PROBLEM SOLVING IS NECESSARY, BUT NOT SUFFICIENT

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ABSTRACT

Some curriculum changes introduced in the 1960's were counter-productive. Too much emphasis was placed on engineering science, and not enough on aspects of engineering. The reduction of engineering drawing, manufacturing methods and similar topics has made matters worse.

Redress was initiated by introducing methods of problem solving at some institutions. Procedural knowledge, especially for open-ended problems, is a necessary addition to knowledge about objects and their related phenomena.

Engineering is not "applied science," it has other tasks and responsibilities, including societal, economic, law-related, innovative, management and coordinating functions. A task for engineers is to provide the basis for making useful products -- summarized as designing. Problem solving alone is not enough. Designing has its own procedures, of which problem solving is a sub-set. Designing is not fully predictable. Nevertheless, procedures and methods for designing can be proposed, and related to ways of modeling systems. The needs to learn such design procedures in a more formalized way have been discussed, especially to enhance creativity.

1. INTRODUCTION

For several years it has been recognized that the curriculum changes introduced in the 1960's, as a result of the Grinter Report[1], were in some ways counter-productive. Quoting from Grinter (Appendix): "The Committee considers that scientifically oriented engineering curricula are essential to achieve these ends and recommends the following means of implementation." This major report then recommended ten "means of implementation" (something helpful in achieving a desired end, Merriam-Webster Dictionary) of which the third is interesting in the context of this paper, it reads:

> "3. An integrated study of engineering analysis, design, and engineering systems for professional background, planned and carried out to stimulate creative and imaginative thinking, and making full use of the basic and engineering sciences." [1]

The Grinter report was written before any serious start had been made on studying procedures, systematic methods and methodologies, modeling tools and theories of **designing** -- a verb describing the necessary and possible activities and processes. Such studies are continuing from about 1955 in Europe. They started at about the same time in the USA, but were neglected between about 1970 and the NSF Initiative in 1985. The implication of the Grinter recommendation is that to stimulate creative thinking it would help to study design(s) -- the word used as a *noun* describing the resulting hardware (artifacts, products, systems) and processes (including phenomena and their mathematical models), and only by implication studying the *procedures and processes for designing*. Newer knowledge about designing has meanwhile been developed. Nevertheless, this part of the recommendations has been sadly neglected -- and little attempt has been made to include the more recent methodical developments.

Too much emphasis was (and is) placed on engineering science, especially on solving the mathematical models, and not enough on other aspects of engineering. Engineering products are so complex, with interactions among phenomena, manufacturing methods, and behaviors, that the analytical tools tend to be simplistic in their abstractions. The progressive reduction, elimination or "scientification" of engineering drawing, manufacturing methods (e.g. as introduced by workshop practice for Mechanical Engineering) and similar topics in engineering curricula has made matters worse. Admittedly, these particular topics are more applicable to mechanical engineering than to most other engineering disciplines, but equivalents exist.

2. **PROBLEM SOLVING AND DESIGNING**

A partial redress was initiated by introducing a more formal instruction and practice of the procedures and methods of problem solving (or "guided design") at some institutions.[2,3] Procedural knowledge of this kind, especially for open-ended problems, is a necessary addition to knowledge about objects and their related phenomena.

Engineering is not only "applied science"[4], it has many other tasks and responsibilities, and uses much other knowledge in addition to science. New or redesigned technical systems are not predictable from the theories of the engineering sciences (even less from the pure sciences) -- the same desired result can be achieved by various alternative principles and means. It is the task of engineering designers to search for, investigate, select, and implement the best (e.g. the most economic) of the available principles and means (concepts and embodiments). The resulting information should provide the complete basis for manufacturing the proposed product. These tasks and items of knowledge include heuristic, societal, economic, law-related, ergonomic, esthetic, innovative, marketing, management and coordinating functions. Some knowledge of these fields is essential for engineering.

A major task for engineers is to provide the conceptual and informational basis for making useful products -- summarized as **designing**. Problem solving alone is not enough of procedural knowledge, designing is much more complex than just solving problems. Designing has its own procedures, of which problem solving is a sub-set.

Designing, whether performed by one person alone, or in a (design or multi-disciplinary) team, is not a fully predictable activity. At times, the design activities are routine, at other times designing is heuristic[5], iterative, recursive, partly intuitive, opportunistic, flexible, and is always to some extent *idiosyncratic*. Given the same problem, no two persons or teams will produce the same solution proposals, concepts or embodiments. The merits of different solutions will also depend on human judgment. This factor depends on different interpretations given to the available information, based on different personal backgrounds and experiences. Nevertheless, many steps and stages of designing can be recognized as common to various design problems and the progress towards solutions.

It is also recognized that designing is a social phenomenon. In one view, the marketplace and society asks for new and improved products, devices and processes. In a different view, generating (designing and producing) these products and devices cannot, in most cases, be performed by individuals. It needs social organizations, typically called industry, business, and government. Even within sections of such industry, business and government, people have to work together as teams, sharing and developing information, and reaching shared understanding. Such social interaction must also be learned.

Nevertheless, some general procedures and methods for designing can be proposed. They can also related to various ways of modeling for systems to assist the transformations of designing. These are described in several books[6,7,8,9], which form a theory-base for designing. One of the insights in these books is that knowledge (explicit and tacit knowledge for designing) can be classified along two axes: (a1) object knowledge -- knowledge about the phenomena of the physical world and the objects being designed; (a2) design process knowledge -- knowledge needed to perform a design process; (b1) theory knowledge -- engineering sciences, and theory of designing; and (b2) practice knowledge -- engineering advice, practice and heuristics about objects and about designing. The needs for learning such design procedures in a more formalized way have been discussed, e.g. in[10,11], especially to enhance creativity[12,13].

An old Chinese piece of wisdom credited to Confucius says:

Tell me and I will forget
Show me and I will remember
Involve me and I will understand
Take one step back and I will act.

In the usual interpretation as separate statements, the first two of this set of items are used to deny the effectiveness of lectures and demonstrations, and to advocate only project-based learning. The last of these items is usually omitted. To me, these statements are best interpreted in combination. Consequently, I would add:

Do all four and I will become competent.

Learning the general and formalized methods (e.g. in lectures and demonstrations) is in itself not enough. Such methods cannot be applied directly, they must be adapted to the problem situation, including the abilities of the designers and the time scales available. This learning can be most effectively achieved by supervised design projects, in which the supervisor acts as a coach to bring out the societal and procedural aspects, and relates them to the theories. This learning can best be achieved by a continuing stream throughout the undergraduate years. After such a formalized stream of instruction, participation in a competition at college, national or international level can become most effective.

Several changes are needed to implement these criteria within engineering curricula. One such essential change is to introduce a more formal sequence of instruction based on current design theory[6,7,8,9], and including teamwork and social aspects of designing, and developing intuition by practicing some engineering design on relatively simple (but progressively more difficult from Freshman to Senior years) problems in the college atmosphere. This also requires changes in college organization, partly to provide the incentives for staff to learn and develop in these fields, and partly to convince other participants in the college that such changes are worth while and necessary.

3. CURRICULUM CONTEXTS

The most recent evaluation criteria for engineering curricula, ABET 2000[14], list (among others):

> "Ability to design and conduct experiments, as well as analyze and interpret data.
> Ability to design a system, component, or process to meet desired needs.
> Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice." [14]

These raise several questions.

The now classical methods of "design of experiments"[15,16] cover mainly the available layouts of experimental patterns (their designs -- the word used as a *noun*), and the analysis of the data to extract estimates of the effects of the variables. Designing such experiments needs other activities as well -- planning and deciding which experiments may be worth doing, what variables may be significant, what measuring tools may be most useful, etc. Even the more recently introduced Taguchi methods[17--23] (which are developments of the classical design of experiments methods) need such prior designing.

I question how the second of these ABET 2000 criteria can be assessed by people (especially by academics) who have never designed a system or product in industry, for industrial production and the commercial market, or at best have only played consultant in their own engineering science speciality on aspects of such products. It needs some experience of designing, preferably by developing the full detail and assembly drawings and/or their computer based equivalents (but at least into a good dimensional layout) to appreciate the difficulties and the range of knowledge needed for effective designing.

The third of these ABET 2000 criteria should include the world best and latest systematic design methods (e.g. [6,7,8,9]). Also necessary are the current "industrial best practice" methods such as TQM, QFD, Taguchi experimentation, etc. Older methods should not be neglected, where they are still useful -- e.g. the methods of iterative working, recursion, problem decomposition, intuitive actions, as well as sketching, verbal descriptions, and mathematical modeling (especially setting them up). I question whether many of the design teachers in our colleges have sufficient knowledge about these developments, and whether their institutions can and will provide suitable incentives for the staff to learn them. The usual promotion criteria for staff -- publishing papers with new research findings -- are a distinct disincentive to adopting the work of other investigators.

4. CLOSURE

The changes resulting from a limited interpretation of the Grinter recommendations (especially neglect of the third recommendation) produced engineering curricula with a heavy emphasis on the mathematical aspects of engineering science. Various attempts have been made to redress the balance, now including the ABET 2000 criteria. Several changes are needed to implement these criteria. One essential change is to introduce a more formal sequence of instruction based on current design theory, and including teamwork and social aspects of designing, and developing intuition by practicing some engineering design in the college atmosphere. This also requires changes in college organization to provide the incentives for staff to learn and develop in these fields.

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