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ABSTRACT

Engineering design is a complex cognitive skill differing from possession of knowledge in tactical use of knowledge to achieve goals under constraints. An operational definition of a design must satisfy a set of constraints and objectives. Several published theories about the design process in terms of the criteria developed leads to the elaboration of hypothetical model of design behavior. The assumed model of design behavior predicts that the design behavior can be determined by measuring the information interchange between the designer and his environment. The use of real-time interactive graphic methods is an educational environment and is discussed in terms of the expected advantages and disadvantages of the approach. (Author)

INTERACTIVE GRAPHICS FOR TEACHING COMPLEX DESIGN SKILLS

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ABSTRACT

Engineering Design is a complex cognitive skill differing from mere possession of knowledge in tactical use of knowledge to achieve goals under constraint. It involves the interpretation of verbal, topological and spatial media as a function of real-time, and communicating or directing solutions via these same media. Engineering design education has suffered from the lack of (1) specific operational definition of design behavior, and (2) an educational technology sensitive enough to detect and measure changes in design behavior as defined.

This paper presents a set of constraints and objectives that an operational definition of design behavior must satisfy. A brief review of several published theories about the design process in terms of the criteria developed, leads to the elaboration of an hypothetical model of design behavior. The assumed model of design behavior predicts that design behavior can be determined by measuring the information interchange between the designer and his environment.

Further, technology to detect and measure design behavior is embodied in real-time interactive graphic methods, and the use of these methods in an educational environment is discussed in terms of the expected advantages and disadvantages of the approach.

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INTRODUCTION

Computer-aided design and design education are related in one essential aspect--both technologies are developed and applied with the unifying purpose of augmenting human behavior, in this case design behavior. CAD serves to augment an on-going skill. Design education seeks to augment the acquisition of a skill. Although both CAD and design education have demonstrated great methodological capabilities, they suffer from the lack of a specific theory of design behavior, they are literally "all dressed up with nowhere to go."[1] The most powerful tool is useless without a behavioral description of purpose.

The notion of specification is fundamental to design. A large part of the engineering task is the development of descriptions of engineering situations, descriptions which are specific to that which is described. Recall that these descriptions are often, but not necessarily, quantitative. However, they must always be specific to be unique descriptions. This paper discusses a technological approach to the development of a specific description of design behavior The value of interactive graphics as a research and implementation technology for theories of design behavior is also discussed.

The next section outlines the constraints that theories of design behavior must satisfy in order to be useful. A plan is developed for satisfying these constraints and, to develop a meaningful theory, some limiting presumptions must be made. Finally, the selection of interactive graphics as the research media and the implementation media is discussed in terms of expected advantages and disadvantages.

CONSTRAINTS A THEORY MUST SATISFY

Several theories of design methodology exist in the literature, but none are adequate theories of design behavior. The lack of such a behavioral theory makes the education of designers more accidental than intentional. The present pedagogical task for the student of design is to match cognitive strategies with the instructor (how does he grade the course) and hours of punishing confusion and misbehavior occur before the student can infer what is expected from him by the instructor.

In order to be useful a theory of design behavior must satisfy certain constraints. The development of these constraints is possible only if there is a unique collection of individuals that can be called designers by common consent. The existence of this group is assumed. Satisfying these constraints is possible only if distinct behaviors exist that are specific to designers and can be detected and measured. The existence of these behaviors is assumed.

The latter assumption is "a sleeper" for most theories of design behavior in that there usually exists speculation about "mental" processes that are internal to the designer (intuition, creativity, analysis, etc.). The technology does not exist to measure these internal processes directly, neither in the behavioral laboratory or the classroom.

What can be detected and measured is the behavior of the designer in this or that situation. Any relationship between design situations and design behavior is largely unsubstantiated in the literature.

Thus, a theory of design behavior must satisfy certain constraints before it is valuable as an element of pedagogical technology. The constraints can be summarized, as we must define:

(1) <u>who</u> can be a designer, and by what aptitudes and skills candidate designers can be identified;

(2) the <u>specific set of behaviors</u> by which designers can be discriminated from nondesigners in such a way that they can be detected uniquely; and

(3) the designer and nondesigner <u>reference groups</u> between which the set of behaviors will discriminate.

For a more complete discussion of these constraints, see Beazley and Allan, 1973.[4]

AN APPROACH TO THE DEVELOPMENT OF A THEORY

Design is a complex cognitive skill differing from mere knowledge in the tactical use of knowledge to achieve goals under constraint. It involves the interpretation of verbal, spatial, and topological media in real-time, and communicating or directing solutions via these same media. The complexity of the behavior coupled with the constraint of finding uniquely detectable behaviors demands a methodology of testing which is versatile and

controllable. The authors have made initial assumptions about the kinds of behaviors they expect to find, and have made media choices based on these assumptions. This is the first of several phases in the authors' plan for developing a behavioral theory of design. The final goal in the development of the behavioral theory is the implementation of the theory in an academic course in machine element design, using the behavioral objectives suggested by the theory.

The constraints that a theory of design behavior must satisfy, and the implementation constraints that are placed on the set of educational modules that will be derived from this theory, dictate a characteristic phasing of curriculum development.

Phase 1. The definition of behavior to be measured and the conceptual design of a system which can be adapted to both empirical testing of experienced designers and instruction of candidate designers.

Phase 2. The empirical testing of experienced designers in a pilot study to insure that the ~~system is~~ sensitive enough to detect design behavior in a way that will discriminate between designers and nondesigners. This phase includes the revision of the criteria for selection of designers and the revision of the system capabilities where required. In parallel, modules must be designed which will change student behavior in desired directions.

Phase 3. Final empirical measurement of designer reference group behavior.

Phase 4. Final revision of modules.

Phase 5. Student use of the modules for validation of the curriculum, showing the degree of design behavior present. Items of tests over aptitudes, prerequisites, etc., which show predictive value, will become the specific description of those who are candidate designers as defined by the theory developed.

Before a method of measurement can be specified some initial capabilities of the method must be proposed. If design is characterized as information flow between a designer and his environment, that flow must necessarily pass through some sort of interface (written instructions, site photographs,

layouts and views, spoken words, etc.)[2] The information that flows will be either verbal, spatial or topological, and will relate to real-time, and can be measured or identified if the interface is sensitive to it. For an initial assumption, the authors characterize this information flow as the following behavior by the designer:

(1) specifying the partitioning of design information (separateness)

(2) specifying topologies of design information (relatedness)

Specifying partitions might be viewed as a complex discrimination behavior while specifying topologies might be viewed as cognitive-conceptual behavior. Before these two behavioral assumptions are drowned in cries of over-simplification, the authors would like to explain them and how an imperfect, limiting environment is seen to dilute and distort them.

First of all, partitioning as discussed here is what a designer does when he specifies a lack of relatedness between one group of things or processes and another group of things or processes. It is the identification of the uniqueness of the collection with respect to another. The behavioral outcomes of specifying, defining, choosing, deciding, are acts that are basically partitioning in nature. A designer "specifies" so that something different is not used.

An imperfect "design environment" is one that cannot satisfy all the constraints of specifications, one that lacks the capacity to deal with a definition, one not capable of offering the choices and options available to the designer. It is the imperfect environment that forces the designer to engage in activities such as programming computer solutions, manual computations, etc.

Topologies are seen as the relations between the design activities, processes, physical components or elements of information. The comprehension that the outcome of one calculation is an input for another, and that the calculations, reference look-ups, laboratory test results, form the evidence for the designer's decision, are all important relations.[3] It is not clearly known what influences the designer's choice of topologies, but it is probably some mixture of problem type, experience, solution and methodological constraints from the environment, etc.

Thus, in an imperfect design environment, with its limited repertoire of options, and its limited capacity for relating those options topologically, the designer is forced into behavior handled best by librarians when gathering information, by computers when performing calculations, by technicians and draftsmen when elaborating the details of a solution, etc.

The authors are not advocating that designers not be skilled in these areas nor that they never work in these disciplines, but are proposing that the two behavior-detectable activities are specific to designers. Hence, any method of detecting design behavior as assumed will be limited by its capacity to detect the specification of design partitionings and topologies, and should hold true for designers of physical, social, economic, and other systems.

The media selected must be able to detect and measure specifically these behaviors in a controlled manner. The authors decided that a vector-capable interactive graphics terminal with a lightpen could do most everything required. Besides satisfying the constraints on theory development, it automatically becomes the implementation media for the theoretical findings.

The use of interactive graphics as the research media gives the authors important advantages in achieving the goal of implementing behavioral objectives in a course about machine design.

(1) The media for theory development is also the implementation media, reducing adaptation and technology transferability problems.

(2) The interactivity of the media increases the contingency of the media on the student response.

(3) The media is sensitive to both verbal and spatial inputs, and allows displays and interaction that are close to real-life situations.

(4) The interface offers near-perfect repeatability and control as a stand-alone interface with host system, and an acceptable repeatability and control in a time-sharing environment.

(5) The authors anticipate that the highly iterative methodology of design makes the computer generation of interactive simulation outcomes more efficient than other methods of media preparation, when hours of programming per number of student solution attempts is compared to hours of lecture preparation, homework diagnostics, and quiz evaluation per number of student solution attempts.

(6) The vector-capable intelligent terminal permits testing and study with more differentiation <u>between</u> verbal and spatial responses, and <u>within</u> these two types of responses as well.

With the lightpen, it is possible to ask not only illustrated questions, but graphical questions whose answer might be a line segment or a point.

(7) The biases in problem solving strategies induced by form of presentation (verbal description or graphical representation) and form of solution communication can be controlled and studied.[5]

Some of the disadvantages of this choice of media might be unanticipated and/or uncontrolled factors introduced that might lead to confounded results and behavior that is not only specific to designers but specific to interactive graphics as well, causing serious transferability problems.

CONCLUSION

Great emphasis has been placed in this paper on the selection of a very sensitive interface and the constraints on the real-life designer imposed by an imperfect environment. These two aspects are met for the designer primarily in the discipline of computer-aided design. It is CAD which seeks to place the designer in an enhanced environment composed of a powerful computer and manifested by a powerful interface. The essential problem is behavioral augmentation.

Similar arguments exist for the training of designers in the classroom; i.e., the essential problem is behavioral augmentation. This paper is directed towards outlining a plan for developing a specific behavioral picture of what a designer does that makes him a designer and why interactive graphics will be used as the research and implementation technology.

The applicability of interactive graphics as a behavioral research and augmentation technology is, for the most part, uninvestigated. The authors' choice of interactive graphics as both a research and implementation medium is hoped to result in a specific model of a highly complex behavior--engineering design. It is estimated that a research and implementation program of the type described here will take at least two years to complete. The theoretical outcomes of this kind of work, if successful, would have impact areas such as computer-aided design, engineering design education, behavioral research technology, and ergonomics.

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