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Implementation of a Mixed-Fidelity Approach to Maintenance Training

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U. S. Army
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A computer simulation was developed and pilot tested within the training environment at the U.S. Army Signal School, Fort Gordon, GA. The microprocessor-based simulation, containing two distinct fidelity levels, was designed to supplement technician training for troubleshooting tasks on a tactical telephone switchboard. The pilot evaluation involving 30 experimental users suggested that computer-based simulation can be effectively used to supplement practice with real equipment. Practice on the simulation, interspersed with (Continued)

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real equipment practice, added a new and valuable dimension to the diagnostic training.

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Education and Training

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FOREWORD

The Training and Simulation Technical Area (Performance Readiness Team) of the U. S. Army Research Institute has been actively supporting research designed to investigate the transfer effectiveness and cost effectiveness of Computer Based Instruction (CBI) in the Army school environment. A key question has been the degree to which CBI, through the use of simulations and similar programs, can substitute for training on actual equipment, thereby reducing training equipment costs and increasing the number of students who can be concurrently trained. This report describes a developmental project conducted at the Army Signal School, Fort Gordon, Georgia. A computer simulation program was developed to teach troubleshooting skills on the SB3614 switchboard to MOS 36H trainees (Dial/Manual Central Office Repairer) as a substitute for practice on the equipment itself. The results from this training experience thus add to the data base needed to determine the utility of CBI.

EDGAR M. JOHNSON
Technical Director

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The participants at Fort Gordon were from the Educational Technology Division, the Training and Development Division, and the Central Office Repair Division of the Signal School. Dr. William Ketner, Mr. Jim Frye, Ms. Margaret White, and Cpt. Sam Palmisano provided assistance from the Office of the Deputy Assistant Commandant for Educational Technology (DACET). Mr. James Atwood provided input from the Directorate of Training Development (DTD). The course instructors and administrators from Saltzman Hall who provided the critical content expertise and evaluation assistance were SSG Leo Bills, Mr. Larry Campbell, SP5 Vivian Patino, Ms. Jan Jessen, SFG Mike, Mr. John Ross, and Mr. John Wiley.

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IMPLEMENTATION OF A MIXED-FIDELITY APPROACH TO MAINTENANCE TRAINING

EXECUTIVE SUMMARY

Requirement:

To document the conceptualization, development, integration, and pilot test results of a computer based simulation for troubleshooting training in an Army electronics environment. The work specifically studied the value of providing a variety of training techniques with mixed levels of fidelity.

Procedure:

The research contained the major components of systematic design of courseware including front-end analysis, definition of diagnostic training goals, identification of appropriate instructional techniques, development with subject matter experts, and formative and summative evaluation. This work resulted in a demonstration and pilot evaluation of a microprocessor-based troubleshooting simulation.

Findings:

The project demonstrated that a computer-based simulation with both low and moderate levels of fidelity can be an acceptable supplement to high-fidelity real equipment training in an Army electronics environment. The pilot test showed the methodology and feasibility of evaluating computer-based simulation training. The results of the pilot test suggest that the computer-based simulation can be exchanged for a portion of the real equipment training.

Utilization of Findings:

The findings provide the framework for similar development and integration projects. The pilot evaluation results and methodology provide guidance for a significant and extensive evaluation.

The menu of choices a student has with the simulation is shown in Figure 1. Items numbered three through seven in the figure make up the "symptom finding" section of the simulation. These items contain the medium-fidelity portions of the simulation along with some low-fidelity portions. Section nine is the low-fidelity section in which failed parts may be replaced. Finally, section eight contains the Framework for Aiding the Understanding of Logical Troubleshooting (FAULT).

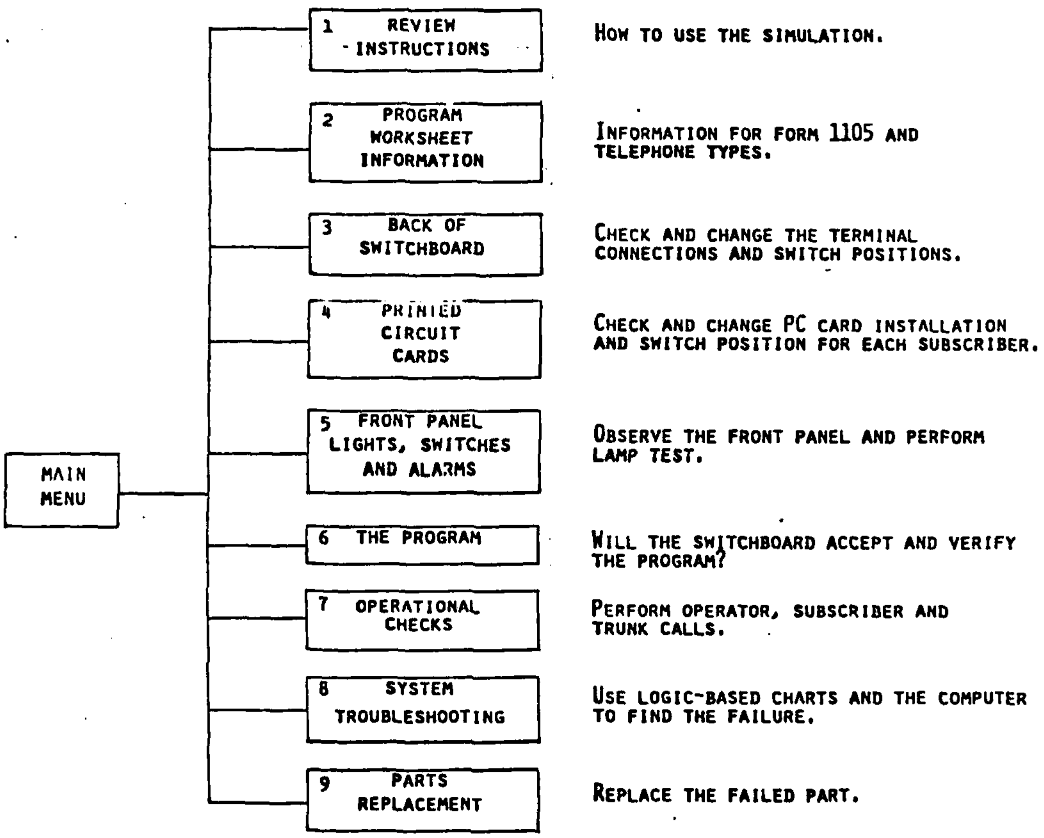

Figure 1. Main menu list of options.

The process of gathering symptom information via the simulation is necessarily different than on real equipment. The simulation does not attempt to teach such high-fidelity skills as turning knobs or flipping switches. It is assumed that students in the SB 3614 class already possess these skills or will acquire them in working with the real equipment.

IMPLEMENTATION OF A MIXED-FIDELITY APPROACH TO MAINTENANCE TRAINING

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and Duncan's Multiple Range tests. In the analysis, experts was a within-subjects variable and training groups was a between-subjects variable.

The analysis of variance showed a significant interaction between the experts and groups for both the composite, $F\ (3,37) = 24$, $p < 0.05$, and the action-by-action, $F\ (3,37) = 36$, $p < 0.05$, rating. For the composite rating, Duncan's Multiple Range test indicated that two of the experts rated the experimental group as having better overall performance, $p < 0.05$. The other two experts' ratings showed no statistical difference between the groups. For the action-by-action rating, Duncan's Multiple Range test indicated that one expert rated the experimental group as having significantly better performance than the control group, $p < 0.05$. The other three experts' action-by-action ratings showed no difference between the groups.

There was a significant main effect of experts for the action-by-action rating, $p < 0.05$. This difference among experts may be attributed to each expert's differing understanding of the instructions for completing the rating forms or to the different standards of acceptable performance of each expert. Subsequent use of this rating scheme must attempt to eliminate this difference by increased expert education with respect to the rating scheme or by scaling the experts' ratings.

3.1.3 Fine-grained Error Analysis

The experts' ratings were studied more closely in an effort to determine the specific types of error committed during the live performance test. An error was judged to be any student action which an expert rated as "inappropriate" or "most inappropriate". It was found that there were 83 actions which at least one expert considered to be in error. Two or more experts agreed that errors had been committed for 29 of the actions. It was decided to consider only those actions for which at least two experts agreed that errors had been committed since the analysis in the previous section showed that there were differences between the experts.

The system used to classify the various errors was that used by Johnson and Rouse (1982). With this system, errors may be classified into five general categories. These categories are defined as follows.

1. Observation of State: Occurred when a student failed to collect sufficient information, misinterpreted the information collected, or collected the same information more than once before forming initial hypotheses about the cause of the symptoms.

2. Choice of Hypotheses: Occurred when a student chose a hypothesis that may have been functionally related to the symptoms but was a poor choice because of the nature of the specific symptoms, a very low probability of

3. PILOT EVALUATION

The primary objectives of the pilot evaluation were to test the training effectiveness of the SB 3614 simulation and to determine the extent to which the simulation is understandable to the user. This section summarizes the results of the evaluation.

3.1 Live Performance Test

The live performance test analysis was the most important in determining the training effectiveness of the SB 3614 simulation. The global measures (solution success and time to solution), expert ratings, and fine-grained errors analyses revealed progressively more detailed information concerning student performance in both the experimental and control groups. Results from each of these analyses are described below.

3.1.1 Global Measures

Ratings of solution success and time to solution for the live system performance test are global measures in the sense that they provide a performance overview. For the test, the mean rates of solution failure were 9% and 7% for the control and experimental groups respectively. Due to the small difference between these rates, no further analysis was performed.

Time to solution comparisons were based on all 133 solutions to the three live performance problems. Mean solution times for both groups are shown in Table 1. A t-test was performed for each problem to determine whether there was a difference between the two groups. For one of the three problems, average solution time for the experimental group was significantly less ($p < 0.10$) than that of the control group.

Table 1

Mean Solution Times (in minutes) for Live Performance Test

Problem	Control	Experimental	Significance
1	14.0	11.6	$p < 0.10$
2	11.7	11.4	
3	10.3	9.3	

3.1.2 Expert Ratings

Analysis of the experts' ratings of student performance on the live system performance test included an analysis of variance

Performance measures for the live equipment test were solution success and time to solution for each problem. Experience with evaluation of live system troubleshooting has indicated that such global measures are not, in themselves, the best measures from which to make comparisons between groups (Johnson and Rouse, 1982a). Therefore, a troubleshooting performance checklist was used to record the step-by-step actions of 39 students (20 control and 19 experimental) solving one particular problem. These checklists were analyzed by four SB 3614 experts who rated each individual student action and then assigned a composite rating to the solution as a whole. A total of 103 control group actions and 113 experimental group actions were rated in this manner. An overall performance rating was then determined using the action-by-action ratings in a manner similar to that described by Johnson (1980).

After completion of the live equipment troubleshooting test, the experimental group was given an opinionnaire. This opinionnaire questioned the students regarding previous computer experience, their feelings concerning the simulation and the generalizability of their SB 3614 training to other equipment.

2.3 Experimental Design and Procedure

As stated previously, two classes of subjects were used in the pilot study. Non-experimental SB 3614 classes receive approximately 12 hours of real equipment troubleshooting practice. Both control and experimental classes received approximately five additional hours of training, for a total of 17 hours of training. Previous experience with training evaluations (Johnson, 1980) suggested that five additional hours of troubleshooting training and/or practice should have a resultant effect on performance. For the control group this five hours consisted of three hours of real equipment troubleshooting practice and two hours of work on a paper and pencil exercise. Experimental group students were given a 1 1/2 hour introduction to the SB 3614 simulation. This was followed by approximately 3 1/2 hours of troubleshooting practice on the simulation.

The program of instruction was not changed to accomodate the experiment, since a requisite of this study was to minimize disruption of normal instruction. Further, instructors were the same for each class so that instructor differences would not bias the evaluation results.

2.3.1 Simulation Training

Following the midterm examination, students in the experimental group completed six sessions of computer practice in a three day training period. The computer-based simulation training was intermingled with the use of real equipment. This arrangement permitted the student to mix practice on high-fidelity real equipment with practice on the mixed-fidelity simulation. Each computer session lasted from 27 to 40 minutes. During the experiment, students solved nearly 700 problems on the simulation for a total of 90 hours of problem solving time. On a per student basis, this corresponds to an average of 23 problems solved in three hours (Approximate time at the learning station was 3.5 hours). The mean solution time was 7.8 minutes with a range of one to 24 minutes.

2.3.2 Performance Measures

Simulation performance data collected included the problem number, time to solution, and a rough accounting of the errors made in working each problem. Diskette space, and other logistical problems related to the Apple, minimized the amount of data collected for each problem.

Post-training data for both groups focused on performance on a live equipment troubleshooting test. In the test, each student was to correctly identify two out of three live system failures in no more than 20 minutes per problem. During the test, 63 students solved 133 live system problems in a 12 hour period.

include the ability to make logical troubleshooting tests and to view a system as a group of interconnected parts. The low-fidelity FAULT section, then, teaches students general cognitive troubleshooting skills.

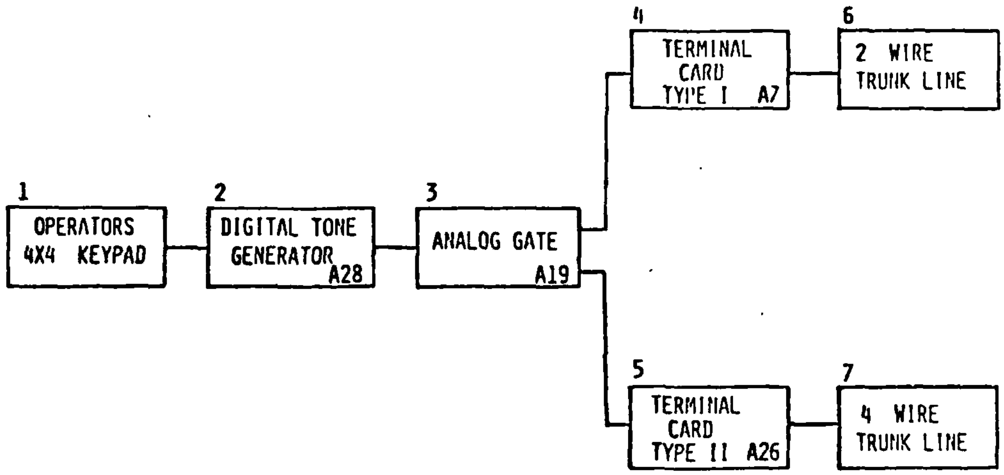

Figure 3. Digital tone generation subsystem.

2.2.3 Documentation

Two user documents are provided for the SB 3614 simulation. These are the Student Manual for SB 3614 and the Instructor Manual for SB 3614.

The purpose of the Student Manual is not only to introduce the student to the simulation, but also to the Apple II computer. All necessary equipment for the simulation is listed in this manual. Further, students are instructed as to the starting procedure for the simulation. Following these preliminaries, the manual explains how and where in the simulation to find problem symptoms. It then describes FAULT in detail. Also included in the manual is a section containing forms to be completed if a student finds an error in the simulation.

The Instructor Manual serves several purposes. The most important function is to provide instructors with materials for introduction of the simulation to the students. For this purpose, the Instructor Manual includes guidelines for integration of the simulation into the program of instruction, a list of points to be emphasized during an introduction of the simulation, and display facsimiles to be used as overhead slides. Another purpose of the manual is to provide instructors with failure information. This information includes a list of the possible failures, an operator's symptom report for each failure, and the failure sequence for each lesson set. The final purpose of the Instructor Manual is to provide instructors with information concerning the use of the instructor program.

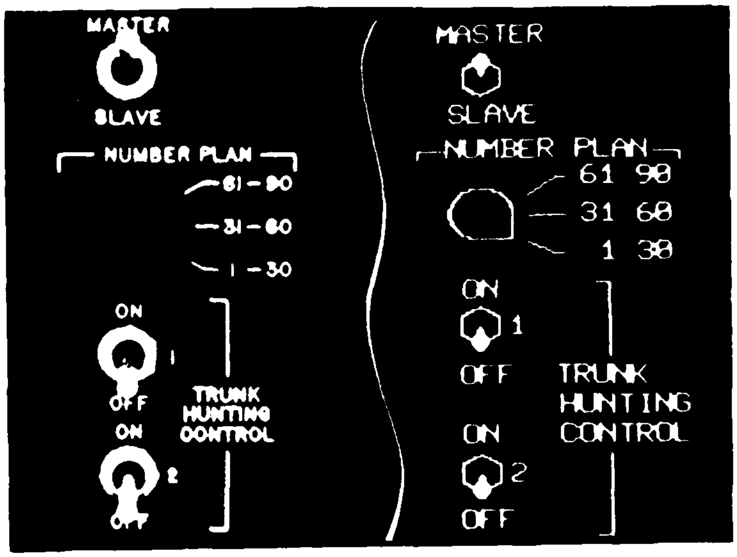

Figure 2. Real and simulated switchboard rear panel.

2.2.2 <u>FAULT</u>

The eighth item in the menu of choices in Figure 1 is System Troubleshooting -- FAULT. FAULT is a direct product of the research base described in Section 1.4. In the FAULT section, students are allowed to view SB 3614 subsystems on a conceptual level using one of seven FAULT subsystem diagrams. With the help of these diagrams, the student may make troubleshooting tests for a subsystem in which a failure is suspected.

Figure 3 shows a FAULT diagram for the Digital Tone Generation Subsystem. The diagram is a low-fidelity representation, since each subsystem component is depicted by a named and numbered box. Relationships between parts are represented by lines between the boxes.

In the FAULT section, students are allowed to make observations between parts, bench test parts, and replace parts. In addition, students may access nearly 60 part descriptions, as well as information on the easiest way to test each component. Further, FAULT aids students in troubleshooting by informing them of errors in logic. When such an error is made, (i.e., testing a known good part) FAULT notifies the student of the error. For more information concerning FAULT, see Hunt and Rouse (1981).

In working a problem with FAULT, a student learns generalizable skills as well as specific SB 3614 information. Specific information learned includes testing procedures and part names, relationships, and functions. Generalizable skills

The simulation stresses the enhancement of cognitive troubleshooting ability over development of manual skills. For instance, the first step a student might take in gathering symptom information is to check the terminal box on the back of the switchboard. To do this on real equipment, the student merely looks at the terminal box on the back of the switchboard. With the simulation, the student must make a menu selection to see the terminal box representation. Further, for real equipment, checking the terminal box connections involves confirming that all connections are pushed securely into place as well as checking that the connections are correct as per the specific telephone system connection chart. With the simulation, however, it is assumed that the connections are already pushed tightly into place. Therefore, the student has only to establish that the connections are correctly positioned.

Another example of the difference between high-fidelity real equipment and medium-fidelity simulation is demonstrated in Figure 2. The left half of Figure 2 shows the real equipment switchboard rear panel, while the right half shows the simulated version. In the simulated version the switches do not move, and the knob does not turn, however it contains all of the important information displayed on the real equipment. In a troubleshooting situation, students merely note the positions of the controls, thus, for the rear panel, all important information is conveyed through a medium-fidelity representation.

Once the symptoms are found and the failure is identified, the student must replace the failed part. Parts may be replaced in the simulation section entitled "Parts Replacement". In this section, a list of parts is presented and the student is required to choose the number of the failed part. In addition, the student must identify the subsystem which includes the failed part.

The fidelity of this section is very low, since only the part names, not their images, are shown. Further, typing the number of a part to be replaced is nothing like physically removing the part from the SB 3614 system and replacing it with a good part. The simulation stresses only the cognitive skill of identifying the failed component, since physical part replacement is a straightforward task.

Eleven t-tests were performed to determine the comparability of the two classes based on the two measures described above. Midterm grades were found to have no statistical difference. One out of the ten ASVAB composite scores was significant ($p < 0.05$). Based on the fact that ten out of the 11 t-tests indicated no significant difference between the two classes, it was assumed that the classes were from the same statistical population.

2.2 Materials

Materials developed for the SB 3614 course included both a mixed-fidelity computer-based simulation and the associated documentation. The simulation has two main sections; a "symptom-finding" section in which students can gather information indicative of failures in the SB 3614 and a section containing FAULT in which students may troubleshoot subsystems of the SB 3614. The simulation, written in Pascal, uses a 64K Apple II Plus, two disk drives, a clock, and a monochrome monitor. Documentation for the simulation includes both instructor and student manuals.

2.2.1 The Simulation

The mixed-fidelity approach lends itself well to simulation of the SB 3614 for several reasons. First of all, medium-fidelity portions of the simulation provide a visual link between the simulation and real equipment. Students readily recognize graphical representations of SB 3614 components and can relate them to the real equipment. Secondly, low-fidelity representations are sufficient to present certain types of information. For example, information concerning the state of a light (i.e., "on" or "off") can often be described in words rather than pictured through graphics. Finally, a mix of fidelity allows the embedding of higher-level problem solving concepts in the simulation. These embedded concepts can then be generalized to troubleshooting of other equipment.

This section describes the SB 3614 simulation with an emphasis on the two levels of fidelity. For a more detailed description of the simulation and its operation, consult the Student Manual for SB 3614 Computer Simulation and Instructor's Manual for SB 3614 Computer Simulation.

The purpose of the computer-based SB 3614 simulation is to allow students to practice troubleshooting SB 3614 failures. In troubleshooting simulated SB 3614 problems, as in solving real SB 3614 problems, the student must first gather information concerning the symptoms of the current failure. Having this information, the student can proceed to check components in suspect subsystems until the problem is solved.

2. METHOD

The mixed-fidelity concept was demonstrated via a computer-based simulation of the SB 3614. Using this simulation, an initial evaluation was performed with two groups of students enrolled in the SB 3614 course. This section presents information concerning the students who participated in the evaluation, the courseware developed, the experimental design for the initial evaluation, and the procedure for the evaluation.

2.1 Subjects

Most students trained on the SB 3614 at the Signal School in Fort Gordon, Ga. are in the Army 36H MOS, the Dial/Manual Central Office Repairer. Soldiers with this MOS have responsibilities related to the installation and maintenance of military telephone exchanges. In order to be accepted into the 36H MOS students are usually high school graduates with above average intelligence and reasonably high Armed Services Vocational Aptitude Battery (ASVAB) scores.

Through informal student interviews, the authors observed that 36H students typically choose this MOS in order to receive valuable electronics training and on-the-job experience that will provide saleable skills in the civilian sector. Thus, students are quite motivated and anxious to develop competency related to installation, operation, and repair of the equipment. This motivation is especially high during the SB 3614 training, which presents students with their first opportunity during the course to use totally solid state equipment. Unlike much of the older electro-mechanical equipment used throughout the training, the SB 3614 equipment represents new technology to the students.

The pilot evaluation was performed with two groups of students. The control group contained 35 students and the experimental group contained 30. The average age of students in both groups was 22 years. Average civilian education of the students was 12 1/2 years.

Two measures were used to determine whether the two groups were matched prior to the experiment. These measures were the ten ASVAB composite scores and class midterm examination grades. Composite scores are combinations of various ASVAB subtest scores. Such data were available for all Army students in the two classes. For more information concerning ASVAB scores, refer to Maier and Grafton (1981).

The midterm is a written test designed to measure the student's overall knowledge of switchboard operation, basic construction, and various subsystem functions. It was administered after the first six days of SB 3614 instruction. Midterm grades were available for all students in the two classes.

designed for portability and for use under rugged conditions. The electronics of the SB 3614 are solid state and represent relatively state-of-the-art technology. The cost of each SB 3614 is approximately $40,000. The equipment will remain as a standard for small systems communications for quite some time. Though it is used by all the branches of the military, the Army and Marine Corps employ the most systems.

aircraft simulators create a highly realistic flying experience through use of motion and of cockpit visual displays. If lower-fidelity simulation could provide some of the same aspects of training as does high-fidelity simulation, then aircraft simulators could be much less costly. The same holds true for any type of simulation.

Full-scope, high-fidelity simulators are potentially effective, in terms of training and cost, for equipment such as aircraft or nuclear power plants. In these applications, the high cost, unavailability, and danger associated with real equipment makes simulation training an absolute necessity. However, many of the knowledge and skill requirements nurtured during training are not necessarily best accomplished through high-fidelity simulation. For example, the pilot trainee does not need a high-fidelity simulator to learn how to use the aircraft's navigational equipment.

Research related to mixed-fidelity training should strive to develop a method to determine the optimal mix of training to capitalize on traditional instructional techniques and the use of a variety of simulation training methods. This project attempts to apply the mixed-fidelity concept to electronics training. The results may be generalized to a variety of technical training environments.

1.5 Selecting Demonstration Hardware

In selecting a hardware system for demonstration of the mixed-fidelity concept, there were a number of considerations. Ideally, the hardware choice would result in the development of needed and useful training courseware while demonstrating and evaluating the mixed-fidelity concept. Therefore the objective was twofold, to satisfy the research-oriented goals while fulfilling operational training requirements.

Consideration of both research and operations missions led to the choice of the SB 3614 tactical switchboard as demonstration hardware. The SB 3614 equipment is relatively new, being introduced into the Army communications hardware inventory in 1976. Therefore, the training developments, if proven valuable, had the potential for extensive use and would serve to justify the development costs. Additionally, the annual number of students trained on the equipment in the 13 day course is quite high, ranging between 250 and 300 at Fort Gordon alone. This high student throughput was especially important for evaluation of the courseware.

The technical manual (TM11-5805-695-12) describes the SB 3614 (V)/TT as a tactical, ruggedized, 30-terminal automatic switchboard. The SB 3614 weighs approximately 65 pounds and has dimensions of 15 inches by 36 inches by 24 inches. It is

A series of ten experiments involved over 300 subjects solving over 24,000 fault diagnosis problems. The details of the experiments are reported elsewhere (Rouse and Hunt, 1984). The first five experiments addressed context-free problem solving. The next three considered the relationships between context-free and context-specific problem solving. The final two experiments studied the transfer of training from the computer simulations to actual live equipment in the domain of aircraft powerplants.

A general conclusion from the experiments was that training for problem solving can be enhanced with computer-based simulation. There was a positive transfer from generalized context-free simulation to context-specific simulation and from context-specific simulation to live aircraft equipment. Further, variations in the types of computer aiding and the types of context-specific information provided during training had an effect on the type of performance errors made during live equipment troubleshooting (Johnson and Rouse, 1982, a and b).

One of the most important outcomes of the early research at the University of Illinois was the concept of mixed-fidelity training. Briefly, mixed-fidelity training involves the identification of a variety of instructional techniques to accomplish the various types of knowledge and skill-related objectives necessary for diagnostic-related training. This concept will be discussed in Section 1.4.

The early work was quite rigorous in terms of empirical evaluation and involved numerous subjects and use of real equipment. However, it did not take place in an operational military training environment. Questions left unanswered addressed the extent to which the mixed-fidelity training approach could be successfully conceptualized, developed, implemented and evaluated at an operational Army school. This project, therefore, sought to answer these questions.

1.4 Mixed-Fidelity Training

While the phrase "Mixed-Fidelity Training" (Rouse, 1982) may be somewhat unique, the notion is by no means a revolution in technical training. The most important attribute of mixed-fidelity training is the conscious effort on the part of the instructional designer to match the fidelity of the training devices to particular instructional objectives.

Fidelity is the extent to which a training device has the appearance and behavior of real equipment. The topic of fidelity has been thoroughly addressed by Hays (1981). The majority of research related to simulation fidelity has concerned high-fidelity aircraft simulators. Because of the potentially substantial cost of high-fidelity simulators in this domain, level of fidelity is a critical issue. For example, some has the potential to alleviate the problem. Finally, the training must be designed and delivered such that there is a reasonable expectation of learning retention.

1.2 Project Goals

This project had several goals, which are listed below:

1. Build upon previous Army-funded research to move the work from the University laboratory into an operational Army training environment.

2. Work with Army electronics training personnel to conceptualize, design, and implement a simulation-oriented computer-based device for diagnostic training.

3. Design an equipment specific training device that also delivers a degree of generic diagnostic instruction.

4. Develop a computer simulation that includes more than one level of fidelity.

5. Conduct a pilot evaluation of the simulation's diagnostic training effectiveness.

The next section describes the evolving research effort that led to this project and offers a rationale for the above goals. In addition, the following sections more clearly define some of the terms introduced above.

1.3 Diagnostic Training Research - Rationale for Continuation

Research concerning the design, implementation, and evaluation of diagnostic-related training programs has a lengthy history and has been repeatedly discussed and reviewed (Johnson, 1980; Johnson, Rouse, and Rouse, 1980; Orlansky and String, 1981; Standlee, et. al., 1956). This section will discuss the work of the authors and their colleagues, since that research established the empirical foundation of this project.

The roots of this applied research at the Signal School of Fort Gordon, Georgia began with ARI sponsored work at the University of Illinois from 1978 through 1981 (Rouse and Hunt, 1984). The research ran the gamut from basic to specific context application for aviation mechanics' training (Johnson, 1980; Johnson and Rouse, 1982 a and b). The extensive empirical findings demonstrated various strengths and weaknesses of the computer-based diagnostic-related training simulations (Rouse and Hunt, 1984).

1. BACKGROUND FOR IMPLEMENTATION OF MIXED-FIDELITY TRAINING

1.1 The Diagnostic Performance Dilemma

Equipment maintenance has placed a heavy burden on financial and manpower resources in all branches of the military (Orlansky and String, 1981). It is generally recognized that the results of ineffective or inadequate troubleshooting of complex mechanical and electronic equipment contributes significantly to the maintenance costs. Inefficiency is reflected in excessive manpower allocation to diagnostic maintenance tasks and excessive erroneous replacement of components that have not failed. The part replacement problem creates the demand for vast spare part inventories and clogs the repair pipeline with non-failed components. Of even greater significance is the fact that deficient diagnostic performance threatens the operational readiness of critical communications systems and other equipment for land, sea, and air uses.

The recent school graduate takes the brunt of the criticism regarding on-the-job diagnostic inability. The standing complaint from the field has been that recent graduates placed in the operational environment cannot troubleshoot. When a maintenance task is diagnostic in nature it is usually the experienced technician who is summoned. The problem is confounded by the in-service course offerings related to troubleshooting. When a special troubleshooting course is offered, quite often a prerequisite to course attendance is a minimum rank or minimum years of experience. This situation creates the conflict that in order to take the troubleshooting course one must be experienced and already know how to troubleshoot.

Various technical schools throughout the Army have the responsibility of providing soldiers with entry-level skills and knowledge for the assigned military occupational specialty (MOS). Since each MOS is responsible for a variety of equipment, it is quite obvious that not every recent graduate is likely to be an "expert" on all equipment in the MOS. It is not atypical for a soldier to be trained on specific equipment in, for example, the fourteenth week of a 40 week course and then not see the equipment again until 20 weeks into the tour of duty. In this example there is nearly a one year delay between training and the demand for on-the-job performance.

Since it is not possible to prevent the delay between training and field performance, other action must be taken to minimize potential performance deficiencies. In many cases the job must be structured to provide recurrent training or review and practice of seldom used skills. Another solution is to provide adequate job aids to prompt refamiliarization with equipment. Embedding training into operational equipment also being true, or a very high cost of testing. Also occurred when a hypothesis was functionally unrelated to the symptoms.

3. Choice of Procedures: Occurred when a student's choice of procedure, including informal procedures, was incomplete or inappropriate with respect to the hypothesis being tested. Also occurred when a systematic procedure was not adopted.

4. Execution of Procedures: Occurred when a student omitted procedural steps, performed steps out of sequence, etc., or committed apparently inadvertent actions.

5. Consequence of Previous Error: Occurred when an error was a logical consequence of a previous error.

The 29 errors were classified using the five error categories. Results of the error classification are shown in Table 2. These results are reported because they are suggestive of the types of results which will be pursued in the formal evaluation. They should not be regarded as definitive results for two reasons. First, as stated in the previous section, there was a difference in the expert action-by-action ratings. This difference raises questions about the experts' understandings of the rating scheme. The second reason is the small sample size. Larger student samples must be examined before definitive results may be obtained.

From Table 2, it is seen that 18 out of 29, or 63% of the errors were committed by students in the control group. This represents 17% (18/103) of the total number of control group troubleshooting actions. Ten per cent (11/113) of the actions taken by the experimental group were rated as errors. In performing a statistical comparison of these proportions (Glass and Stanley, 1970) it was found that this difference is significant at the $p < 0.05$ level. Therefore, in comparing the actions of the experimental and control groups, it can be concluded that a greater percentage of the actions taken by control group students were errors.

Table 2
Fine-grained Error Analysis Results

	General Category	Specific Category	Control	Experiment
1.	Observation of System State	a. incomplete	1	0
		b. misinterpreted	0	0
		c. repeated	3	5
2.	Choice of Hypothesis	a. inconsistent	3	1
		b. unlikely	0	0
		c. costly	0	0
		d. irrelevant	1	0
3.	Choice of Procedures	a. incomplete	0	0
		b. inappropriate	9	5
		c. lack	0	0
4.	Execution of Procedures	a. omission	0	0
		b. other	0	0
		c. inadvertent	0	0
5.	Consequence of Previous Error		1	0

The two types of errors most commonly committed were the repeated observation of state (1c) and the failure to choose the appropriate procedures (3b). More repeated observation of system state errors were committed in the experimental than the control group. The simulation does not penalize students for accessing the same section more than once. Thus, the simulation may not sufficiently stress thoroughness in checking displays for symptom evidence before continuing on to other sections.

Of the total number of errors committed by the control group, 50% were classified as inappropriate choice of procedure. Forty-five per cent of the experimental group errors were so classified. This may reflect a point which needs to be emphasized in the current program of instruction.

3.2 Student Acceptance

The student opinionnaire addressed the three general categories of previous computer experience, simulation instructions, and the simulation itself. Of the 27 students who completed the opinionnaire, all but one had had at least some experience with video games. Thirty-seven per cent of the students used computers in high school and an equal percentage used computers some time after high school.

Every student considered the verbal instruction presentation for the simulation to be either helpful or very helpful. Eighty-one per cent of the students used the Student Manual for additional instructions. All students who used the manual considered it to be either helpful or very helpful.

Every student found the simulation itself interesting. Eighty-one per cent of the students believed that simulation practice helped them in troubleshooting real SB 3614 equipment. Further, 96% believed that the same type of simulation should be used in other 36H courses. Concerning the issue of generalizable troubleshooting skills, 89% said that troubleshooting skills learned through use of the SB 3614 simulation would help in troubleshooting problems in other courses and on the job. Overall, all of the students were satisfied with the SB 3614 computer-based simulation as a classroom learning aid. The final question on the opinionnaire asked for general comments.

3.3 Instructor Acceptance

After the simulation had been used by the experimental group and four other classes, the instructors were formally asked their opinions of the simulation's technical content, ease of use, instructional effectiveness, and implications for the Program of Instruction. In general, the instructors were quite positive about the simulation and all seemed to accept it as a useful instructional tool. The following are specific comments and suggestions for future work with the simulation.

The instructors felt that the simulation provided the same types of information that would be available using real equipment. The FAULT subsystem diagrams were quite helpful for understanding the subsystems of the switchboard. In fact, some of the instructors contemplated using the simulation's FAULT drawings as training aids for teaching logical and functional relationships of parts in the various subsystems.

Concerning ease of use of the simulation, it was noted that students could learn to use the simulation with an instructor's introduction supplemented with consultation of the Student Manual. Instructors found that their introductions were most effective when they included a demonstration of the simulation. They commented that the FAULT section was the most difficult portion to explain, but stated that the FAULT subsystem diagrams were helpful. It was suggested that a 15 to 20 minute video tape be made for introduction/demonstration of the simulation.

The instructors observed that students enjoyed the challenge of simulation problems but were frustrated by the relatively long computer execution time, particularly during disk access. This problem could be alleviated with the use of a more efficient and larger storage element such as a Winchester hard disk drive and with increased RAM.

The instructors were reluctant to suggest that simulation practice could replace real equipment practice. They indicated that they wanted more course time to allow them to increase the complexity of the real equipment problems.

All instructors felt that the simulation should become a part of the SB 3614 Program of Instruction. They also commented that the ideal number of hours of simulation use had not been determined but this issue can be resolved in the future.

In summary, the instructors were very supportive of the simulation and recommend its continued use. There are certain segments of the simulation that could be modified and certainly the computer hardware should be slightly enhanced.

3.4 Summary of Statistical Results

The results of the pilot evaluation suggest that live system troubleshooting performance is the same with additional training with the SB 3614 simulation as it is with additional real equipment training. Based on the performance measures of solution success and time to solution, the experimental group performed as well as the control group on the real equipment test. Regarding the quality of the troubleshooters' methods, especially with respect to the number of errors made, the experimental group had better performance.

For the global measures, the experimental group solved one problem out of three in significantly less time than the control group. There was no difference in the number of solution successes between the groups.

When there were significant differences in experts' ratings of individual student performance, the experimental group was rated significantly higher than the control group. Two experts gave significantly higher composite ratings to students in the experimental group. On an action-by-action basis, actions of students in the experimental group were rated significantly higher than those of the control group.

A significantly higher percentage of the control group's actions were considered to be errors by the experts. More data must be gathered before any conclusions concerning errors may be drawn.

Student response to the simulation as recorded via the opinionnaire was very positive. Students, both with and without video game and computer experience, found the simulation interesting. They also believed that the training method used in the simulation would help them troubleshoot other equipment and that the same type of simulation should be used in other courses. The students that used the Student Manual found it to be helpful. Overall, students were satisfied with the simulation.

4. CONCLUSIONS AND RECOMMENDATIONS

This section provides conclusions and recommendations that are specific to this project, and others that are meant to be generally applicable to conceptualization, design, implementation, and evaluation of computer-based training systems.

4.1 Simulation Strengths

Generally, the project's pilot evaluation showed that a microprocessor-based, mixed-fidelity simulation can be successfully integrated into an Army electronics course. The computer simulation can have a positive effect on student troubleshooting performance. While the simulation was of low to moderate fidelity it presented challenging troubleshooting practice that was well received by the students as well as the instructors.

The results from a pilot test cannot be considered as conclusive evidence. However, the preliminary data suggest that simulation-based training intermixed with real equipment practice may be more desirable, in terms of post-training troubleshooting performance, than use of real equipment exclusively. Since many aspects of real equipment troubleshooting are cognitive, involving mental processing of displayed symptomatic information, there is not a great need for high-fidelity hardware. In fact, computer-based, mixed-fidelity simulation has the potential to present considerably more troubleshooting practice than does real equipment. In addition, the computer can keep records of student performance, provide appropriate feedback regarding errors, and permit a student to work independently at a personalized pace. The computer simulation can also provide a framework for generalized troubleshooting while delivering equipment specific diagnostic experience.

Another very important aspect of simulation-based diagnostic training is its interactive nature. The simulation permits the learner to actively engage in problem solving without the fear of personal injury or damage to the expensive real equipment. This heavy emphasis on learner involvement is of significant instructional value and cannot be overstated.

4.2 Simulation Weaknesses

The pilot evaluation exposed a few problems that can be corrected. The shortcomings of the SB 3614 simulation were primarily attributable to microprocessor hardware constraints and did not seem to have a significant effect on the simulation's training effectiveness. The nature of the simulation design resulted in a situation where the computer hardware was taxed to its limit in terms of RAM and disc storage. As previously mentioned, approximately 98% of system capacity was used. The result, as expected, was relatively slow loading and execution time for certain segments of the simulation. Since the entire program was too large for RAM, program segments were loaded only when requested. Increasing RAM would have alleviated the problem slightly, however access time would have remained high due to the nature of the 8-bit machine and the use of the high-level programming language rather than assembly language. Other shortcomings related to memory, storage, and access were the inability to select and use special purpose keys (like "help") and long delays while information for each new screen was retrieved from the disc. Both of these problems stemmed from insufficient memory.

The resolution and quality of the color graphics was another significant shortcoming. Color graphics would have made the simulation more attractive to the student user. While color graphics may not have affected the information transfer from the display, it may have enhanced the student's enthusiasm towards using the simulation. The poor quality of text written on the graphics screen prohibited the use of color graphics for this project.

Another problem related to the use of microprocessor hardware was data collection. The limited storage capacity of the standard diskette made the logistics of data collection rather tedious. While these problems could be alleviated with a hard disc, the systems used for this project were not so equipped.

There are a number of solutions to the hardware deficiencies which can be briefly mentioned. The final choice, of course, must be defined by such requirements as the necessary level of fidelity, the need for extensive data collection, the availability of hardware for student stations, and the resources available for courseware development.

The hardware solutions fall into three basic categories. These solution categories are the following: expand the present Apple system; use a 16 or 32 bit computer and have multiple users for each computer; or use videodisc technology.

The first solution, Apple upgrade, would require the necessary peripherals to increase RAM and disc storage, and decrease disc access time. A high resolution color terminal and improved Apple graphics capabilities would also be needed. Another solution in this category would be to convert from Pascal to ASSEMBLER.

The second solution hinges on increased computer power. A larger computer (i.e., 16 or 32 bit) would be much faster in execution time and more compatible to increased RAM and hard disc storage. This system would require a high resolution color graphics terminal for each student station. A mini or super micro, would likely support from three to six student stations as the simulation was configured for this project.

The third solution is videodisc. This technology would require the videodisc player and interface to the micro computer. If videodisc was used it would permit higher fidelity representation of the switchboard than was possible with computer graphics. Further, the videodisc could store all of the pictures that were generated by the program. This videodisc picture storage would reduce the demands on RAM and diskette storage and thus make the personal micro a quite feasible alternative again.

Whatever the hardware choice, the overall effectiveness of a training device is most dependent on the pedagogical considerations and organized systematic design. The training design decisions must ultimately drive the hardware choice.

4.3 Cost Effectiveness Implications

The extent to which the use of computer-based training can be optimally mixed with real equipment practice certainly needs further study. The authors contend that the mix of real equipment and computer simulation training provides excellent instruction for troubleshooting. By exchanging inexpensive microprocessors for a portion of the real equipment units there could be a reduction in training costs. Cost reduction is desirable only if the quality of the training is not adversely affected. In the case of this computer simulation, it may be successfully argued that simulation combined with real equipment practice for a given time period is better than real equipment practice alone for the same time duration. The formal evaluation of training and retention effectiveness planned for the second year of this project will certainly provide a thorough test of this hypothesis.

While hardware procurement is one cost of training, the higher costs are often student and instructor salaries. The computer will not replace the invaluable instructor. However, computer stations have the potential to increase instructor efficiency. In a normal, real-equipment troubleshooting laboratory, one very busy instructor may be able to supervise ten students. With the ten to one ratio, students may find themselves waiting to receive their portion of instructor attention. It is reasonable to expect that class size could be expanded as the number of computer-based work stations is expanded. Of course, the number of added work stations would depend on a variety of economic and organizational tradeoffs, the resolution of which was not part of the work reported here.

4.4 Summary

The SB 3614 software/courseware has been developed and implemented at the Signal Center. Preliminary analysis indicated that the additional computer-based experimental training resulted in post-training troubleshooting performance comparable to that achieved through additional real equipment practice. The simulation is acceptable to the instructors and to the student users. On-going evaluation and modification to provide continuing support to the SB 3614 simulation should be established. Such support will guarantee the continued use of this courseware and open the way for additional developments in areas of need.

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