AN EXAMINATION OF PART AND WHOLE APPROACHES TO TRAINING RELATED TO THE DESIGN OF SIMULATORS

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As an experimental psychologist with an educational emphasis upon learning theory, an experiential emphasis upon human factors in the electronic aerospace industry, and an intellectual interest in training per se, I have attempted to examine the area of simulator training from its periphery, and generally in terms of a psychological rather than an engineering point of view. I have done this in an attempt to achieve some relevant insight into the total simulation training problem area, and to recognize and define any new approach or shift of emphasis that appears potentially fruitful. Much of what I have concluded is speculative in nature.

PROBLEM

Examples of familiar problems are; transfer of training from simulator to operational equipment, selection of the whole task or the part task approach to training, application of adaptive training and other features of programmed learning techniques, monitoring and measurement of trainee performance, fidelity of visual and motion cues, and psychological fidelity. These may be grouped as primarily psychological problems. Each is a function of the phenomenon of human learning.

In addition to psychologically related difficulties, there is another constellation of problems, all of which derive from the engineering complexity of simulator installations. These are problems of design, in maintenance, reliability, portability, flexibility, and the burden of excessive initial and life cycle costs.

Among these examples of problem areas, there are two which are truly critical, in the sense that if not resolved, all the rest become irrelevant. Of these two, one takes precedence. I refer to transfer of training. Certainly the only justification for a planned simulator is that it possess training validity. Transfer of training is a psychological problem.

On the other hand, no matter how useful a device is anticipated to be, its expense must not be prohibitive and its design requirements must not extend beyond engineering capabilities. The other problem, therefore, rests within the equipment complexity of training simulators and the excessive costs derived from such complexity. This is an engineering problem.

I have now asserted that the transfer of training phenomenon and the complexity of simulator equipment are the major critical problem areas, being fundamental to the success of simulator use. Reference to several recent studies will highlight the difficulties.

EVIDENCE

In June of this year, Hall, Parker and Meyer (1) published a study of Air Force Flight Simulator Programs which had been conducted for the Aerospace Medical Research Laboratories. The authors report that the Air Force contains no fully satisfactory simulators with respect to visual and motion parameters. They found not a single visual simulator in operating condition. It "costs in excess of one million dollars" to install an aircraft simulator facility, and "many millions of dollars" for operating costs. Yet, such simulators are used primarily for teaching flight procedures, which certainly should not require high fidelity simulators. The authors cite the extent of pilot and instructor pilot dissatisfaction with simulators, and express recognition of the need for "increased emphasis upon controlled research."

Heintzman (2), Project Engineer on various simulation programs at Wright-Patterson

Air Force Base, discusses in detail the compromises in fidelity that must be made in simulators for conventional systems, due to engineering limitations, and anticipates even more severity of compromise in V/STOL systems for which RFP's are presently issued.

Smode and Meyer (3), for Aerospace Medical Research Laboratories, report that "... the employment of simulators and the results of training have been less than desired when viewed in terms of cost and time." They also point out that "The researchable issue of greatest immediate importance is the determination of ways of achieving maximum training value (transfer) from available synthetic devices," and that "Measuring and describing performance continue to be a most persistent problem area in pilot training."

PART TASK TRAINING

The two problems, transfer of training and equipment complexity, intersect, as it were, at the point at which the training analyst must decide the degree to which he can use a part task approach in his development of simulator specifications. The analyst has a body of conventional knowledge to guide his deliberation. One pertinent generalization available to him is that the closer he adheres to a whole task training approach, the greater will be the transfer of training. A second generalization is that the closer he is able to achieve environmental realism, the more complete will be the transfer of training. But in both cases, the more severe will be the complexity and cost requirements placed upon the training device. On the other hand, the more the analyst can break the desired ultimate performance into elements, the simpler and less expensive will be the required training devices. But according to traditional assumptions, the less will be the validity of the training, and certainly its face validity. The training analyst is impaled upon the horns of a dilemma, and whichever way he moves, it hurts. In engineering terminology, we say he must conduct a trade analysis and optimize the balance of dollars, engineering state-of-the-art, and transfer of training.

It may be argued that the analyst cannot easily move any further against the horn representing cost and required state-of-the-art. It appears conclusive that the engineering state-of-the-art is being pushed beyond its limits by simulator requirements. This is not to say that engineering techniques will never advance, or breakthroughs will never occur, but it is to say that present requirements for whole task, or mission, simulators already exceed engineering feasibility and available dollars, particularly with respect to fidelity of visual and motion cues. So it would appear that the only alternative open to the analyst is to examine more closely the possibilities of part task training.

LACK OF DATA

The analyst needs more evidence and better insight into the phenomenon of learning, but at an empirical rather than a theoretical level. In specifying requirements for a pilot transition trainer, for example, it is rarely feasible to apply data collected in psychological laboratories on college sophomores, rhesus monkeys, and albino rats, using nonsense syllables, discrimination stimuli, and conditioning techniques. Such information is designed to illuminate relatively abstract hypotheses within general theories of learning. The training device analyst needs concrete field data, collected from intelligent and motivated men learning complex performance sequences. He particularly needs to know more about how a trainee acquires such performance, what the bits and pieces may be, and how the trainee manages to integrate the bits and pieces into a coordinated, efficient, and purposeful performances sequence, particularly when one realizes that the operational performance can never be identical from mission to mission simply because of the numbers of cues and cue combinations possible.

Knowledge of the bits and pieces would define the parts for part task training, and knowledge of how they are integrated by the man would determine the sequential arrangement of the training.

BEHAVIORISTIC APPROACH

When one considers the span of years during which men of determination and dedication have struggled to establish tight relationships among the variables of performance and part vs. whole task training, one begins to wonder if the approach has been correct. Lack of resolution of the problem does not imply necessarily that the approach has been wrong, but it certainly does justify an assessment.

The approach has been behavioristic. One may speculate that training psychologists, and training people derived from other disciplines influenced by psychology or the physical sciences, have inevitably approached their problems with a distinct behavioristic bias. This has been inevitable because graduate training in experimental psychology has uniformly emphasized behaviorism, meaning the general concept that psychology, to be scientific, must deal only with observables. In the case of human performance, behaviorism examines the stimulus inputs to the man, and the response outputs emitted by him.

The internal state of the man has only been ignored, rather than denied. It is recognized that between sensation (cues) and muscle contraction (response) is an extraordinarily complex net of internal, mediating chemical and neural events. Certainly every graduate student is exposed to information regarding such concepts as set, emotion, motivation, perception, consciousness, illusions, defense mechanisms, physiological events and social influences. But the relevance of these internal, and less directly measurable, events has tended to be set aside in the struggle to establish predictable relationships between observable inputs and observable outputs, to be rigorously scientific, and to construct theoretical edifices.

BEHAVIORISM IN ENGINEERING

It can be asserted that the seductiveness of the behavioristic approach has been even more compelling for psychologists immersed in an engineering environment. This is because engineering is, by and large, the direct application of the physical sciences, and engineers have been trained to think rigorously in terms of direct cause and effect relationships, uncluttered with the misty, mediating vistas of the internal workings of human endocrine and central nervous systems. It has been easier for applied psychologists to maintain communication with engineering by extending their behavioristic bias to the adoption of engineering terminology and concepts, and by concurring in the perception of the man in a system as another component within that system, amenable to the same kind of systems engineering analysis used in examining all the other black boxes.

NEW APPROACH

The behavioristic approach has been necessary and valuable because it did create within engineering a consciousness of the presence of the man, and the necessity for attending to his characteristics in design of man/machine interfaces. Now that engineering is aware of the human being, and does understand human engineering requirements for equipment and systems, it is time for psychology to lead another step forward. It is time to create a consciousness of the unique attributes of the man in the system, and suggest correspondingly different methods of analysis. It can be suggested that we must begin emphasizing man as being individualistic and in conscious control, thinking of him as being a user of the system rather than another component of the system.

It follows that in simulator technology, we would adopt an approach which describes the trainee as an active manipulator and user of the training device for his own ends, rather than continue emphasizing his role as an object to be shaped and passively manipulated by the device, at the direction of its designers or the instructor at his console.

INTROSPECTION

This change in approach suggests the potential value of an introspective, or clinical, method of obtaining the data the training analyst needs. The analyst's questions remain the same. What is the effective division of a total performance into parts, effective in the sense that the parts are meaningful to the trainee and efficiently trainable? How does the trainee go about acquiring proficiency in these parts? How does the trainee go about combining these parts into the mission performance? What is it that the trainee needs and looks for during the training process? The synthesis of answers to these questions should clarify the presently amorphous descriptions of competent performance. Smode and Meyer (3), state that "It appears that a precise understanding of the pilot's job is not generally known." Individuals couldn't describe what pilots do and know, and when they tried, their descriptions corresponded with content of training rather than what the performance really is.

Application of an introspective technique would involve more than simply a correlation of answers to standardized questions put to beginning trainees, or a task analysis of accomplished performers. The training analyst would first develop, within his experimental group of trainees, a proficiency in introspection itself. Then he would subject them to the training process being researched, and determine, from the trainee's point of view, the sequence of learning events, and the necessary cues for acquiring and combining these events. The discovery of points of divergence among the experimental group would illuminate those places in the learning sequence where the training device must be especially flexible and responsive to the trainee.

PHYSIOLOGICAL DATA

The method of introspection provides a means for probing mental events associated with a training sequence. In conjunction with this emphasis on the state of affairs internal to the trainee, physiological data could be collected for concurrent analysis. The interest in medical instrumentation for diagnosis and surveillance has accelerated the development of miniaturized body sensors. These would permit heavy instrumentation of the trainees used as research subjects. The correlation of changes in emotional states and muscular action with the introspective data, and performance proficiency, could be illuminating. Detailed records of the sequential activation and integration of specific, isolated muscle groups, as motor performance matured, might very well define methods of bypassing long simulator practice sessions of complex motor performance in favor of simple exercises, if you will, of small muscle units. Physical instrumentation also probably could be used in monitoring progress and diagnosing difficulties during real training, as differentiated from training research.

ENVIRONMENTAL FIDELITY

Suggesting as it does, that every response is a mechanistic function of some specific cue or cue complex, behaviorism supports the assumption that the greater the fidelity of the simulated environment, the greater will be the transfer of training to the real environment. A change in emphasis, recognizing the autonomy of the trainee and analyzing the learning process from his point of view, might reveal that many of the cues we try to provide in a simulator are not needed at all.

Man has a remarkable ability to fill in his environment. Only a few cues are necessary for his experiencing a whole perception. The content of cartoons, caricatures, perception itself, is an inference made from incomplete but entirely adequate sensation. Simulation technologists differentiate between physical and perceptual fidelity. Gibson's (4) differentiation is between schematic and literal perception. Schematic implies completion of a perception by inputs from the perceiver. Literal refers to the ability of the perceiver to restrict his perception strictly to the external stimulation when necessary. The question is, what evidence do we have for requiring a high degree of physical fidelity on the basis of a need for literal perception?

Man can also fill in roles. He can, in imagination, construct an artificial reality to which he reacts. If he can do this as a youngster playing cowboy and indians, as an actor in the theater, and as a citizen shift his behavior according to the differing roles he plays as father, son, husband, lover, employer, employee, to what extent might he be asked to play a role as trainee?

The supposition is, having the capability to do so, the trainee could be asked to contribute much more to the simulated situation than he ordinarily does. So much of perception is illusion created by the man, it seems reasonable to assume that he could be trained to generate illusion at will, in order to fill out the environment simulated for training purposes. It also seems reasonable to speculate that the more complete a simulated environment is, the more apparent to the trainee will be the inevitable omission or distortion of detail, and the greater the distraction, even if the defect is not particularly relevant to the response being trained. Cases have been reported in which simulator control dynamics, bitterly complained of by trainee pilots, subsequently were found to be perfect. One may speculate that the pilots sincerely but erroneously blamed control dynamics for an uneasiness caused by an unrecognized defect in some other aspect of the simulated environment.

PROGRAMMED LEARNING

The kind of approach about which I am speculating has something in common with the intent of programmed learning techniques. It encompasses an attempt to individualize training by breaking a total performance into discrete steps, giving the trainee control over the rate at which he takes the steps, and providing feedback appropriate to his learning process rather than to his gross performance. It isn't stretching an analogy too far to compare the experience of inadvertently flying a simulator into the ground, with that of discovering on Monday a flunking grade on the quiz taken the previous Friday. In each case, the feedback is too late to be maximally effective.

The change in emphasis in programmed learning technology, from evaluation by comprehensive final exam to stepwise evaluation, is similar in intent to the proposed shift in emphasis from construction of high fidelity mission simulators to attending to the subtle learning processes within the trainee.

In summary, I tend to agree with Smode, Gruber and Ely (5), in their discussion of simulator technology, when they assert, "Any attempt to manipulate the conditions of learning has, of necessity, involved much more art than science." My intent here has been to suggest to you that the intuitional aspect of that art might be clarified through a controlled method of introspective analysis.

I have asserted that engineering state-of-the-art cannot fulfill current mission simulator requirements for environmental fidelity, even if cost restraints were slackened. I have suggested that the only alternative rests within the transfer of training phenomenon, specifically with respect to part task training. I have suggested that useful differentiation of whole task performance into parts may be achieved by a shift from the behavioristic approach in research, to an emphasis upon clinical introspective techniques, centered upon the trainee's apprehension of his goals and his requirements for achieving them. I have suggested that extensive physiological monitoring might be a useful adjunct to the introspective data. And I have suggested that the trainee may be capable of self-generating sufficient illusion of reality for many simulator training purposes, and that much of the detail may be unnecessary anyway.

I am sure that although my comments have been generally speculative, and perhaps controversial, we would all agree that resolution of current simulator training problems requires more psychological research, in the field as differentiated from the laboratory, and not necessarily instead of, but at least concurrent with, hardware research.

References:

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EXTENDING THE POTENTIAL OF OFT's

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The operational flight trainer (OFT) has made for itself a secure place in military aviation training. The OFT is designed to simulate the aircraft so that training in the OFT will positively transfer to the aircraft. However, we find a wide divergence of opinion as to the extent to which the OFT simulates the aircraft. Those who are concerned with the physical or mechanical aspects of similarity maintain that the level of simulation is extremely high. Those who are concerned with the extent to which the OFT represents the aircraft environment hold that the level of simulation is extremely low. In this latter regard the Air Force, some years ago, investigated for a number of aircraft accident situations the sensory cues experienced by the pilot. When the flight simulator was examined to determine how many of these cues could be provided, it was found that very few of them were available in the simulator.

If we examine the uses to which the OFT is put we find that it is mainly used for procedures and instrument training. It appears clear that the OFT does not adequately represent all of the tasks that are required in actual flight. The question I wish to raise is how the OFT can be made more representative of the aircraft without undue increase in cost.

The Center has, within the past few years, sponsored a number of studies which bear on the problem of extending the potential of the OFT. Guy Matheny (1) (2) (3) has investigated the effects on pilot performance of reducing the level of fidelity of simulation. As part of this work an exploratory study of the feasibility of adaptive training techniques was conducted.

Joseph Ruocco (4) (5) has studied the effect of combined cockpit motion and visual display on performance in carrier and runway approaches. Alan Burrows (6) investigated the problem of visual time sharing with particular reference to the detection of intruder aircraft. Hugh Bowen (7) did a study to develop means of assessing pilot proficiency in the OFT.

While these research efforts resulted in a number of implications for training in OFT's they also resulted in uncovering needs for further research and development efforts. These