

**Integration of design in the engineering core:
Teaching engineering science courses with design in mind.**

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For more than twelve years, design has been successfully integrated into two, erstwhile, lecture courses in the ME curriculum of Indiana University Purdue University Fort Wayne. The courses are Fluid Mechanics (a required course) and Vibration Analysis (a technical elective). This concept is part of an educational philosophy that distributes design experience across the curriculum before it culminates into two capstone-design courses in the senior year. This success has led the author to change the way he teaches engineering science courses.

In this paper, the author synthesizes the experiences and success that he has had in integrating design in fluid mechanics (Njock Libii, 2002)²⁵ and in vibration analysis into the essential pedagogical practices that led to this success.

There has been renewed interest in examining the teaching of design in the engineering curriculum in the past decade (Martin, Adams, &Turns, 2002)²¹. This interest has been spurred in part by the new accreditation criteria required by ABET-2000 and in part by critical reviews of undergraduate curricula in engineering (Njock Libii, 2002)²⁵. A review of the literature has revealed that more than 850 papers were published on design from 1990 through 2002. Approximately 60% of these papers are concentrated on teaching engineering design. The contents of these papers fall into five categories: design experiences in first-year courses; focused-design courses; integrating design in the engineering core; capstone design courses; and general discussion of issues related to teaching engineering design.

Categories

The categories into which the papers that were surveyed fall are defined and discussed briefly below; representative samples of papers from each category are referenced in the discussion as

well.

A. Design experiences in first-year courses. Design courses in this category have three main goals: to introduce the concept of design; to give hands-on experiences in design early in the undergraduate careers of students; and to motivate students to study engineering, thereby, enhancing their retention and persistence in that major. A sample of references to papers that illustrate these ideas is: Richards & Carlson-Skalak (1997)³²; Hall (1998)¹⁴; Zhang (1999)⁴⁵; Ghosh (2000)¹³; and (Njock Libii, 2002)²⁵.

B. Focused-design courses. These kinds of courses are specifically dedicated to teaching design. However, their goal is focused on teaching design techniques that are specific to a given topic or a narrow subject. Typically, they are offered after the freshman year; but they tend to be found during the third and fourth years. Examples of such courses are: design of mechanisms (ME), design of experiments (IE, ME, EE), design of filters (EE), electronics design (EE), design of structures (CE), design of hydraulic systems (CE), design of software (EE, CompE, Software Engr.), chemical processing (ChemE), mechatronics (ME). A sample of references to papers that illustrate these ideas is shown below: Cairns & Chrisp (1996)⁵; Durfee (1995)⁹; Garimella (1999)¹¹; Gerhard (1999)¹²; Lightner et al (2000)¹⁷; Tullis (2001)³⁹; Dunn-Rankin, Bobrow, Mease & McCarthy (1998)⁸; (Smith, 1998)³⁷; Bhadeshia (1995)⁴; and Seville (2000)³⁶.

C. Integrating design in the engineering core. The goal in this category is to integrate design into core courses that are not dedicated to design. Sample references in this category are shown here. Gosh (2000)¹³ describes a seven-year experience with integrating design into undergraduate honors theses at Brown University, Njock Libii (2002)²⁵ describes a ten-year experience with integrating design in the first course in fluid mechanics; Lissenden, Salamon and Wagle (2002)¹⁸ discuss design projects in advanced mechanics of materials; Atherton (1998)¹ discusses controls; Schilling & Hagen (2000)³⁴, sanitary engineering; Lightner, Carlson, Sullivan, Brandenmuehl & Reitsma (2000)¹⁷, the concept of a living laboratory in Colorado; and Westerberg & Subrahmanian (2000)⁴³, product design.

D. Senior year: Capstone Design courses: These courses are offered toward the end of the undergraduate career of students to allow them to integrate what they have learned. Typically, they solve a practical problem that is both substantial and relevant. Capstone design courses are taught in a wide variety of approaches. Two sample references to capstone designs are: a case study in which senior designs were supervised and evaluated by practicing engineers at the university of Oklahoma (Knox, Sabatini, Hughes, Lambert, & Ketner, 1998)¹⁶; and Capstone design courses in the Civil Engineering department at the university of Missouri-Rolla taught by faculty with extensive experience in both teaching and in engineering practice (Morris & LaBoube, 1995)²³.

E. General issues and principles in, and approaches to, teaching engineering design. Sample references in this group are: Computation in design (Vanderplaas, 1993)⁴⁰; a discovery approach

to teaching design (Parcover & McCuen, 1995)²⁸; hands-on, practical approaches to teaching design (Miri and Fu , 1993)²²; learning design by reading a textbook about it (Atman & Bursic, 1996)²; creative problem solving in design (Mackinzie, Allen, Earl & Gilmour, 1999)²⁰; using behavior modification to teach design (Gerhard ,1999)¹²; Donald Schon's philosophy of design education (Waks, 2001)⁴¹; education in new product design (Cardozo et al , 2002)⁶; teaching engineering design (Walter, 2002)⁴², multidisciplinary product development (Srinivasan & Lovejoy 2002)³⁸; and problem solving in design (O'Shea, 2002)²⁶.

To the author's best knowledge, the literature does not appear to suggest step-by-step procedures to be followed by engineering educators who want to integrate new design experiences into existing core courses. In the remainder of this paper, we present a synthesis of our experience with integrating design in existing core courses in the form of steps to be followed in doing so. These steps are consistent with what other writers have reported about teaching engineering design (Miri & Fu, 1993²²; Pascover,1995²⁸; Morris & LaBoube,1995²³; Cairns & Chrisp,1996⁵; Ribando & O'Leary, 1998³¹; Zhang,1999⁴⁵; Dunn-Rankin,1998⁸; and Walter, 2002)⁴².

Pedagogical Practices

Upon reflecting on our success and reading the literature on teaching design, it was determined that seven practices were responsible for this success. They relate to course structure and philosophy, course assignments, and the conduct of the course itself (Bhadeshia, 1995⁴; Smith, 1998³⁷; Hall, 1998¹⁴; Gerhard, 1999¹²; Ghosh, 2000¹³; Tullis, 2001³⁹; Srinivasan & Lovejoy 2002³⁸). The detailed manners in which these were done are discussed below.

A. Course structure and philosophy had to be reconsidered and revised in two ways.

1-The structure of the course had to be reconsidered and modified in two ways:

Some material had to be eliminated from the course in order to make room for hands-on activities that are necessary for learning design.

2- It became necessary to change the philosophy of the course from one of teaching engineering science for its own sake to that of teaching engineering science for the sake of learning to apply its results to solve practical problems and to create products that work.

B. Course assignments were reconstituted in two ways.

1- Assignments were studied to identify the specific role that each played in helping achieve course objectives. They were then grouped into five categories: definitions and drills, comprehension, integration, applications, and design, respectively. The role of each group of assignments was explained to students.

2- Design assignments consisted of several open-ended problems from which students had to choose and they were assigned very early in the semester. The problems were stated in simple terms; they were related to the material being learned in an explicit manner; and each involved

hands-on activities. Progress reports were required on a periodic basis.

C. Conduct of the course was changed in three ways.

1- Integrate all course work carefully to help students see it as a coherent whole. Encourage students to actually do the assigned reading. Proofs of basic results presented in the textbook were not reproduced in class. Students were required to read them on their own. Class time was then spent on: a) highlighting basic concepts and results found in the reading assignment; b) relating them to each other; c) demonstrating their use in problem solving; and d) discussing their application to engineering design and scientific work.

2- Feedback on submitted work must be rapid and useful; it must also provide incentives to learn. Progress reports were collected, graded, and returned to students quickly. Feedback comments had to be specific, clear, unambiguous, and encouraging. Partial credit was administered to reward progress made toward achieving course objectives.

3- Students were strongly encouraged to work in small groups in order to enhance collaborative learning, stimulate peer teaching, and cultivate effective skills in communication.

Conclusion.

There appear to be different ways to approach the teaching of design and, at present, however, there is no agreement among authors regarding how to teach engineering design. But the increasingly large literature on teaching design is making it possible to begin to see common elements among the different ways of teaching this subject. Although there is not a consensus yet on how to teach design, a central element that helps one succeed in this endeavor is emerging, nevertheless. In teaching design, theory and analysis cease to be ends in themselves. Instead, they become means to assist students in learning how to solve practical problems and make products that work.

In order to integrate design into an existing core course, the author's experience shows that changes must occur in four aspects of the course: course philosophy, course structure, course assignments, and the conduct of the course. This paper explains how this transformation process was achieved with success in two engineering science courses: fluid mechanics and vibration analysis. It also cites many references that demonstrate that teaching design involves course transformation and innovation.

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