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IS SIMULATION FIDELITY THE QUESTION?

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William E. Montague

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Recent work on the analysis of learners' representations of complex physical systems was reviewed. These results were used to introduce the concept of mental models, which, on one hand, are an important part of what must be considered in designing simulation. On the other hand, faulty mental models of what simulators should be like ignore almost everything known about how to teach people complicated tasks. It is suggested that design specifications for training simulators should include features intended to promote learning and understanding. Sometimes it may be necessary to violate physical and

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temporal fidelity to promote learning. This is not a new idea, but it is apparent that, in the acquisition of training devices for new weapon systems, little or no attention is paid to this advice. Recommendations include a development effort to operationalize guidelines for specifying and designing instructional task fidelity, as well as to promote and monitor their use.

FOREWORD

This paper is the basis for an invited talk delivered 23 July 1981 at a workshop on "Research Issues in the Determination of Simulator Fidelity" held by the Army Research Institute for the Behavioral and Social Sciences, Alexandria, Virginia. It provides a review and statement about the current "state of the art" in the design of simulation for training. It was intended to raise questions regarding the specification of the characteristics of simulations for training that are in need of research and development attention.

The paper is the second prepared under laboratory independent exploratory development project ZF66-512-001-03.08 (Theory of Graphic Representation). In the project, a preliminary review of the literature and current practices in designing instruction and textual communication revealed that no theoretical framework existed to serve as the basis for techniques needed to determine appropriate graphical forms of presentation. The overall goals of the project are to survey current techniques for determining instructional representations, review the state of current theory about how people represent knowledge, and derive and test prescriptions for effective means of representing instruction.

The project is part of the five-year plan for exploratory development. The review and subsequent empirical research effort are focused on the role of representations in learning and how to arrange graphic instructional presentations to train efficiently and effectively. The theoretical description of learner knowledge structures is intended to lead to the development of techniques for specifying how to match task requirements and learners' structures in training. It will, therefore, be of ultimate use in training design and development. The empirical studies will develop directly usable training materials because the efforts will be carried out on Navy training tasks.

JAMES F. KELLY, JR.   JAMES J. REGAN
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SUMMARY

Problem

The word "fidelity," when applied to simulators and training devices, means different things to different people. At a general level, it is assumed that high fidelity is necessary for a device to be an effective trainer. "High fidelity" is often defined in terms of whether the device generally actually looks, feels, smells, and runs like the object being simulated. The problem is that this approach is too general. Specifications for the training the device is to support are vague. The design specifications do not specify the actual training requirements to guide performance measurement to document learning nor do they specify the use conditions necessary for training. This seems to be due to a limited "mental model" or conception of how to specify the design requirements held by program managers who are responsible for procuring simulators and training devices for new weapon systems.

Objectives

The objectives of this paper are to:

1. Introduce the concept of mental models to provide perspective about specifying principles for designing training devices and suggest why they are not designed well.

2. Review the design inadequacies of planned Navy training device procurements as evidence that the state of the art is poor.

3. Propose some guidelines that should be included in the design specifications.

Approach

Recent work on the analysis of learners' representations of complex physical systems was reviewed. This was used to introduce the conception of mental models to show that they are an important part of what must be considered in designing simulations and, if faulty, they impede development of the state of the art.

Findings

The review summarizes the characteristics or principles that should guide the acquisition of training simulators. It is pointed out that, in some cases, the requirements of designing a good trainer may force a departure from the physical and operational characteristics of the object or system being simulated. There will be resistance to such departure from operational realism. An educational effort appears necessary to change people's mental models so that the art can be advanced.

Conclusions

Systematic guidelines need to be prepared from available research and practice to guide the design specification of training devices. Fidelity requirements are derived directly from specific training objectives and conditions known to produce effective training. They cannot be specified solely in a general fashion based on the physical characteristics of the equipment and tasks to be accomplished.

Recommendation

A substantial effort is recommended to develop the guidelines for improving the state-of-the-art capability in designing training devices. In addition, systematic implementation of these guidelines is necessary. In some cases, research may be necessary to clarify some persistent problems and improve the design guidelines.

CONTENTS

INTRODUCTION

Objectives

The objectives of this paper are to:

1. Introduce the concept of mental models to provide perspective about specifying principles for designing training devices and suggest why they are not designed well.

2. Review the design inadequacies of planned Navy training device procurements as evidence that the state of the art is poor.

3. Propose some guidelines that should be included in the design specifications.

Background

The word "fidelity," as applied to simulators and training devices, means different things to different people. At a general level, it is assumed that high fidelity is necessary for a device to be an effective trainer. "High fidelity" is often defined in terms of whether the device generally looks, feels, smells, and runs like the actual object being simulated. The problem is that this approach is too general. The device is to support training but training is only vaguely specified. The design specifications do not include the actual training requirements to guide the performance measurements that document learning nor do they specify the conditions necessary to bring about training. This seems to be due to a limited "mental model" or conception of how to specify the design requirements. Program managers, who are responsible for procuring simulators or training devices for new weapon systems, know little about training design principles and, therefore, do not consider them. This paper discusses criteria that may be used to specify the degree and type of fidelity needed for training using simulation. First is the concept of mental models. An analysis of the mental model to be learned by trainees can produce a task representation (simulation) that substantially differs from physical reality. Second is a discussion of criteria associated with pedagogical or instructional features. These criteria must be included in design of training systems or devices.

The notion of mental models is a useful way to discuss some issues relevant to the question of the fidelity of simulations for effective training and maintenance of competency. The mental models notion is really not new, but is receiving considerable recent attention among cognitive scientists (e.g., Johnson-Laird, 1980; de Kleer & Brown, 1981). The notion has considerable heuristic value that can be used in the current discussion.

Basically, the idea is simple: A person makes use of an internal model of the world to reason and explain things about the world.

> If the organism carries a "small-scale model" of external reality and of its possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future, and in every way to react in a much fuller, safer and more competent manner to the emergencies which face it. (K. Craik, 1943, cited by Johnson-Laird, 1980.)

Mental models are composed of autonomous objects associated topologically with others, rules for their interaction that allow them to be "run" in one's imagination or mind's eye

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and the outcomes assessed. They assist human reasoning by producing explanations or justifications of complex system behavior. They are mnemonic devices or learning devices (Hollan & Williams, in preparation). Thus, they aid in the apprehension of how systems work and provide a strong means for generating expectancies about how things are done, should be done, or the consequences of certain actions. It is important to realize that mental models are powerful analogical devices humans use in learning about their world.

There are two main points to emphasize about this notion of mental models. First, people develop mental models through the interaction with physical and social systems. Thus, we must consider the best way to present materials and simulations to develop effective training. The principles for designing and critiquing instructional presentations (simulations) need to be developed (de Kleer & Brown, 1981). Second, since adults may have strong models replete with errors or "bugs," they can also inhibit new learning, or changes in systems. So, on the one hand, mental models are used by individuals to consider systems qualitatively and "handle" their world and, on the other, they may be barriers to change or correction.

In training with simulation, we are attempting to help people build up their representation of the physical world to be able to operate equipment effectively; we must design training and training devices to allow the most effective buildup of appropriate mental models. Many of the tasks to be trained are procedural and involve decisions about reporting and classifying signals, or anticipating outcomes resulting from changes in a system. Simulation for these tasks must be done in a way that maps into what the trainees already understand as well as the critical aspects of the terminal task to be learned.

In addition to needing to consider the mental representations of the learner to design simulators, one needs to be concerned with the mental models of training simulators possessed by the managers of the personnel and training system, the program, or the weapons system. From the point of view of the educational/training psychologist, these people are laymen. They do not consider how students represent knowledge and physical systems to themselves or that performance measurement, practice, and feedback are needed for learning. Thus, it has been difficult to introduce systematic changes into how they specify requirements for training devices.

Problem

Limited Conception of Simulation for Training

When "fidelity" of simulation is discussed, most people think of how much physical resemblance or isomorphism exists between the simulated and "real" task situations. This seems to be the reason that we work so hard to create simulators that look, feel, smell, bounce around, and otherwise appear to operate like the real equipment. A simulated plane's cockpit must be indistinguishable from the real thing. A simulated power plant must generate steam power. This philosophy guiding the construction of simulators is costly, but is considered worthwhile because it is so real. Fidelity is a close synonym of "realism" in this usage. Realism may be useful for some things at some times, but it may not provide the best training situation in many--even most--instances and it may slow learning down considerably.

This probably describes most laypersons' idea or model of what an effective simulator or training device should be like. Mental models like this influence expectancies and,

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therefore, what they buy or build when they are assigned the task of developing training devices. Since most program or training system managers are "laymen" when it comes to knowing how to train, the simulation characteristics needed for effective and efficient training are often not specified and required. Similar perspectives about classroom instruction held by teachers or instructors allow ineffective methods to persist and slow down the rate of acceptance of more effective teaching techniques (Montague, Ellis, & Wulfeck, 1981). Everyone thinks they know how to teach because they went to school. Similarly, it is easy to assume that a realistic training device will be an effective trainer. Such misapprehensions are difficult to overcome. In these cases, the problem is that the training/teaching is approached in too general a fashion. No specification of training requirements and objectives is made with the consequential failure to define performance criteria needed to judge the success or failure of trainees.

Example of the Problem Showing the State of the Art

Let us examine the consequences of this limited mental model in action by examining the state of the art of designing simulators. In this case, state of the art is defined in terms of the simulators being acquired for training sonar operators and scheduled to go into use sometime in 1985. We will outline the task, briefly describe the training, and discuss the concepts behind the simulation to be used for training. From this, we can evaluate the quality of these training simulators based on what is known to be required for effective training and for understanding the effect of more limited, erroneous, but prevalent mental model on training device design.

The tasks of detecting and then classifying signals on various displays are the primary and mission-critical tasks required of sonar operators. They are complicated and difficult and, interestingly, they are not emphasized in training. Operator training concentrates on the somewhat simpler tasks of searching, tracking, and localizing possible targets (Mackie, Shultz, & Beardon, 1981). The trainers for operators historically use simplified detection and classification tasks, sometimes eliminating them completely as tasks performed in training. A few--rare--operator trainers have been developed recently that present recorded or good simulated signals; however, they do not provide assessment of errors and appropriate feedback. Thus, the use of these devices in schoolhouse training is unlikely to train operators effectively to enable them to perform well when they are assigned the tasks of detecting and classifying signals on the job.

The job itself does not provide systematic experiences that will develop the detection and classification skills. At sea, most ships are in areas that have few contacts of military significance. In addition, a sonarman is assigned to many tasks other than sonar watchstanding. Even when a ship regularly participates in exercises, there is no assurance that each operator will receive systematic exposure to the military targets so that they can develop the high skill levels needed to perform the complex pattern recognition tasks involved. Novice operators are not assigned systematically during exercises and there is not sound basis for rapid, thorough feedback to the operator regarding either successful or erroneous performance. Thus, neither formal schooling nor on-the-job experience provide for the systematic development of these skills so necessary to readiness and the Navy mission (Mackie, Shultz, & Bearden, 1981).

Naturally, these problems have not gone completely unrecognized. However, it is important to examine the quality of the solutions proposed. By 1985, the Navy is supposed to deploy the AN/SQQ-89 passive sonar system to many of its ships. This system integrates three sensor systems: the LAMPS (for light airborne multipurpose system) Mark III sonobuoy system, the tactical towed array system (TACTAS), and the improved hull mounted sonar system. Because this sonar system is so complex to operate, the Navy

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is procuring a few, very expensive dynamic team trainers to provide teams with "practice." The design concept for the AN/SQQ-89(V) Acoustic Operator Training System is captured in the words: "high fidelity." The actual operational equipment is stimulated, giving the equipment the ability to show targets as they actually might occur, permitting their detection and classification and realistic execution of other phases of ASW operations. On the surface, this sounds good, but the cost restricts the number of units to be purchased. Since such simulation works in "real" time, few people can be trained on the system and its use is restricted to more "advanced" training in preference to initial operator or refresher training. In addition, such systems require many, highly trained personnel as instructors who provide feedback to team members.

To take care of more fundamental operator training, the Navy is developing a series of basic sonar operator trainers (BSOT). These are designed around the mainframe cabinets and represent the operator consoles of specific sonar systems. In this instance, "high fidelity" refers to the physical consoles and their knobs and buttons. Trainees can manipulate console controls in response to static information presented on slides by carousel slide projectors holding 80-120 slides. Also, they can learn to set up the equipment and to perform certain procedures c.1 such devices. Training in the critical skills of detecting and classifying signals is rudimentary.

As this example is representative of the state of the art in simulators for training, we can detect two design approaches. First, operational training devices are designed to provide high fidelity presentation of the actual equipments to be operated and the signals to be handled. These devices are expensive, work in real time, and provide exercise for a team of operators on the various subsystems. This is the case in the example described, as well as in propulsion engineering, aviation, and other complex weapon systems. In these systems, there is no provision for measuring the performance of various operators to assess the adequacy of their performance and diagnose their errors. There is also no provision for systematic exposure to critical or difficult signals and tasks appropriate to operator deficiencies or lack of skill. These systems make no provision for rapid and comprehensive feedback.

To take care of basic operator training, the emphasis is on a trainer that teaches people how to set up and calibrate the equipment and carry out some of the simpler procedures. But the interactive capability is poor. The important operator tasks of detecting and classifying receive only cursory attention. The presentations are static and their number is severely limited by the use of slides. The dynamic character of the actual task to be performed on the job is not well represented. In sonar, much of the critical target information is time dependent. Important aspects of performance, such as detection latency, reporting accuracy, and classification latency and errors, are not addressed. The state of the art in trainer design seems to ignore almost everything we know about how to teach people to do complicated tasks.

APPROACH

The approach taken here was to review the characteristics that should be present in training devices and to suggest how they might be used prescriptively in designing simulation.

FINDINGS AND DISCUSSION

Simulators that Teach

Expensive, physically isomorphic simulators may not be good instructional devices or exercisers for a number of reasons. They are so big or complex that the student cannot "see" the results of his/her action on the operation of the system. Events happen too slowly over long time periods to give trainees good feedback about the consequences of actions. The simulators provide little systematic practice. The system may not provide good feedback about errors. In other words, they do not provide good analogical models for learning; students cannot envision system functioning. They also violate what we know about how to teach people.

Training simulators/devices are required to provide the cues—the opportunities for trainees to respond, make and correct errors, and observe the consequences of their actions—that allow them to understand the system. Simulation that teaches well may violate the physical and temporal isomorphism, and its effectiveness in training may be due to this. This idea is counterintuitive to the naive view that the most important design goal is to provide high physical and stimulus fidelity.

Simulators that are effective trainers need to simulate faithfully the tasks to be learned in a way that teaches students to think about the problems they confront in using the equipment and to build appropriate mental representations of the systems and the way it operates. With such simulators, they learn to operate a system well and can respond effectively to emergencies and anomolies in its operation. To do this, simulators need to show—perhaps quickly, perhaps not—what changes occur in a system because of certain actions. They should allow frequent and rapid practice of the procedures to be learned, as well as allow and provide corrective feedback for errors so that the errors can be eliminated. Often, the real equipment, as well as physically and temporally close simulations of the real equipment, do not provide this instructional environment.

Simulators intended to train novices and those intended to provide extensive practice or retraining for moderately competent people may need to be designed quite differently. The extensive corrective feedback needed by these groups is substantially different. Novices need extensive guidance and precise corrective explanations for their errors and their causes, while already trained individuals may need refresher training or to broaden their knowledge of situations, signals, or events that may be encountered. They may need relatively simplified examples of problems to facilitate learning. Normally invisible events or processes may need to be made visible to support understanding. More experienced individuals, on the other hand, need to refine their skills, which may require more realistic representation of critical aspects of the task.

Primarily, simulation needs instructional "task fidelity" (Semple, Hennesy, Sanders, Cross, Beith, & McCauley, 1981) and this requires determining the training device cue and response capabilities needed to support learning and the practicing tasks that lead to or support the operational performance required. Instructional task fidelity requires both the design of the appropriate representation(s) for learning and inclusion of the necessary learning principles that support acquisition. A major difficulty is that such design is based on learning/cognition task analysis procedures, which are not well developed—especially for complicated tasks involving decision making and problem analysis. Better techniques are needed so that training devices can be designed to support trainee learning and practice, rather than simply mimicking operational system characteristics and uses. To do this, the final skills to be learned need to be specified in terms of task performance, the performance conditions, and performance standards. Also, the steps involved in

apprehending the skill need to be identified, which would include the representation(s) appropriate for the learner's competency level.

There is another problem that impedes progress in the development of specification and standards for training simulators, especially since systematic performance assessment is involved. It is resistence to being evaluated. Users, who are threatened by systematic measurement of performance, are often encountered. Their perception of the potential for punishment when simulators can measure skill levels leads them to avoid their use. This creates problems in monitoring the use of simulators and perpetuates a mental model of simulation that slows or prevents the adoption of more effective principles of design. Therefore, systematic implementation and management, including educating the users to overcome this bias, are needed.

The following sections of the paper attempt to outline some tentative guidelines for designing training devices in terms of training task fidelity. "Fidelity" is directly linked to the specification of the knowledge and experience required to support specific performance. The focus is on identifying specific training objectives and arranging the process of training to accomplish them.

Some major general goals of training devices are listed below:

1.   Build up in the learner's mind/memory a representation of the tasks to be performed and how the system functions. The goal is to build the trainee's understanding of the system and his role in it so that he can make appropriate inferences, under various conditions, about what to do and what will happen as a result.

2.   Produce smooth, error-free, execution of needed procedures/responses.

3.   Teach in a safe, less complicated environment and perhaps show the consequences of unsafe actions.

4.   Provide for the development of skills.

5.   Provide tutoring (especially intelligent) that gives hints, coaching, warnings, and explanations.

All simulations are trying to accomplish these goals. They try to build up experience that will aid the student in the performance of the real task. For the most part, these goals are self-explanatory. The first item, however, needs a little more explanation. A major goal is to help people build a mental model of the system and its functioning and of the consequences of their actions in the system. In complex systems, we would like the learner to develop an accurate understanding of the system that will allow him or her to infer what will happen if some action is taken or what produced some problem or symptom. In part, limits in our ability to specify and train exhaustively on complex systems require this understanding.

Guidelines for Designing Simulations for Training

What makes a good simulation? There are two main characteristics. The representations of some aspect of objects or systems must be recognizable and they must help us to understand, by manipulating, enjoying, or predicting their behavior. How can we deliberately contrive simulations to facilitate learning to provide insight into complex system functioning?

To be powerful for training, simulators must not only simulate reality and be useful in anticipating and controlling that reality, but they must affect or change those manipulating them. Effective simulators involve the learner; for example, he perspires when he "flies" a Link trainer, he gets upset when he views injustice in a film, and he is chagrined when he recognizes that he could have caused a real disaster by opening a valve too soon.

But, as just indicated, physical similarity or identity may not allow the most effective training (i.e., the most involvement). For example, Johnson (1981) recently demonstrated that limited fidelity simulation (a paper mock-up) was more effective than the real equipment in producing performance resistant to forgetting (over 60 days or so). This effect was produced because the limited fidelity simulation required trainees to rely more on their memory during learning. Similar findings have been reported by a number of other researchers (see Johnson, 1981, for other citations).

The essence of simulation is placing the learner in a sufficiently realistic situation that requires the same sequence of inquiries, decisions, and actions as does the actual situation. Each of these activities triggers appropriate feedback that may or may not alter the situation, but that can be used for subsequent decisions about further actions that may change the nature of the problem. Therefore, a prime characteristic of effective simulation is how well it mimics the critical characteristics, problems, and functions of the system from the point of view of the learner.

The analogical relationship between the simulation and the real task function is primary. People build up representations by observing the effects of procedures they apply (at least active practice is better, although passive practice can be effective in some cases). So design must make this observation possible. Often, realistic simulators do not make this observation easy; and some even, impossible (e.g., in a steam plant simulator, the effects of actions cannot be seen for long time periods or without physically moving somewhere to observe events or situation readouts on gauges).

Teaching by simulation is teaching by analogy. In such teaching, the mapping between a learner's existing knowledge structures and the training (simulation) determines learning difficulty and how and what is learned (Anderson, Greeno, Kline, & Neves, 1981; Bott, 1978; Rumelhart & Norman, 1980). Similarly, the mapping between the training/simulation and the actual task should determine learning and the adequacy of the resulting performance. Therefore, "analogical correspondence" (Riley, 1981) between the actual task situation and the representation is a primary dimension in designing simulation. The problem, of course, is defining that dimension. Gentner (1980) proposed a structural characterization of good scientific analogies where the mapping between the analogy and the scientific explanation/model/task can be specified. Perhaps this method can be used to describe better the relation between "simulated" and the "real" tasks.

An analogy or simulation should be readily interpretable by trainees. They need to understand how the simulated objects/symbols represent the real objects. This ensures the salience for the learner. Familiarity with the representational system is thus an important determiner of the simulation's adequacy. It is probable that this factor is the basis for requiring different types of representations for people completely unfamiliar with the task and system to be learned than for those needing refresher training or extending their experience. When the symbols are not understood (e.g., because of cultural differences) or are otherwise difficult to discriminate, their effectiveness is poor.

Another important characteristic is "transparency." The learner should be able to "see" readily the results of his actions on the system represented. In this sense, the representation may be quite different than the actual task. The simulation should reveal

the interaction of the familiar entities represented whether or not they are "visible" normally.

Salient design guidelines are listed below:

1. Novice or journeyman level?

2. Representation quality:

   a. Transparent.
   b. Understandable and familiar.
   c. Provide qualitative understanding.

3. Provide practice. Cues and opportunity for error--diagnostic.

4. Arranging training sequence--relax certain constraints, like time, especially early to produce better understanding.

5. Systematic measurement of performance--defined conditions and performance standards.

Let's return to the example used for critiquing the state of the art in the design of an ASW simulator. The example pointed out that the simulation was "high fidelity" in the naive physical sense. The equipment and the signals to be seen were realistic. However, the training on critical tasks received little emphasis--performance and feedback about errors was left up to the instructors. What characteristics should be included to design or redesign the simulator to make it an effective training device?

1. <u>Fidelity of representation.</u> For the novice, simple representations of problems unconfounded by multiple targets or poor transmission conditions would be needed. Perhaps dynamic (developing over time), rather than static displays, would be useful to teach detection skills. To permit straightforward transfer to the job, more realistic displays could be introduced gradually. For more experienced individuals, already competent in detection and tracking, it might be more appropriate to provide exposure to a broad range of likely-to-be-encountered signals. For this, static displays might be quite appropriate. What is needed is a complete description of what individuals do at different levels of competency and, then, more adequate design of the simulation for promoting learning can be contrived.

2. <u>Analyze and identify the critical aspects of the task.</u> From the analysis, the conditions and standards of the performance measures that will assess student progress and evaluate the training are specified. Sufficient opportunity should be provided for making errors, especially common ones, and for correcting their causes. This provides diagnosis of problems in student performance and understanding of task.

3. <u>Vary problem development time according to the student's level of learning.</u> Slow things down for early learning or to allow the student to get used to time sharing among several signals or tasks. Change the difficulty systematically and progressively to ensure an appropriate range of experience. Adjust conditions appropriately to maximize practice.

4. <u>Automate problem presentation and performance measurement to reduce instructors' load.</u> Incorporate wide range of signals to provide appropriate experiences needed. Provide an expandible library of signals.

5. _Provide for record keeping and communication._ Any system should include methods for keeping track of student progress and providing informative, diagnostic feedback to him/her about performance tests. In addition, instructors and managers need information about student progress and about the adequacy of the course.

This brief listing of what a simulator should include to make it an effective trainer needs to be clarified by detailed "how to" information before it can serve as a design guide. Substantial progress is possible using available knowledge. The inclusion of these characteristics in simulators will do much to make them effective training devices and provide a potential means to assess competency.

CONCLUSIONS

This paper began by asking: "Is simulation fidelity the question?" In the sense of a naive realism, it is not. Realism may be useful for some things at some times, but in many instances it may not provide the best training situation. In fact, if it is required, learning may actually slow down considerably. The simulation characteristics needed for effective and efficient training are often not present in physically realistic situations, which is one reason that some tasks hard to learn.

It is easy to assume that a realistic training device will be an effective trainer. Unless the representation is easily understood by the trainee and appropriate training conditions are included, however, this assumption is wrong. Such misapprehensions are difficult to overcome. When this assumption is made, the approach to the training/teaching is too general. As training requirements and objectives are not specified, the performance criteria needed to judge the success or failure of trainees are not available.

To attain training task fidelity in a simulation, it is necessary to describe the task precisely in terms of the way it needs to be represented mentally and to provide conditions for learning the representation. These requirements are not met simply by providing conditions very similar to those of the actual job. Testing the adequacy of performance, diagnosing problems of understanding that lead to errors, and systematic exposure or practice on infrequent or dangerous, critical events are needed. The real problem is to provide usable requirements for the simulation development that can be included as design specifications. Fidelity requirements are derived directly from students' cognitive representations, specific training objectives, and conditions known to produce effective training. They cannot be specified solely in a general fashion based on the physical characteristics of the equipment and tasks to be accomplished. Simulation is an attempt to contrive a set of experiences for the learner to allow learning to occur. Such contrivances should not be designed casually.

Perhaps a more substantial problem is to convince the personnel and training system managers and those who develop new weapons systems to include the guidelines for the design of training simulation in their specifications. For this, a political and educational effort is needed. To be effective, we need to be persuasive enough to have training characteristics included in specification standards. We have such standards for instructional program development (see Branson, Rayner, Cox, Furman, King, & Harnum, 1975; de Kleer & Brown, 1981).

The preliminary set of goals for simulation and the charcteristics needed for training simulation presented herein represent preliminary guidelines for designing training simulations. Further elaboration of these characteristics and goals, together with the

development of "how-to-do-it" procedures, is needed. Their development will probably improve the state of the art in designing effective simulators for training and evaluation.

RECOMMENDATIONS

Formal development of instructional prescriptions for task fidelity should be undertaken. This can begin using existing knowledge from research and practice. However, although there is a growing body of research analyzing student representations and their role in task performance, usable prescriptions cannot easily be derived from this work. Considerable effort is needed to refine the procedures for prescribing training and, even though our knowledge is incomplete, development of design guidelines must begin. These prescriptions should then be included in the specification of all training devices. This will allow improvement in simulator design now, as well as point out specific gaps in our knowledge that additional research effort can fill. Finally, an implementation and monitoring system (quality control system) should be formalized to ensure the proper use of the training devices and to provide performance assessment. Training for instructors and training managers should include a review of the need for systematic performance measurement to assess the adequacy of training simulation.

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