasks that would be viewed by others as meaningful, thus furthering the group activity. Concerning disabled students, a virtual field trip to anywhere, and in particular to the job site, can be as easy as pressing a key on the student's personal computer. This provides persons with disabilities an opportunity to visit the construction site.

Graduate students will also benefit greatly from the plan, particularly those pursuing a career in education. In academia, it is widely recognized that junior faculty are often ill-prepared for their roles as instructors[3]. Graduate students will be invited to participate in the reform and in writing software modules. Advanced students will be invited to team teach courses with their faculty mentors.

EVALUATION

This project will use the services of an on-campus expert in educational evaluation to conduct both summative (e.g., we want students to (a) learn how to handle design problems more effectively, (b) become familiar with and proficient in the use of industry-standard computer hardware and software, and (c) be able to make high quality oral and written technical reports) and formative (e.g., have the students had the desired kinds of experiences in their various courses, as they work their way through the revised curriculum evaluation activities. Results will be reported at future ASEE conferences as the data becomes available.

SUMMARY

In closing, we feel that a change in engineering pedagogy is needed; a change that produces graduates who are self-disciplined, responsible, curious, team-oriented, and effective communicators; a change that produces graduates who are not only prepared for their technical jobs as sophisticated computer users, but for their places in the larger real world; a change that prepares students to be life-long learners; and a change that prepares them for multiple career paths. Our proposed systemic initiative is a step in this direction. By using a team-oriented, project-driven setting, we are developing the students oral and written communication skills, preparing them to work in groups, and teaching them how to teach themselves. By centering the pedagogical steps around a common design theme, we are teaching them valuable work skills. And by using laptop computers as the instructional medium, we are teaching them important technical skills as well. We feel confident that these reform efforts will make an significant contribution to re-engineering the engineering curriculum, both at the University of Oklahoma and beyond.

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BIOGRAPHICAL INFORMATION

DR. R. L. KOLAR received his B.S. in civil engr. and mathematics from the U. of Idaho in 1983 and his Ph.D. in civil engr. (water resources) from the U. of Notre Dame in 1992. He is a registered professional engr. Research interests center on computational hydraulics/hydrology. Educational interests center on alternative delivery techniques, critical thinking, the use of high technology, and bringing research/consulting results into the classroom.

DR. K. K. MURALEETHARAN, P.E., received his undergraduate degree in civil engr. from the U. of Peradeniya, Sri Lanka in 1983 and his M.S. and Ph.D. in civil engr. from the U. of California, Davis, in 1987 and 1990. He has 6 years experience in geotechnical/environmental consulting. Research interests centers on soil dynamics. Educational interests center on the use of technology (mobile computing) freshmen education, alternative paradigms.

DR. M. A. MOONEY received a B.A. from Hastings College, a B.S. from Washington U. (1991), an M.S. from the U. of California-Irvine (1993), and a Ph.D. from Northwestern U. (1996). Research interests include dynamic soil compaction and smart materials/systems. In addition to Sooner City, Dr. Mooney has developed an instructional strategy predicated on student-teaching, where discovery, critical thinking, and communication skills are fostered.

DR. B. E. VIEUX, P.E., received his B.S. from the U. of Kansas in 1978, M.S. from Kansas State U. in 1982, and Ph.D. from Michigan State U. in 1998, all in civil engr. Research interests include distributed hydrologic modeling using GIS. Teaching responsibilities include graduate courses in GIS applications, water quality modeling, and hydrology. He was one of the first instructors at OU to use Web-based tutorials for his graduate classes.

DR. H. GRUENWALD, AIA, received his architectural engr. degree from Rudolph Diesel Politechnikum Augsburg, West Germany in 1983, Master of Arch. from U. of Houston in 1984, and Ph.D. from OU. Research interests focus on computer applications in architecture and construction materials and methods. He uses a practice- oriented, high-tech approach to teaching. Other educational interests include digital media and continuing ed.