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Integrating Design into Civil Engineering Education*

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This paper identifies the need to incorporate design concepts into Civil Engineering Curriculum from the freshman through the senior years. The existence of a single requirement for a capstone senior-level design course, which is implemented in most engineering programs as per ABET basic requirements, does not fulfill the goal of preparing design-oriented, creative engineers. The paper describes an integrated approach to the inclusion of design aspects in those courses most geared towards design. It also demonstrates that design is a total educational and learning experience, and its success depends on the implementation of a program which integrates a number of desirable educational approaches. These include, but are not limited to: creative thinking, active learning, increased awareness and participation, integrated research, teamwork, decision making, communicating, managing conflicts and interacting with the public and the professional community.

INTRODUCTION

THIS PAPER PRESENTS an integrated program which will incorporate design concepts into the civil engineering course curriculum from the freshman through the senior years. This program not only includes design in civil engineering course content, but also outlines teaching mechanisms and educational activities which enhance design value for both faculty and students.

Since the Fall of 1994, the Civil Engineering program at Kuwait University has included a senior-level capstone design course in its curriculum structure. While the inclusion of this single course is an essential ingredient of a program which trains competent design-oriented engineers, it nonetheless falls short of achieving this goal due to a variety of factors.

Studies have shown that engineering design is a crucial concept in the total educational and learning experience [1], and its success depends on the implementation of a program which integrates a number of desirable educational approaches. These approaches are summarized in Fig. 1, and will be discussed in this paper.

TOTAL DESIGN EXPERIENCE

Fostering the ability to design systems, products, or projects lies at the heart of engineering education. Engineering design is the process of devising a system, component, or process to meet desired needs. This activity involves understanding the characteristics of the components that need to be put together as well as the rules and regulations that govern these components. Engineering design requires knowledge, creativity and vision. ABET has given design in engineering education very special attention; engineering programs should not only teach design courses but also integrate design concepts into their engineering curriculum [2]. It makes no sense to wait until students are in their senior year to teach them what engineering is all about. This standalone approach to teaching design is unsuccessful because:

- Design is a total incremental experience which involves many techniques and skills and which requires practice and teamwork. Thus it cannot be squeezed into one course within one final semester.
- Engineering students will not be exposed to design challenges until it is too late. Statistics show that the attrition rate at the College of Engineering at Kuwait University is an astonishingly high 55%, or higher, which exceeds, but is still close to, most US institutions [3]. According to students leaving engineering programs, this high attrition rate is due to many factors, but most importantly frustration with the boring and impractical material in freshman and sophomore courses. Thus, the introduction of design concepts to freshman and sophomore students will help attract and retain engineering students [4].

This section presents a number of teaching approaches and learning skills which are important to the successful incorporation of design at all levels of educational experience over the four or five years of undergraduate engineering study.

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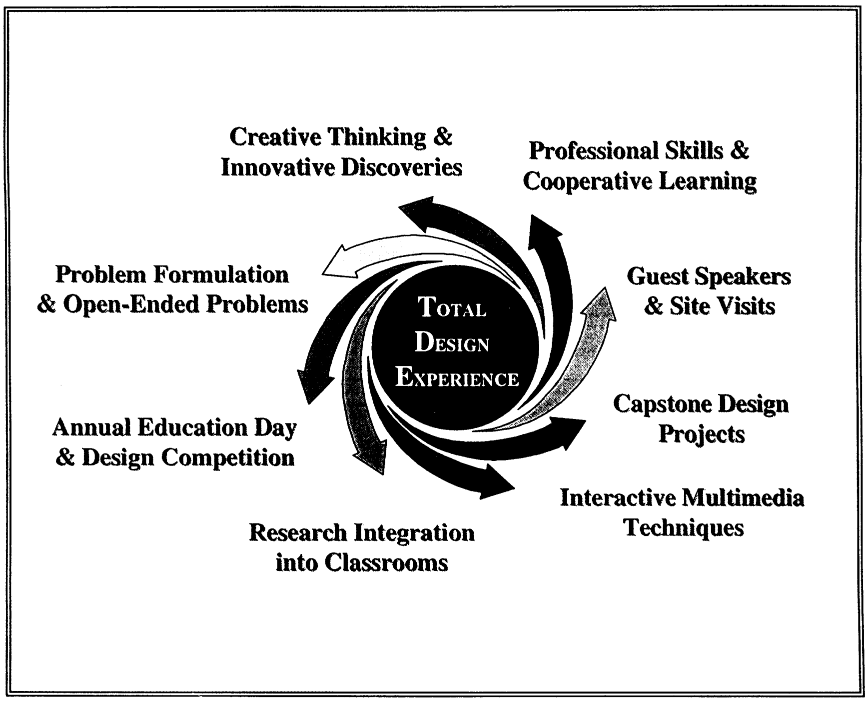

Fig. 1. Integrating the design concept into engineering education.

Emphasize creative thinking among students

Creativity can be seen as what others don't see [5]. It is important to put students in an active learning environment rather than the passive-learning lecture style. In such an active environment students are encouraged to express their ideas and make suggestions; participate in problem identification and formulation; learn to think; adapt to different contexts; understand the stages of new idea(s) development; and plan a logical sequence of events.

Introduce design competitions

Design competitions provide motivation and challenge for students to compete outside course curriculum boundaries. They provide an opportunity for students to experience the excitement of engineering. By designing and/or fabricating components of a product or a system, students acquire the hands-on experience that will help them put their theoretical knowledge into meaningful perspective. Two examples of design competitions include: designing and building a model villa from scrap materials with special focus on environmental and design creativity, and designing and constructing a truss bridge with the least possible total weight and least deflection.

Implement interactive multimedia techniques

Multimedia techniques allow developers to represent knowledge efficiently and users to navigate through the sea of expertise interactively. Simulations of construction methods and equipment movement are well-suited to the educational needs of the student engineer. The combination of video-tape segments, along with pictures, text, and sound, provide an effective impression of real-life engineering operations.

Schedule an annual educational day

It is proposed that we set aside one-day per year in our College to focus on educational problems and solutions. On this day lectures can focus on the assessment and evaluation of the whole educational process, especially design concept integration, by both faculty and students. Seminars and workshops can take place to strengthen awareness of the significance of integrating design in engineering education and the different approaches for the accomplishment of this goal. Faculty and students can document problem-solving methods in journal manuscripts and present feedback on the total design experience in magazine articles.

Integrate research into the classroom

Engineering students, especially in their junior and senior years, should be aware of current state-of-the-art research developments in their areas of interest. Faculty members should brief the students about new discoveries and state-of-the-art research projects. Assignments and projects can introduce some of the unsolved issues in research activities.

Develop team-building and management skills

Being a team player is an essential asset of any successful engineer since most engineering tasks require multi-disciplinary skills and management experience. In groups, students can bounce ideas off of one another, and generally be more informative and creative. Such brain-storming sessions need to be well organized and managed to maintain focus [6]. Therefore, students should practice working in teams to acquire the techniques and skills needed in leadership, making decisions, communicating, building trust and managing conflicts [7]. Such techniques and skills especially in oral and written communication require a comprehensive approach of a taught course [8, 9]. In addition, workshops focusing on professional presentation and brainstorming methods will enable our students to practice in expressing their ideas in a clear and convincing fashion.

Produce professionally aware students

It is essential to take students outside the classroom and increase their exposure to engineering practice through case studies, problem-solving workshops, visits to major companies and sites, and other interactive sessions. Such field trips will provide students with an opportunity to examine current engineering projects and to discuss procedures adopted by companies in implementing their projects. The goal is to prepare our students for real-life challenges through greater interaction with the professional community and hands-on engineering experience.

INTEGRATION OF DESIGN INTO THE COURSE CURRICULUM

Integrating design into course content is the main aspect of the total design educational concept and a key ABET requirement for engineering programs [10]. The heart of engineering education is to develop the ability to design: 'To engineer is to design'. This includes the design of components, systems, products, and/or projects. Design cannot

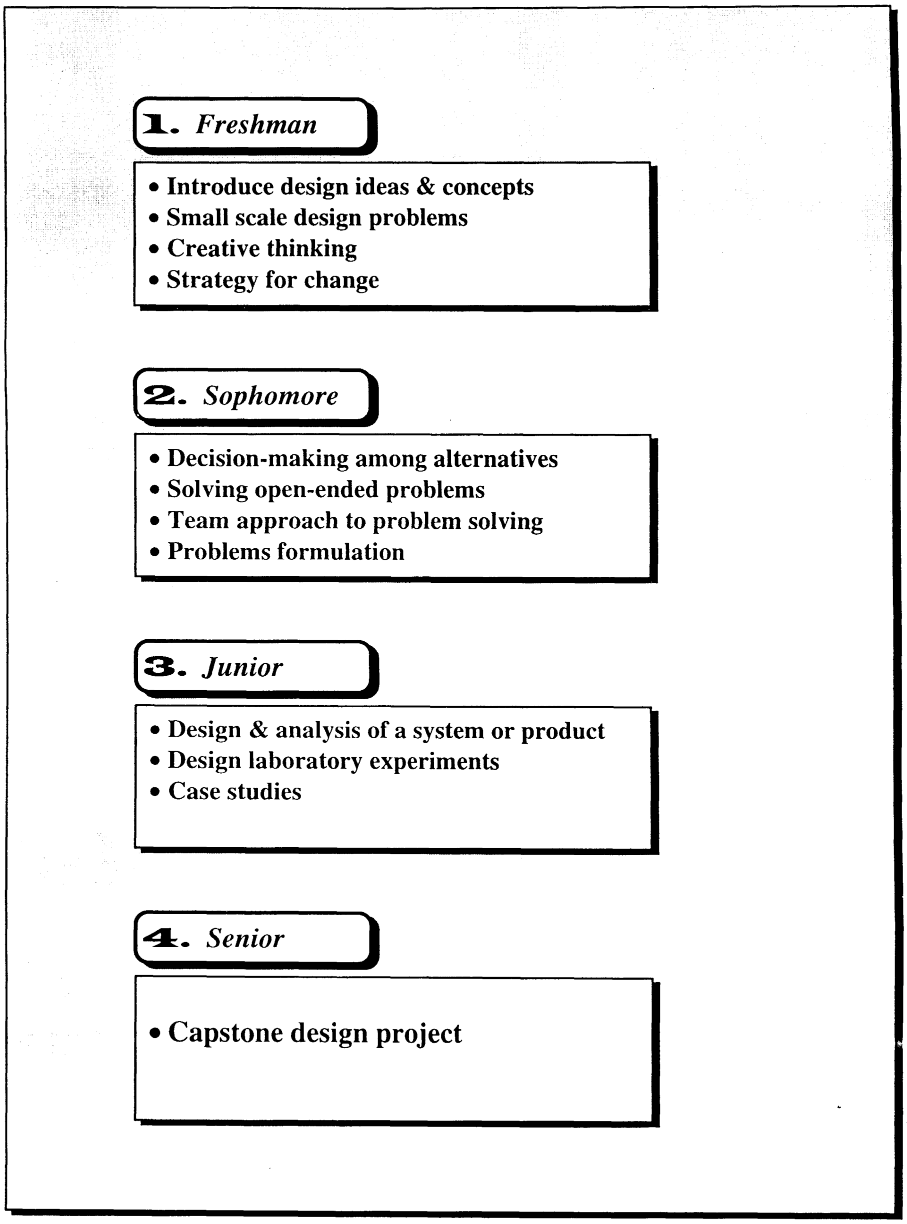

Fig. 2. Development progression of design in engineering education.

be taught as a separate entity, but rather as an additional tool which can be used to teach the fundamentals of engineering [11]. The challenge here is to introduce design into as many courses as possible, especially those courses geared towards design principles, while keeping the focus on the subject material of each course [1]. This is an incremental continuous development of design concepts for engineering students during their four or five years of undergraduate education, as demonstrated in Fig. 2. The process starts with freshmen by teaching them basic design concepts and exposing them to small-scale design problems. Then, sophomore students can be given open-ended problems and encouraged to participate in problem formulation [11]. For a given open-ended problem, no single solution can be unique and therefore grappling with such problems is the best way for the student to learn to apply the various analytical and computational tools that are available. During these first two years, students should be trained in the basic concepts of creative thinking, strategies for change, co-operative learning, productive teamwork and effective communication. These skills are essential for the real design process.

Then, junior students should be ready for a component or system design, e.g., thermal and moisture insulation of a structure. Case studies, mini-design projects and design laboratory experiments are suited to sophomore and junior students. Finally, senior students can wrap up their educational experience in a comprehensive capstone design project guided by both academic and industrial experts.

The process for integrating design into the course curriculum can be broken down into the following steps.

Course selection

Examine and identify those courses within the existing Civil Engineering Program whose effectiveness will be further enhanced by integrating design experience into their contents. Special attention should be given to Statics and Strength of Materials courses because: (a) these courses are design-oriented by nature and (b) students will probably continue in engineering if they find these courses interesting and practical [3].

Design content

Determine the percentage of design content for each course. Design content in civil engineering courses should range from 0.5 to 3 credits: from as low as 20% (about 0.5 credit) in courses such as Engineering Materials, to as high as 100% (3 credits) in the Capstone Design courses.

Following a review of course descriptions presented in [12], and further consultation with faculty members in Kuwait University's Department of Civil Engineering, a list of design-oriented courses was drawn up, including the percentage of design elements in each. This list is presented in Table 1. For simplicity and practicability, multiples of 10 were used as design percentages in a given course.

Table 1 demonstrates that civil engineering students must complete *at least* 20 credits' worth of engineering design content, i.e. about 14% of Kuwait University's Civil Engineering Curriculum of 144 credits. Taking into consideration the fact that students will select from elective courses which also include design content; this design content percentage will be 25% on average.

Special attention should be given to the evaluation and selection of new textbooks for these courses since many authors now include design problems as part of their texts.

Library resource

Prepare a library containing examples of methods, open-ended problems, case studies and mini-projects for each course. These examples

Table 1. Engineering design content in civil engineering courses (compulsory courses are written in **Bold**; elective courses are written in *Italics*)

Course number	Course title	% of Eng. design
CE 200	**Civil Engineering Drawing**	**60%**
CE 202	**Statics**	**20%**
CE 204	**Strength of Materials**	**20%**
CE 236	**Construction Surveying**	**20%**
CE 252	**Engineering Materials**	**20%**
CE 271	**Structural Analysis I**	**20%**
CE 308	**Numerical Methods for Engineers**	**20%**
CE 310	**Fluid Mechanics**	**20%**
CE 311	**Water Resources**	**20%**
CE 350	**Soil Mechanics**	**20%**
CE 366	**Transportation Engineering**	**50%**
CE 371	**Structural Analysis II**	**20%**
CE 373	**Reinforced Concrete I**	**70%**
CE 395	*Engineering Training*	*100%*
CE 404	*Advanced Strength of Materials*	*20%*
CE 411	**Water & Wastewater Treatment**	**30%**
CE 412	*Open Channel Hydraulics*	*30%*
CE 413	*Groundwater Hydraulics*	*30%*
CE 414	*Hydraulic Engineering*	*70%*
CE 419	*Environmental Pollution Control*	*30%*
CE 429	*Groundwater Contamination*	*50%*
CE 430	**Legal, Prof. & Social Aspects of Engineering**	**50%**
CE 434	*Construction Estimation & Cost Control*	*30%*
CE 435	**Construction Engineering & Management**	**50%**
CE 436	*Construction Work Improvement*	*30%*
CE 437	*Concrete Construction & Technology*	*30%*
CE 449	*Civil Engineering Systems*	*30%*
CE 451	**Foundation Engineering**	**60%**
CE 452	*Earth & Earth Retaining Structures*	*60%*
CE 455	*Computer Appl. in Civil Engineering*	*50%*
CE 461	*Traffic Engineering*	*30%*
CE 462	*Traffic Control System*	*20%*
CE 463	*Highway Materials & Construction*	*50%*
CE 464	*Urban Transportation Planning*	*20%*
CE 465	*Pavement Design*	*70%*
CE 471	*Steel Design*	*70%*
CE 473	**Reinforced Concrete II**	**80%**
CE 475	*Prestressed Concrete*	*60%*
CE 478	*Reinforced Masonry*	*60%*
CE 49X	**Capstone Design**	**100%**

should introduce ABET category content such as ethics, safety, economics and creativity [10]. Ethical case studies are enlightening to students on matters related to plagiarism, sexual harassment, conflict of interests, etc. Such an exemplary library will help in the overall evaluation process and will serve as a reference for new instructors to develop their own design components.

Ongoing assessment

Develop a methodology for the assessment and evaluation of the design-integrated program's effectiveness by both students and faculty. This assessment process includes documenting results and giving evidence that the results are applied for further development and improvement of the program.

Assessment is an ongoing process aimed at understanding and improving student learning. It involves making our expectations explicit and public; setting appropriate criteria and high standards for learning quality; systematically gathering, analyzing, and interpreting evidence to determine how well performance matches those expectations and standards; and using the resulting information to document, explain, and improve performance [13]. Clearly, no one assessment device will serve for all modern educational objectives. Measures of student results in the absence of information about their entry level will not reflect the impact of the program on students as effectively as a system of evaluation that can measure students' development after entering the program. These assessment measures include:

- Self, peer, faculty, employer and alumni evaluation sheets to cover pregraduation and postgraduation indicators. Reference [14] presents samples for some of these evaluation sheets. Evaluation criteria include effective use of time, development of ideas, ability to decide issues, overall productivity, teamwork, contemporary and fundamental knowledge, and effective communication.
- Transcripts, college exams, and professional exams such as the Fundamentals of Engineering (FE) and the Graduate Record Examination (GRE).
- Portfolios of student work containing, for example, an original design report to demonstrate a student's competence and skills.
- Video recordings of the students presenting examples of their work. Such videotapes can capture the levels of student accomplishment in oral communications and effective teamwork.
- Co-curricular résumés showing honor society membership and community service participation.

With proper assessment, we can identify those capabilities likely to be needed by engineering graduates throughout their professional careers, and the ways to best develop those capabilities for lifelong learning.

CONCLUSIONS

This paper has presented a number of educational recommendations for the realistic implementation of a total design experience into the Civil Engineering Curriculum. Special attention should be given to integrating design principles into engineering science courses. Fulfillment of these goals promotes graduates who, in the short term, are better able to meet the needs of the construction industry and, in the long term, are better prepared to solve problems in the rapidly changing professional world of engineering.

Statistics show that the attrition rate in most engineering programs is as high as 50% [3]. The introduction of design concepts to freshman and sophomore students will help to attract and retain engineering students. This is expected since these students will experience how interesting and challenging engineering disciplines can be, how to apply theoretical principles and equations to practical experience and, most importantly, how engineering can make them think.

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