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Some Perspectives for Integrating Computers into Design Courses*

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The integration of computers into design teaching offers exciting opportunities. The full potential of the computer will be realized, however, only if the design process itself is made paramount in engineering design education.

Engineering design is an imaginative, disciplined, professional activity carried out for, and in, the social context. It requires not only sharp analytical skills, often the major emphasis in engineering science subjects, but also a creative mind building on the profession's body of knowledge. It demands the courage and conviction to devise new and better ways of doing things, sometimes in the face of conflict both internal and external to the designer.

The learning of design demands considerable intellectual development and maturation on the part of the student. It is essential therefore to match learning experiences in design to intellectual growth so that students are faced with the challenge and excitement, but not with frustration or boredom.

INTRODUCTION

ENGINEERING design teaching in tertiary institutions is experiencing a new wave of change, generated by the power and availability of the modern digital computer. Computer packages for computationally difficult analyses such as finite element methods have long been in use. The new emphasis, however, is on using the computer to enhance the entire design process, from its goal setting and conceptual beginning right through to either the production of workshop drawings or to direct communications with manufacturing equipment. Computer aided design adds a far-reaching and exciting dimension to design courses as they develop towards the 21st century.

To develop the full potential of the computer in design, however, it is the design process itself which should be made paramount in engineering design education. There are two dimensions to the task. Firstly the design process needs to be examined so that a clear perception of design forms the basic fabric into which learning experiences are woven. Secondly, throughout a four-year engineering course students go through various stages of intellectual development and it is essential that learning experiences in design be matched to and enhance that development. We believe that this task is the greatest challenge facing teachers of design and this paper is intended to help define the two key dimensions and their interrelationship.

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The paper begins with a critical look at the problem solving view of design and points out some deficiencies of that view. It then suggests a broader framework within which to identify the characteristics and skills needed by the designer. Perry's model of staged intellectual development is described to provide a background for the development of those characteristics and skills. The paper concludes with a discussion of the role of the computer in learning design.

THE PROBLEM SOLVING VIEW OF DESIGN

The 1960s saw an increasing demand for the design of complex engineered systems and design courses in tertiary institutions reacted by placing more and more emphasis on systematic approaches to the design process such as described by Krick [1], Dixon [2] and Woodson [3]. Design and indeed engineering itself, became to be seen as problem solving, amenable to a structured approach. Krick for example stated bluntly 'an engineer is a problem solver' and gave a general five-phase procedure for solving an engineering problem, his design process, composed of problem formulation, problem analysis, the search for solutions, decision and specification. More recent writers (Love [4], Page and Murthy [5] and Kappuraju *et al*. [6]) continue to think of engineering and engineering design this way although the general approach is now described as systems engineering [7]. Perhaps the classic description of this view of design is contained in Hall's morphology of sytems engineering [8]. Hall modelled the problem solving procedure as a series of steps which must be performed no matter what the problem, but which may be performed in any order; problem definition, value system design (develop objectives and criteria), systems synthesis (collect and invent alternatives), systems analysis (deduce consequences of alternatives), optimization of each alternative, decision making (application of value system) and planning for action.

Checkland [7] includes Hall in a list of 12 authors who had written accounts of this 'hard' systems methodology up to 1976. More recently Love [4] wrote that 'designing can be treated as a process where the input is a problem and the output is a solution' and outlined seven systematic steps within a design phase, virtually identical to Hall's procedure. The problem solving model of design seems to be widely accepted as orthodoxy.

Checkland [7] discusses at length the limitations of applying 'hard' systems thinking, i.e. problem solving techniques, in what he calls 'soft' systems. The problem solving approach takes the starting point that 'the problem is to select from a number of alternatives an efficient means of achieving an end we know we wish to reach' [7]. It assumes that goals and values can be defined. Checkland demonstrates from his studies of management problems that more generally goals and design criteria are not definable and, for such soft systems, goal-oriented methodologies searching for guaranteed efficient achievement are of limited use, providing at best only a starting point for a more general system analysis. We believe that even for hard systems, problem solving methodologies need to be used with caution. After all goal specification and the establishment of design criteria are human activities and as such cannot be considered value free even in 'technical' systems. Furthermore, the methodologies appear to relegate creativity in design to just another step (systems synthesis) whereas good design is suffused with imaginative thinking. There is no doubt about the usefulness of design methodologies but they must be used within a broader conceptual framework.

A PERSPECTIVE OF DESIGN

Engineering design is an imaginative, disciplined, professional activity performed in a social context. The designer works at three different but interlinked levels, a fundamental level, a professional level and a social level.

Design on a fundamental level

Greatly simplified, each step in the design process consists of two elements, an idea and a test of that idea [9]. Each test creates new insights so that if an idea fails a test, increased understanding leads to a new improved idea. This improved idea would not have been available in the original pool of ideas. Design is therefore a learning experience. As Love [4] puts it 'Designing something new is like being on a voyage of discovery. As you progress into the design you discover more and more that you did not know in the beginning'. The process is adaptive and evolutionary. Figure 1 is a schematic of design interpreted on this level; the learning process is repeated again and again, from the conceptual stages right through to the last nut and bolt. The process is imaginative and disciplined.

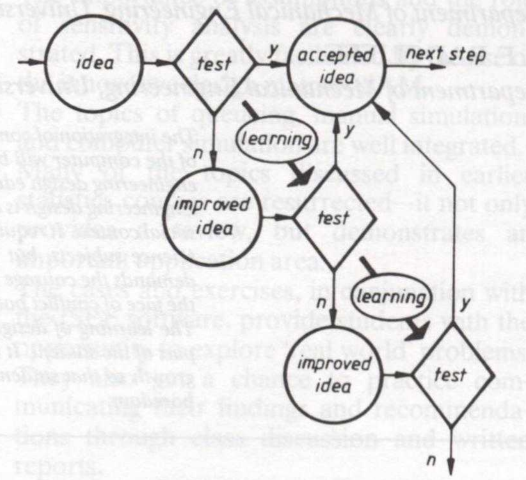

Fig. 1. A basic element of the design process.

Design on a professional level

Design is characterized by a continual leapfrogging of theory and practice [10]. It builds on what has gone before and in turn the experience of today deepens the understanding of the theory to be used tomorrow. The accumulated amalgam of experience and theory becomes the body of facts, models and procedures which define a profession [8]. This provides the input to the fundamental design process of 'idea and test' which at this level may be interpreted as designing for function (idea) and design against failure (test). The output is a new machine, structure or process which in turn adds to the profession's store of knowledge. The process is depicted in Fig. 2. Design is an evolutionary process; if it were not our designs would be continually primitive .

Design on a social level

Design is the creation of something that does not already exist and therefore it brings change. It is misleading, however, to think of engineering design as introducing change only to technology, as though technological change can be isolated within a society. The various dimensions of a society, the stucture and assigned roles, the shared values, the way power is distributed and conflicts resolved, and the technology of tools, techniques and knowledge are all interrelated, having evolved together. Significant change in one triggers changes in others. According to Schon [11] a society resists change

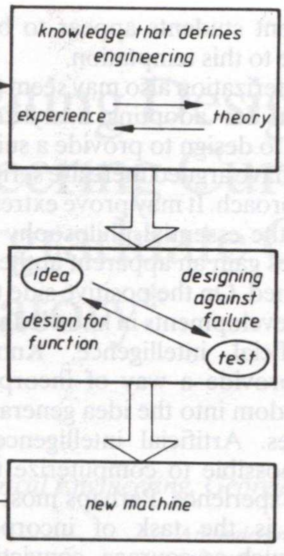

Fig. 2. The evolutionary character of design.

with an energy roughly proportional to the radicalness of the change. The design process will therefore always be accompanied by some degree of conflict, whether internal to the designer, in the workplace or in the wider community. Design is about people, it is a human activity system [7].

DESIGN LEARNING AND INTELLECTUAL DEVELOPMENT

The nature of the design activity that emerges from this perspective shows that design draws from a wider spectrum of human qualities than implied by problem solving techniques. Design is an intelligent activity, the quality and range of ideas depending on the generation of images, whether visual, kinesthetic or linguistic. Design is a knowing, disciplined activity in which ideas must be thoroughly tested. Design is a learning activity, both individually and professionally. Design is a social activity, not only because it creates things of social utility but also because it brings change and conflict to society. The learning of design thus demands of students a considerable intellectual development and maturation. It is essential that learning experiences for students be designed within a realistic framework for that development.

During the 1950s Perry [12] undertook a study at Harvard University to determine what happened to students exposed to four years of a liberal arts education. From that study Perry formulated an empirical model for the sequence of intellectual development, which he subsequently tested using larger samples under better controls. Culver and Hackos [13] believe that Perry's model can help engineering educators to design key courses to encourage intellectual growth.

According to Perry, one of the major accomplishments of students is progress from a simple, dualistic view of life and knowledge to a more complex, mature view which is also relativistic. Until this transition occurs students do not develop their own set of values and attitudes. There are various stages or positions in this intellectual development and students vary widely both in the rate at which they develop and the extent to which they develop. Perry identified four major positions, dualism, multiplicity, relativism and commitment in relativism [13].

Dualism. This position is characterized by a tendency to see things as right or wrong, a belief that right answers exist for everything, that Authority knows those answers and that judgement is unnecessary because alternative answers do not exist. Any uncertainties are thought to be due to the poor qualifications of certain Authorities.

Multiplicity. In this position diversity and uncertainty are acknowledged as existing but considered temporary. Hard sciences and mathematics seem to be better understood by Authority than the social sciences and humanities. As uncertainty becomes more pervasive students may believe that anyone's opinion is as good as that of anyone else.

Relativism. Students begin to recognize that all points of view are not equally tenable and begin to understand evidence. While students start to make a personal commitment rather than hold on to an unquestioned belief, they may not be able to synthesize evidence for themselves.

Commitment in relativism. Students make a stronger commitment, in a career for example, and examine their own views in the light of evidence, opinions of experts and reasoned conjecture. They make up their own minds but admit and expect that they may change their minds in the face of other evidence. They realize that their development has laid the foundations for an ongoing lifelong intellectual journey.

It is clear that students require time to develop intellectually and time to make a mature personal commitment. The learning experience in design therefore needs to be spread over a number of years. During this time, the individual student must be challenged to perform at appropriate levels and be set realizable goals. A student who believes that there is only one right way of doing something (intellectually at the 'dualism' position) is going to be completely frustrated if presented with an open-ended design task. Alternatively a student who has already developed a mature 'commitment in relativism' may find the same task enormously stimulating and interesting. The overall design course needs to be carefully structured with graded tasks extending the students to higher intellectual levels.

THE ROLE OF THE COMPUTER IN DESIGN LEARNING

The central theme in design courses must be the design process itself, the parallel development, through doing, of designing skills at the fundamental, professional and social levels. These developments will certainly need to be spread over several years. The introduction of computer aided design, both as a concept and as hands-on experience, should be subservient to the main aim of developing skills. The computer is a tool and must be used as such. At present the use of computers in design is mostly restricted to two-dimensional drafting and innumerable application packages for detailed analysis of systems and components. Some of these packages are interactive but neither running a computer package with simulated data nor drafting by itself is design.

The use of computers in a more integrated way is a daunting task. There is a powerful temptation to fall under the spell of the new computer technology, becoming enthralled with computerization itself, and thereby neglecting the fundamental activities in the design process. Encouragingly, our more recent students appear to be less and less vulnerable to this temptation.

Computerization also may seem to be a compelling reason for adopting a stylized, 'systematic' approach to design to provide a suitable algorithm but as we have argued there are serious deficiencies in this approach. It may prove extremely difficult to maintain the essential philosophy of design once procedures gain an apparent authenticity by being programmed. On the positive side there have been exciting developments in knowledge based systems and artificial intelligence. Knowledge based systems provide a way of incorporating professional wisdom into the idea generation and testing procedures. Artificial intelligence systems may make it possible to computerize the idea/testing learning experience. Perhaps most daunting of all, however, is the task of incorporating human qualities such as courage, conviction, judgement, imagination and conscience into computer based design courses.

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