ENGINEERING DESIGN: A NEEDED COMPONENT IN THE ENGINEERING CURRICULA AT SAUDI UNIVERSITIES

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ABSTRACT. This paper identifies the deficiencies in design content of the curricula in many engineering programs. It points out some of the causes of such deficiencies and the circumstances that led to them. General guidelines about the means to provide effective design education are also provided. This is followed by the recent experience of the College of Engineering Sciences at KFUPM in emphasizing engineering design in its programs, with a brief description of the two main techniques to achieve that. The authors conclude with some recommendations to other engineering programs interested in strengthening the design content of their curricula.

1. INTRODUCTION

For engineering educators, the suitability of engineering graduates to work in the local engineering industry is a prime concern. Traditionally the success of engineering education in any country is measured by the extent of demand for its graduates by the local industry. During the seventies and eighties, there was a very high demand for fresh Saudi engineers, mainly by the government sector. Most of these graduates advanced quickly to occupy managerial and supervisory positions in their fields. However, in the past few years the private sector began to play a bigger role in the recruitment of new Saudi engineers. Whether engineering graduates of Saudi universities succeed or not, as practicing engineers in the private sector will be the litmus test for engineering education in the Kingdom. Unfortunately, there have been numerous complaints from the private sector about the capabilities of some fresh engineering graduates.

For years, a debate has been going on between the universities and the industry about who is responsible for the gap between them, not only in Saudi Arabia but in most countries. But this fact should not prevent universities from investigating the sources of the problem or making adjustments, if needed, to enhance the marketability of its graduates in the local industry. The most common complaint of the engineering industry has been the existence of a gap between what engineering students learn, and are exposed to, on campus and what is expected from them on the job. Many engineering firms have indicated that fresh graduates are not always able to function as good design engineers nor as creative innovators, which are the main roles for them in the private sector. This observation is a clear indication to engineering educators that the design content of the engineering curricula is probably insufficient and requires more emphasis. It seems that due to the limited number of credit hours in the curriculum, and the large number of basic sciences and engineering sciences courses that need to be included, the design component of most engineering curricula has faded away.

This paper will argue for the importance of engineering design in any curriculum and its vitality to all future engineers. It will present the opinion of the authors regarding the gradual extinction of effective design education from the curriculum of most engineering programs in Saudi universities, despite the impression that it is still there. Suggestions regarding introducing engineering design back into engineering programs are also presented, in conjunction with the means to achieve this crucial task. The paper also describes the efforts of the College of Engineering Sciences at King Fahd University of Petroleum and Minerals in that direction.

2. ARE WE TEACHING DESIGN?

Engineering design is undoubtedly one of the key aspects of the engineering profession. The degree of emphasis on engineering design in the education programs of any country is usually linked to its technological advancement, as observed in the different European countries, Japan, and the United States. This fact did not escape the attention of engineering educators, and thus has led to the existence of some engineering design components in the curriculum of almost any undergraduate engineering program.

Due to the differences between the engineering disciplines and the philosophy of education in different societies, it is not easy to specify a certain percentage of the curriculum that should be devoted to engineering design. But one of the leading engineering accreditation agencies, Accreditation Board for Engineering & Technology (ABET) has set a minimum engineering design content equivalent to one semester, which is about 16-18 credits [1]. By reviewing the curriculum of many of the engineering programs in Saudi universities, it is noticeable that many fail to satisfy this criterion qualitatively, and sometimes even quantitatively. In these programs, the main tools of design education are the so-called, Design Courses, e.g. Reinforced Concrete Design, Steel Design, or Machine Design, in addition to projects carried out by graduating students known as Senior Projects, or alternatively Graduating Projects. Although these two methods are the proper tools to teach engineering design, closer scrutiny show that in most cases, the objective is not fulfilled.

As far as design courses are concerned, the main problem stems from the fact that these courses are usually taught in a way more akin to teaching any engineering science course. Although the design courses are usually claimed to have 100% design content, the actual genuine design content rarely exceeds 10%. Of course, design courses are expected to have some engineering science content, but this should not dominate the course material at the expense of the design component.

To illustrate the design deficiency of these design courses, the first course in Reinforced Concrete (RC) Design in a typical Civil Engineering program is used as an example. During such course, students are exposed to the design procedures of typical RC structural members including beams, slabs, columns and footings. A significant portion of the course is devoted to explaining the structural behavior of these components, which is inevitably classified as engineering science. But the applications in this course tend to be numerical exercises in which students repeat the same design procedures used in previous examples, albeit with a new set of data. In almost all the exercises, material properties, loads, parameters, and even most of the dimensions are clearly defined. As a result, the outcome of these exercises is typically a single numerical value, usually representing the capacity of the section or the amount of steel reinforcement. In addition, at the end of most RC design courses, it is common to have a project in which students are supposed to integrate their knowledge about the different structural components into a complete design of a real structure. Such projects, when presented properly to the students, can serve as excellent design exercises. Unfortunately, this is rarely the case, since in these projects students are usually provided with most of the design data and the problem is well-defined to the extent that the project frequently turns into an assembly of the previously taught segments of the course, with very limited interaction.

The second tool commonly used to deliver design education is the senior project course(s). Ideally, this course is to include a practical engineering project in the student discipline, giving him an opportunity to address a real engineering problem. However, the reality is that these senior project courses seem to have transformed into research projects in which students execute a small part of a larger research project of interest to the supervising faculty member. A review of the title and scope of these projects indicates that the majority have no design content at all, and are solely devoted to research. Even the projects that have some design content, which are uncommon, seem to suffer from the same deficiencies mentioned earlier regarding design courses.

3. EFFECTIVE DESIGN EDUCATION

The previous section pointed out the key deficiencies of existing design education. It has shown that although the importance of engineering design has been realized, it was not being delivered effectively to the students.

It is not easy to give a strict definition of an effective design exercise, because of the diversity of the engineering practice. However, a basic rule-of-thumb for setting up design exercises is to try to simulate, as much as possible, the real design problems faced by practicing engineers but obviously on a much smaller scale. In general, a good design exercise contains most of the following aspects: an open-ended problem, requires investigation of more than one plausible answer, requires iterative analysis, selection of an optimum solution, includes consideration of other factor, as applicable (e.g. economic, environmental, aesthetic, functional, etc.). These exercises should include the minimum amount of numerical calculations that follow a pre-determined sequence of steps or a flow chart. The objective here is to train students on handling problems that require creativity and that branch in different directions.

Due to several reasons, it is not an easy task to teach design effectively. One of these reasons is the fact that preparation, supervision, and grading of open-ended problems require more effort than that needed for well-defined problems that have unique correct answers. Therefore, to encourage faculty members to emphasize design in their courses, there has to be a mechanism that reflects the additional efforts that they need to exert in their design courses. Another reason is the limited practical design experience of many engineering faculty members in Saudi universities, since most of them are research-oriented and only a minority have practiced engineering. To alleviate this problem, engineering colleges need to focus on the industrial experience of future applicants to faculty positions, and to encourage current faculty members to get more involved with the industry to gain more design experience. Finally, the students' attitude towards design problems also make our job as engineering design educators more difficult. In general, students feel very uncomfortable and confused when attempting open-ended problems, or those involving the investigation of alternative solutions. Some of the factors contributing to this discomfort are beyond our reach, such as the complete absence of open-ended and analytical exercises from pre-college education. But there is an opportunity for us to train students, as early as freshman, on handling simple design problems that help them to understand the problem and then think of possible solutions. In the past few years, the introduction of Freshman Engineering Design courses in the curriculum of several U.S. engineering programs has proven to be extremely successful. In addition to introducing freshmen to basic fundamentals of design, these courses have also helped in getting freshmen excited about their engineering majors and hence reducing the attrition rate of students from engineering colleges to other majors [2].

4. ENGINEERING DESIGN EDUCATION AT KFUPM

During the academic year 1992-93, the College of Engineering Sciences at King Fahd University of Petroleum and Minerals (KFUPM) reviewed the design content of its programs. Consequently, the decision was taken to re-emphasize the design content of all its programs, as part of a bigger scheme to improve the quality of education provided to its students, and to prepare them properly for their future professions. The first step, which has already been implemented involve the substitution of the existing senior project courses with new equivalent Capstone Design Courses. The next step, yet to be implemented, involves the introduction of engineering design applications to many courses in the curriculum of each engineering program. The following sections briefly describe the efforts of the College of Engineering Sciences at KFUPM towards achieving these challenging tasks.

4.1 Capstone Design Courses

The concept of capstone design courses has been evolving through the past decade, and it is now one of the most popular ways to prepare students for the engineering profession [3,4]. One of the reasons is that the ABET criteria for accrediting programs require that each engineering program should include a major meaningful design experience, towards the end of the program, that integrates the student's previous knowledge [1]. During such an experience, students are to investigate a practical engineering problem, preferably from the local industry, propose a solution, and then carry out their complete design. The main objective of the course is to prepare senior students for the industry by sharpening their design skills and improving their oral and written communication skills.

In 1994, several departments at the College of Engineering Sciences at KFUPM effectively replaced their senior projects courses with capstone design courses. Some departments have a series of two capstone design courses with a total of 3 credits, while others have only a single course which is either 2 or 3 credits. Detailed description of KFUPM capstone design courses is provided in [5], but following are some of the pedagogical features of the courses:

a) Projects: It is essential that all capstone design projects address practical engineering problems. Although engineering design is the main theme of all projects, some of the projects also involve the manufacture and testing of a prototype, which simulate the full product realization process. Currently all project titles are obtained from the department faculty members. However, the next phase will include projects that are suggested by local engineering firms. Each project is investigated by a team of 3-4 students to train students to be effective team members, which is the common practice in the industry.

b) Supervision: Depending on the number of students enrolled in the capstone project courses, there can be one, or more, course coordinators. Their role is to liaise between student teams and the supervising faculty members, in addition to ensuring the smooth progress of the course. They also lecture students on several important engineering practices including preparation of a proposal, philosophy of design, preparing progress reports and memos, and giving oral presentations. Other key functions include the solicitation and selection of appropriate projects from faculty members and the industry, in addition to forming and assigning student teams to each project, which can be a delicate task.

c) Evaluation: Although each program has its own evaluation policy, the common evaluation philosophy is to strike a balance between rewarding individual efforts of each student and the success of the whole team in carrying out a good design. During the course, students submit at least two progress reports that contribute to their final grades and also help in ensuring that progress is being achieved. Upon completion of the project, each team submits a final report describing the attempted problem, the final design and other relevant details. The final report and an oral presentation are evaluated by a team involving the supervising faculty members, the course coordinator, and in some cases an external examiner.

4.2 Design in Engineering Courses

For capstone design courses to be effective, the experience has to be the culmination of a progressive sequence of design exercises. Therefore, it is essential that students get exposure to simple design problems in as many engineering courses as possible, otherwise they will be unprepared for the comprehensive capstone design project. This fact is clearly reflected in the recent decision by ABET to change its program accreditation requirement from 1 year of engineering sciences and ½ year of engineering design [1] to a combined 1½ years of engineering topics with many embedded design components [6].

Although not yet implemented at KFUPM, the plan is to develop a well-thought sequence of design exercises vertically integrated throughout the curriculum, while avoiding the concentration of design applications in few courses only. One of the useful techniques towards that goal is to emphasize analytical problems that depend more on understanding the behavior, rather than on numerical exercises that focus on calculations [7]. This technique is applicable to all engineering courses, even those traditionally classified as pure engineering sciences courses. Problem-based-Learning (PBL) is another valuable tool for training students for understanding and solving open-ended problems, as well as on being creative [8]. Although it is debatable whether creativity can be taught or not, the fact remains that PBL can at least stimulate student creativity and prepare them for more challenging engineering problems.

Finally, efforts need to be intensified to emphasize computer applications in as many courses as possible. All students need to be conversant in at least some of the modern design aids, including Computer-Aided-Design (CAD), Computer-Aided-Manufacturing (CAM), and the Finite Element Method. These tools will help students in attempting more challenging problems, as well as prepare them for the engineering profession in which these tools are extremely popular.

5. CONCLUSIONS AND RECOMMENDATIONS

a) There is a genuine need for engineering programs in Saudi Arabia to strengthen the design content of their curricula, and to adopt innovative and modern techniques to prepare graduates for the industry.

b) It is more effective to spread the design content throughout the curriculum. This can be achieved by putting more emphasis on analytical exercises, problem-based-education, and computer applications.

c) Capstone design projects can be extremely valuable tools for providing engineering students with a comprehensive genuine design experience that closely resembles the full design process carried out by practicing engineers.

d) Design education is best delivered by faculty members who have practical industrial experience. To improve the existing situation, engineering colleges need to encourage faculty members to get more involved with the local industry.

e) Any modifications to the curriculum, involving courses or capstone design projects, need to be assessed based on feedback from graduating students and the local industry, to ensure that these modifications are effective.

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