A MEANINGFUL UNDERGRADUATE DESIGN EXPERIENCE

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CHANGE IS THE way of life for engineering curricula. There are many obvious reasons: emergence of calculators and computers to replace slide rules; technology advances; faculty research interests; and the genuine faculty desire to improve education.

The present discussion of a meaningful design experience addresses three topics. First, the question "What is design?"; second, current and proposed ABET design requirements; and third, criteria to define a minimum design competence.

DESIGN

Let us start by comparing Webster's (1973) definitions of engineering and science:

> ***Engineering:*** . . . the application of science and mathematics by which the properties of matter and sources of energy in nature are made useful to man in structures, machines, products, systems, and processes.
>
> ***Science:*** . . . knowledge attained through study and practice.

Simplistically, and perhaps overly so, the key difference between engineers and scientists is that engineers apply what scientists discover. And the importance of economics is epitomized by the adage, "A good engineer can do for $1 what any fool can do for $2 or more."

In other words, "Scientists tackle those problems which can be solved; engineers are faced with problems which must be solved." [8]

The original Encyclopedia Britannica definition, "Engineering is the art and science of weaving technology into the fabric of society," is worth discussing [4]. Webster [9] defines technology as: (1) technical language, (2a) applied science, (2b) a technical method of achieving a practical purpose, and (3) the totality of means employed to provide objects for human subsistence and comfort.

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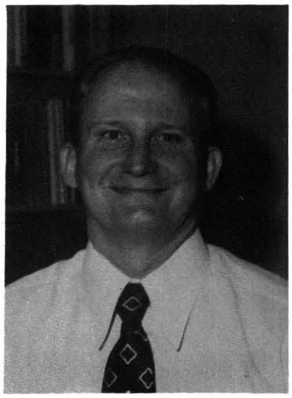

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Hugh Guthrie [4] observed that coupling the Britannica definition of engineering with Webster's definition of technology generates an all-encompassing description of engineering. For (1) weaving "technical language" into the fabric of society implies the need for public understanding and approval; (2a) "applied science" reinforces the previously stated key difference between engineers and scientists; (2b) emphasizes the importance of combining theory (science) with practice (art); and (3) is equivalent to the Webster definition of engineering.

Now let us examine what is meant by design. Not surprisingly this is a prime example of "*Quot homines, tot sententiae.*" However, a safe start is the ABET definition [1]:

> **Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-**

> **making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include at least some of the following features: development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, and detailed system descriptions. Further, it is desirable to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.**

Because this all-inclusive ABET definition is open to many interpretations, let us remember AIChE's Program Criteria statement:

> **The various elements of curriculum must be brought together in one or more capstone engineering design courses built around comprehensive, open-ended problems having a variety of acceptable solutions and requiring some economic analysis.**

Peters [5] extends the above definitions of design to capstone courses "where principles previously learned are put to use in situations with real-life aspects of economic evaluation, social consequences, communication, and other directly practical considerations."

Traditional though it may be, Peters' definition of design is not universally accepted. Denn [3] correctly observes that "design" is not restricted to "process design." Denn also eloquently states that design can be taught in open-ended problems and that computing technology can be a great help in solving such open-ended problems. However the statement that design is an open-ended problem is necessary but not sufficient criterion. Playing chess is certainly an open-ended challenge but who will claim design credit for a win? While design is unquestionably open-ended, it is also "real world" complete with stated or implied constraints such as economics, codes, insurance requirements, government permits, safety, environmental regulations, *etc*. Again simplistically, "Design fulfills a need while science satisfies a curiosity." [10] In design the objective is finite and includes a productive purpose. Design involves judgement which frequently includes selection from an apparently overabundant and sometimes contradictory supply of data, methods, "laws," and equations.

Successful design implies innovation and entrepreneurship. In fact, design is the *sine qua non* that differentiates engineers from scientists. Faculty who attribute omnipotence to "a strong grasp of the fundamental sciences," or "to teaching students how to think," overlook the truism—practice makes perfect, or you learn by doing. Motive also separates design from engineering science. Studying the stress tensor is engineering science but how to increase crude oil flow from an offshore platform through an existing pipeline to the onshore treating facility is a design challenge.

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Can anyone imagine training doctors without hospitals? Shouldn't industry play a comparable role in engineering education? The recently initiated NSF funding of university-industry-government partnerships is a welcome new contribution to the challenge of adding a practice-base or industrial know-how to the existing science base.

ACCREDITATION CRITERIA

Current accreditation practices (especially those involving design) have been subjected to much criticism. Invectives such as "mess at accreditation," "stylized charade," "bean counting," "fraud," "mindless exercises in mediocrity," have been used. Why this assault? Is it a sincere desire to improve the engineering design stem? Or is it a clever ruse to decrease the design content and thus make room for favorite research topics disguised as fundamentals? As usual, the truth lies somewhere between these two points of view.

ABET has suggested that the current curricular requirements of one year of engineering science and one half-year of engineering design be replaced with a single criterion:

> **One and one-half years of an appropriate combination of engineering sciences and engineering design, with a distribution of design throughout the curriculum, that culminates in a meaningful design experience in the final year of the program.**

This proposed change is very similar to the recently adopted change which combined the old criteria of one half-year of mathematics and one half-year of basic sciences into one criterion: one year of mathematics and basic sciences. Has this change improved the mathematics and/or basic science stems? Or has it merely permitted more mathematics at the expense of physics and chemistry?

The proposed one and one-half years of combined engineering science and design will, it is claimed, reduce the problem of "bean counting." And, if adopted, program evaluators may no longer be required to undergo the alleged "stylized charade" or "fraud" of seeking partial design content in many engineering courses. While trying to detect design content in engineering science courses, this ABET program evaluator has developed sympathy for Supreme Court justices. Theirs is the no-win task of distinguishing between "redeeming artistic content" and "pornography." Who pleads more fervently—professors or proprietors of adult bookstores? And who receives more criticism—ABET or the Supreme Court?

Before we rush to climb on the bandwagon and adopt this proposed panacea, we would do well to ponder three questions recently posed by Saperstein [7]:

1. **Do the criteria lead engineering programs into sufficient depth in the design experience?**
2. **Do the criteria allow the programs to instill sufficient independence and creativity?**
3. **Will the criteria prevent programs from offering a single, isolated course as their response to the design requirement?**

The last question is frightening. Will 45 credit hours of engineering science and 3 credit hours of design produce engineers or scientists?

RECOMMENDATIONS

Saperstein has stated the challenges facing ABET (and AIChE) very well and succinctly:

1) **Can we write criteria in such a way that program evaluators can judge the sufficiency of a design experience?**
2) **Within our review process, can evaluators be assured that the students have acquired the intangible understanding of the design process while they have produced the tangible product seen by the evaluator? The ultimate question for all of us is**
    - **Can all of the above be reduced into a few, mutually understood words that can be easily enforced?**

While Saperstein's challenge appears monumental, I respectfully suggest that AIChE define meaningful design experience as:

1. *A year-long sequence of two or more, senior-level capstone design courses comprising one quarter of an academic year (*e.g. *two four-credit hour semester-long courses).*
2. *These capstone design courses shall include the three "ingredients" recommended by Peters [5] (see Table 1).*
3. *We should encourage departments to include the AIChE Design contest in their senior capstone design experience.*
4. *We should encourage variety in the design projects and discourage an endless sequence of traditional chemical process projects. By all means let us include biochemical engineering, microchip manufacture,* etc.
5. *Students should be exposed to open-ended, real world problems prior to the senior-level capstone design experience. AIChE could solicit such problems and make them available (with solutions) to interested faculty.*

TABLE 1
"Ingredients" Recommended by Peters

1. **Economic Evaluation**
    - A. **cost estimation**
    - B. **concepts of cash flow and interest**
    - C. **measures of profitability**
    - D. **choice among alternative investments**
2. **Enginnering Design**
    - A. **from preliminary estimates to firm process designs**
    - B. **strategy of design including shortcut methods**
    - C. **areas of practical significance such as plant location, plant layout, safety, pollution, etc.**
    - D. **equipment and component design**
3. **Real Industrial Processes**
    - A. **The course should be organized so that the students work in groups as well as individually, [on problems of varying length]**
    - B. **Computers should routinely be used where appropriate**
    - C. **Examples of real-life events should be given**
    - D. **When the course is finished, the students should complain about all the hard work they had to do, but they should also say that they finally found out where all the material they had studied previously can be put to use.**

My reasons for the above recommendations are:

Recommendation 1

Open-ended, incompletely specified design problems often constitute a "culture shock" for students accustomed to "one-right-answer" mathematical problems. A "soak time" of one year is required to wean would-be engineers from the one-correct-answer viewpoint. Adequate practice, individually and in groups, on problems of increasing length and complexity easily requires eight semester credit hours.

Recommendation 2

Max Peters' excellent summary should be interpreted broadly—surely "process" is not restricted to "traditional chemical processing," but rather is "the manufacture of any product." The design stem should include the widest spectrum of real world events: incomplete, incorrect, or contradictory data; the overriding necessity of economic viability; the practical consequences and ethics of specifying "too big" or "too small" equipment; troubleshooting; improving existing processes; *etc.* Allowing students to exercise and to develop judgement is more important than learning specific methodologies. Feedback and open-ended problems are essential.

Recommendation 3

The AIChE design contest problems are prepared very thoughtfully by outstanding design engineers. These industry experts make sure that the design problems are realistic and contain "traps" for the naive and unwary. In the 1986 contest, forty-four student solutions were submitted but only five did not commit some fatal mistake, such as extrapolating a vapor pressure curve below the freezing point [6]. Surely the place for learning such facts of life is in the classroom and not on the job. AIChE devotes a session at the annual meeting to the design contest, and the contest problem, the first-prize solution, and the judges' comments are published (*e.g.* AIChE, 1985). However, expansion of the judges' comments and publication in a more widely-circulated journal such as *Chemical Engineering Education* would be very helpful.

Recommendation 4

In the past chemical engineering has "missed the boat" in aerospace, process metallurgy, pollution control, *etc.* We must not let current and future opportunities such as biochemical and electronic-component manufacture slip away.

Recommendation 5

Senior students with three full years of fundamentals (mathematics, basic sciences, engineering sciences, computer programming) will not automatically start designing and innovating the moment the first capstone design course begins. Nor will graduates with four years of fundamentals magically become design engineers their first day on the job. Early and repeated exposures to the "engineering facts of life" are essential.

We must never forget that far, far more BS graduates work in design, manufacturing, sales, technical services, operations, and troubleshooting than in research. Let us put student welfare first and make sure that all accredited undergraduate programs contain a truly meaningful design experience.

ACKNOWLEDGEMENTS

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ChE book reviews

ENGINES, ENERGY AND ENTROPY

by John B. Fenn
W. H. Freeman and Company, 1982,
288 pages, $12.95 paper

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"Thermodynamics is a state of mind," one of my colleagues has said, referring to the fact that the desired approach to and understanding of this noble human construct depends on one's personal taste as much as anything else. Thus, the plethora of available beginning treatments range from the mathematical and abstract, such as the impressive work of C. Truesdell, to the historical and physical, such as this charming book by Fenn, and all have at least a few champions.

Fenn's apparent objective is to make plausible and understandable the needs and uses of thermodynamic properties and analysis in two ways. One is his direct connections to the reader's everyday experience, and the other is his incisive descriptions of the evolution of thought from the rudimentary observations of cavemen, represented by Charlie (who is shown in comic

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