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HUMAN ENGINEERING IN THE DESIGN OF INSTRUMENTAL SYSTEMS

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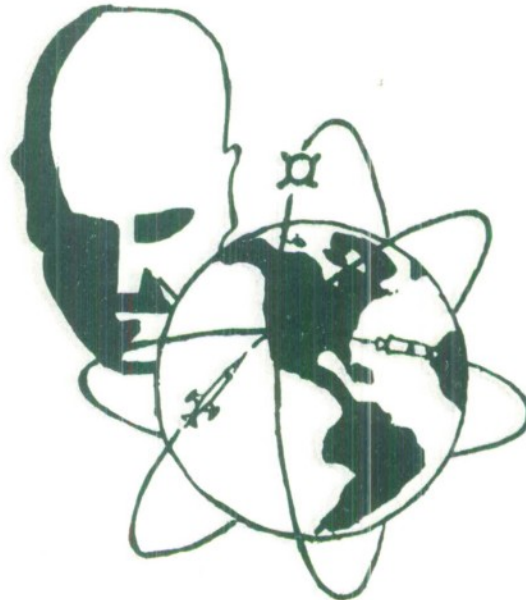
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Project 7682, Task 768204

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FOREWORD

This report is a product of the applied research program of the Decision Sciences Laboratory. The study was conducted in-house in support of Project 7682: Man-Computer Information Processing, Task 768204: Automated Training for Information Systems.

Papers based on this report were presented at the convention of the National Society for Programmed Instruction, Symposium on Systems Development April 1964, and at the convention of the American Psychological Association, Division of Military Psychology in Los Angeles September, 1964.

HUMAN ENGINEERING IN THE DESIGN
OF INSTRUCTIONAL SYSTEMS

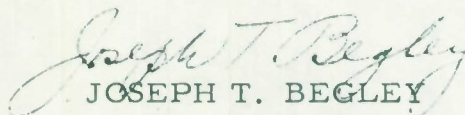
ABSTRACT

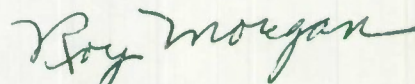
A conceptual model is proposed for use in the application of human engineering principles and techniques to the design of instructional systems. The trainee and instructor are viewed as operators within an information system. To illustrate this model and its application, examples are drawn from the literature and from current research on instructional systems. A preliminary human engineering guide is outlined which presents factors critical to design decisions for instructional systems.

The model and guide attempt (1) to counteract current tendencies toward premature standardization of instructional system structure, and (2) to bring instructional system development into the main stream of the applied science of human engineering.

REVIEW AND APPROVAL

This technical documentary report has been reviewed and is approved.


JOSEPH T. BEGLEY
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INTRODUCTION

This study is addressed to the question of how the applied science of human engineering can be used systematically to optimize development of instructional systems. It is intended to serve the many training specialists, engineers, and physical scientists who are beginning to participate in the design of instructional systems. The human engineering concepts and system design practices outlined here may provide an orientation to a body of knowledge useful in instructional system design.

The problems now confronting instructional system designers strongly resemble those that psychologists have been facing in the human engineering of non-instructional systems. In fact, programmed instruction's prime tool - subject-matter analysis and definition of terminal objectives - is an outgrowth of the human engineer's task analysis methodology. This paper proposes that additional concepts and methodologies from human engineering can serve as heuristic devices in instructional system design. Furthermore, some of the research questions being posed in programmed instruction are similar to ones being researched by human engineers. Perhaps the elusive instructional concepts of "step size," "frame," "response type," "programming style" might prove more amenable to analysis and measurement if they were re-examined in the light of the human engineer's concepts and tools.

This study begins with an historical overview of human engineering. Such a brief over-the-shoulder look may illuminate the role human engineering seems destined to play in the future of instructional systems.

Following this backwards glance will be an attempt to identify and describe the subtle, but major, change in the concept of the human roles in instructional systems which can result from the exploitation of human engineering psychotechnology. This will be followed by an examination of some of the design dimensions in instructional systems that are highlighted if human engineering is used as a focusing agent. Current research and development will supply illustrations.

This is not an attempt to say all that could be said about human engineering as applied to instructional system development. Primarily this is an interpretation of past, current, and possible future impacts of human engineering theories, concepts and methods on instructional system design. Hopefully, these borrowings may lead to a subtle re-definition of instructional system design and result in an upsurge of a theory of instruction.

II. HUMAN ENGINEERING DEFINED

Air Force Regulation 30-8 defines human engineering as "the application of knowledge about man's capability and limitation in planning and designing systems which result in the most reliable and efficient man-machine combination possible. This includes human design considerations relative to maintenance, operation, communications, etc. Human engineering is needed to obtain reliable and efficient man-machine combinations"(1).

The term human engineering means engineering equipment for human use - not engineering the human. (Perhaps training could be defined as "engineering the human"). "Good" human engineering means that the designer has made optimum use of both man and machine capability. Thus human engineering is concerned with assigning to each - man and machine - the function each performs best, but always considering that man-machine operate as an integrated unit. The human engineering design problem is then not how to design a machine, but how to design a system (3, 4, 11).

The goal of the human engineer is to maximize the effectiveness of the system. This is a difficult task since man as a system component contributes flexibility and reliability as well as many latent and variable sources of error.

What does the human engineer actually do in system design?

- He makes explicit the decisions men in the system must make.
- He defines the nature and amount of information a man or team of men require to make appropriate decisions within that system.
- He decides how to display this information.
- He decides on the number and character of the controls the operator needs to carry out his decisions.
- He allocates system functions to man vs. machines, or combinations of men/machines.
- He defines and describes man's system functions in language comparable to that used by the equipment design engineer in describing machine functions.

III. HISTORY OF HUMAN ENGINEERING

Since prehistoric days man has made slow, steady improvements in his tools and methods of using them. However, until recently these improvements have been based on trial and error, and intuition - not on a program of systematic solution of design problems such as provided now by the applied science of human engineering. This fact is most emphatically true with respect to educational tools and methods.

In the mid-20's human engineering had its beginning with what is now called the "knobs and dials" approach. These studies were concerned with legibility and readability as a function of placement of controls, design of dials, and color-coding for single pieces of equipment. In the mid-30's the focus was still on single equipments - particularly aircraft components. Emphasis shifted to optimizing psychomotor skills and sensory capacities. In the mid-40's human engineers began to consider man as a link or component in systems. This radically new concept of the human arose from the growing need to examine entire systems - not just components. At this point concern shifted to optimizing man's perceptual capacities. In the mid-50's to the present, this trend has blossomed into the systems approach called "systems research" which deals with the principles governing the behavior of systems. Here the human engineer's concern shifted to enhancement of certain cognitive capacities particularly decision-making and information processing (4).

In the foregoing brief history, eras are roughly categorized in terms of the equipment features and psychological functions studied by human engineers. Another method of characterization is suggested by the cybernetician, Watanabe (15). He characterizes eras in terms of the functions of the different types of tools that man created. Thus the earliest class was the "geometrical machine" which involves no transfer of energy. Examples are a box, a table, a paper clip. The next class was the "intensity-converting machine." In this type of machine, energy remains within each major class of energy. Examples are the lever, the torque converter, the optical lens. These machines initiated the process of substituting machines for muscle and sensory acuity. The third class was the "energy-converting machine" which changes energy of one major class to another. Examples are the steam engine, nuclear pile, hydroelectric station.

Now the 20th century is characterized by the emergence of an entirely different type of machine - the "information machine." Although these machines consume a certain amount of free energy, their

major function is storage, transmission and processing information. Examples include television, computing machines, phonographs, and instructional systems. These new "information machines" substitute machines for brains.

IV. A NEW CONCEPT OF THE HUMAN ROLE IN INSTRUCTIONAL SYSTEMS.

Several factors pertinent to instructional system design emerge from the two foregoing characterizations of the history of man's tool-creating behavior.

First, human engineers have had time to compile considerable experience with equipment design for optimizing man's sensory-motor and perceptual capacities. To a certain degree this body of knowledge is being used in instructional system design. However, it could be used more systematically if the view propounded in point three below were adopted more widely.

Second, an instructional system is a special case of the new general class of "information machines." There is as yet only a small but growing body of knowledge on human engineering to enhance the cognitive functions of man-machine in these new information machines. This new knowledge could be generalized to instructional system design.

Third, in recent years human engineers have evolved (a) a conceptual model for viewing the human as a system component, (b) terminology for describing his system contribution in machine-like terms, and (c) techniques for defining and assigning his system role. These human engineering assets are not yet being used widely to full advantage in instructional system design. They lead directly to the conception of human behavior (student or teacher) in the instructional system as "transforming inputs to outputs," and the human role as a "system operator." They suggest it would be useful to cease referring to these instructional system operators as students and instructors, or describing their respective functions in such global, nonspecific terms as learning and teaching. Further, they suggest it would be preferable to analyze and describe human functions in systems terminology. Dependence on such terms as "student," "instructor," "learning," "teaching" - with all their rich but ambiguous performance implications and role-associations - inhibits utilization of the human engineer's approach. Use of these terms will continue to lead into the all-too-common trap in system design of simply automating the old manual methods - as opposed to designing new information systems for instruction.

What is to be gained by viewing the student and instructor as information system operators having the common purpose of transforming inputs to outputs? Does this human engineering approach add anything to instructional system design methodology which is not already available? Yes, it provides several additional tools.

This orientation leads to analysis and specification of the operators' functions in instructional systems in terms of the information-processing functions of sensing, identifying, interpreting, and the decision-making functions of integration, synthesis, prediction, comparison and response-selection. Such an approach leads in turn to consideration of the conditions required to support these functions. These conditions include minimum display requirements, filtering, focusing and shunting requirements, short-term memorial inputs, and long-term memorial inputs, etc. (6).

Finally a human engineering approach provides a language directly related to other non-human events and operations in a system. This common terminology is useful in considering the relative limitations of machine and human when instructional system functions are assigned to man or machine.

V. APPLICATION OF HUMAN ENGINEERING TO DESIGN OF INSTRUCTIONAL SYSTEMS.

A. Task Allocation

The first phase in human engineering design is to define the system functions. The human engineer decides which are best assigned to the man, which to the machine. In instructional systems, allocation of system tasks between operator-teacher, operator-student and machine is analogous to the problem of assignment of function in any man-machine system.

The human engineer knows machines are best at making rapid responses and computations, handling simultaneously many operations and performing repetitive tasks reliably. Man is not competent at these tasks. But man excels where inductive reasoning, judgment, imagination and broad memory are required. Furthermore, man can modify his characteristics to match many situations (16).

This adaptiveness has given rise to a basic disagreement among human engineers as to the complexity of the function which should be assigned to man. Some human engineers feel his assignment should be

simple in order to reduce the possibility of error and free him for decision-making. Others say his adaptive abilities should be used to the fullest extent - regardless of the possibility of minor errors. This disagreement on systems in general is reminiscent of the opposing Skinnerian vs. Crowderian views of the operator/student function in programmed instructional systems. The failure of both human engineers and programmed instruction designers to establish which of these views is correct, or the conditions under which either is optimum, suggests neither is asking the right question.

B. Design of Operator Tasks (9)

After completing task allocation of system functions the next step is design of the human tasks. For instructional information systems, the task design principles can be divided into two groups - those relevant to information processing and those relevant to decision making. These apply equally to student and instructor tasks.

(1.) Design factors in information-processing tasks.

a. Load constancy and input variation.

The primary principle in information-processing task design concerns load constancy and input variation. Momentary demands on the operator's identification and memory capacities must not be excessive. "Sensory and memory overload" must be avoided. In programmed instruction systems the small step or frame principle provides one safety device to reduce the possibility of such sensory and memory overload. This is in contrast to the lecture or conventional textbook presentation which provides no such safety device.

It is well-established that when signal input rate exceeds operator information-processing capacity, signals are not only unidentified but they function as a distraction. On the other hand, when the input rate is too low, loss of vigilance occurs. Below some optimum number of events-per-unit time man's performance degrades with the passage of time. It then becomes necessary to provide additional signal input to avoid such performance decrement.

The technique of applying additional inputs and the selection of a type of input is a major design problem in any system. In programmed instruction, branching is being studied as one solution to this design problem.

b. Content variability.

A second principle relates to the requirement for content variability of signals. This principle must be observed in the way information is sequenced, spaced and reviewed. Within an instructional system the technique of "spiral programing" is one application of this principle.

c. Task habituation.

This principle states that the task must include sufficient variability to keep the operator expecting the unexpected. Some of the frequent criticism of the monotony generated in the learner by current programmed instruction formats suggest this principle is not yet being successfully implemented in our instructional systems. However programmed instruction has reduced in the conventional instructor's task the monotony generated by task habituation.

(2.) Design factors in decision-making tasks.

For those aspects of the operator-task which involve decision functions one principle is paramount. This concerns goal specificity and means flexibility. The objectives of the system as well as the interrelationships among them need to be made explicit to the decision-maker, but the relationship of means to the end should be left as unspecified and flexible as possible (9).

The traditional interpretation of the instructor role exemplifies one application of this rule wherein the entire decision-function is assigned to the operator-teacher. If the entire decision-function is assigned to the operator-learner, a "table of contents" specifying goals and means should be made available to the learner. He would then be free to choose his sequence of performance. The decision-making function can also be shared by operator-teacher, operator-learner, and machine. Some of the computer-based instructional systems exemplify this latter approach (14).

C. Designing Equipment for the Instructional System.

Having reviewed some human engineering principles for designing operator-student or operator-teacher tasks, consideration must be given to the hardware and software portion of the instructional system.

"Good" human engineering of equipment simplifies operator-student performance (or learning). By making displays easier to read

and interpret, by simplifying decisions and actions to be taken the operator performance (learning or teaching) can be made more efficient (5).

Equipment design problems for instructional systems can be grouped into two categories: displays and controls.

(1.) Display design.

Display variables to be considered include (a) readability and legibility, (b) sensory modality, (c) multiparametric features, (d) coding, (e) filtering, (f) clutter and noise, (g) medium.

Instructional systems are particularly concerned with the coding, filtering, clutter and noise variables. Some current research is investigating the use of different language levels, forms, and symbols on instruction (13). The principle of filtering is represented by programmed instruction's concern with removing all non-essentials from the statement of instructional objectives and especially from frames themselves. The effect of clutter and noise - as represented by language redundancies and grammatical ambiguities in programs - is also being explored in instructional systems. Similarly, color coding is being used in the teaching of reading (18).

When the medium of display for instructional systems is explored one can ask such questions as: should the information display be animate (i. e., by instructor or fellow student) or inanimate (i. e., by book or machine)? The answer would be different for presentation of information concerning instructional subject matter or for information presented purely for motivational purposes. Much early and ambiguous programmed instruction research touched on this animate vs. inanimate display dimension in studies ostensibly comparing conventional lecture presentation (animate) with teaching machine presentation (inanimate) (7, 10, 17).

There is no best sensory modality for presenting information. Change and overlap in sensory modality is an effective device to maintain performance. It permits the human to recover information previously ignored or discarded. This principle is carefully observed in conventional teaching systems. It is generally being disregarded in many current instructional systems.

The choice of modality, modality combinations and media is affected by the nature of the information displayed. For example, a message unit presenting knowledge of results in the form of detailed task information might be best presented in an inanimate visual display.

Whereas knowledge of results concerned with incentive motivation might best be presented by an animate, auditory display (i. e., operator-instructor). Furthermore, different kinds of knowledge of results might require different display media at different stages of learning (12).

(2.) Control design.

Instructional systems should exemplify these principles of control design: (a) accessibility, (b) functional arrangement, (c) differentiability, (d) safety, (e) reliability, (f) display compatibility, and (g) ease of operation (8, 9).

a. Accessibility.

The accessibility principle states that the operator should be able to manipulate the controls without having to contort himself. Self-evident as this principle is, it is being ignored in many current instructional systems. There are teaching machines available which require the users to assume wierd positions, while they try to operate inaccessible controls.

b. Functional arrangement.

This principle is observed when controls are grouped into categories based on system structure. Priority of location should be given to those most frequently used or requiring precision of action. Grouping of controls should be based on order and pairing in use (13).

c. Differentiability.

Controls should be designed so that their differences in function are emphasized, by location, physical characteristics, etc.

d. Safety.

Safety is observed when provisions are made to prevent accidental activation of any control.

e. Reliability.

Controls should indicate their on-off state by position and labels.

f. Display compatability.

Displays and controls should appear to be correlative.

g. Ease of operation.

There should be a minimum amount of "work" (mental and physical) required in control operations to obtain a unit of information. Current programmed textbook design, which requires much repetitive physical work to turn many nearly-blank pages, cannot be considered an example of "good human engineering." "Page-turning" is one function that could better be relegated to machines.

One Air Force project is concerned with the design of a control console for a special purpose teaching machine. Console layouts which are topographically related to the structure of the task to-be-learned are being studied. This study represents an application of all the above display and control principles. The resulting layout of the console vastly simplifies the instructional process - from the viewpoint of the learner as well as the instructional system designer. The console layout actually serves as a job aid which supports performance during the learning task (13).

D. The Criterion Problem.

Finally, instructional system designers could borrow some of the human engineer's criteria of system performance. Instructional system designers are now trying to define reliable and valid operational criteria to assess component and system effectiveness. For the most part they have used criteria developed in and best suited to research on the psychology of learning, i. e., training time, efficiency, user acceptance, errors during learning. Instructional system designers might borrow additional criteria from human engineering studies such as manpower (type and time) for operations and maintenance, time-to-construct, dollar cost for development, dollar cost for use, etc.

Human engineers are also researching the question of how systematically to assign relative weights or values to multiple criteria measures in order to arrive at a single index of system design efficiency. This would be particularly useful in instructional system design.

VI. ROLE CHANGES IN INSTRUCTIONAL SYSTEMS.

Acceptance of this human engineering orientation to instructional system design is bound to expedite changes in the roles of the two types of operators in instructional systems. The role of the teacher is going to become more that of a manager of information, resources, and media than of people. The instructor role which is limited to lecturer

and tester will soon be a thing of the past. He will spend most of his time trying to determine what students need to do their jobs. The student will bear more of the responsibility for his own success. This system should result in a reversal of traditional teacher-student roles. This type of role reversal has already been shown in Air Force SAGE system studies. Students increasingly sought out additional information from the instructors as the responsibility for their own learning was shifted to them. This shift in roles should promote development of new skills in the student in that he will acquire practice in searching out information, recognizing information deficits, and developing flexible and systematic ways of looking at different problems (2).

VII. CONCLUSION.

This paper leads to the conclusion that many of those "new" concepts, principles and methods which seem to contribute most to the effectiveness of instructional systems closely parallel and can be deduced from human engineering concepts, principles and methods developed in non-instructional systems. It was also shown that with respect to a few principles, "conventional instruction" was far better human engineered than some of its contemporary "programed" instructional system counterparts.

From this discussion, it could be concluded that the "instructional systems movement" is the first small but significant step in a slowly evolving process of applying human engineering technology to education and training. This study is an attempt to speed up that evolution by focusing the attention of instructional system designers on contributions which a human engineering approach can make to instructional system design.

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14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional