Generalized Virtual Simulations for Adaptive Maintenance Training

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ABSTRACT

There is a growing need for system maintainers to apply general principles for using an array of Test, Maintenance, and Diagnostic Equipment (TMDE) with common functions to diagnose a variety of equipment with common capabilities and faults. In the current operating environment, different versions of equipment may be in use in a single unit. Also, units may be falling in on different equipment versions than were used for their training. If the system maintainers do not understand the functionality of the diagnostic equipment available to them in the field for the weapons systems in their units, then unit readiness suffers and logistics costs rise.

Traditional maintenance training is designed for a specific weapons system using the TMDE allocated to that system. This task-based knowledge is not easily transferrable, and novice unit maintainers have not adapted to different equipment in the operational environment. Stringing together separate training for each possible system that the maintainers might face in the field is not an acceptable approach due to constraints on training schedules.

This paper describes an alternative process that combines acquiring skills and deliberate practice in virtual environments on generic equipment with familiarization on multiple versions of specific equipment. This approach can reduce the overall training time by investing in repeated practice on common skills with generic equipment and then providing familiarization with the different variations in TMDE and weapon systems. Examples will include variations and commonality in the operation and maintenance of tactical generators and Force XXI Battle Command Brigade and Below (FBCB2) configurations in different vehicles.

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INTRODUCTION

There is a growing need for system maintainers to apply general principles for using a variety of Test, Maintenance, and Diagnostic Equipment (TMDE) with common functions to diagnose an array of equipment with common capabilities and faults (Hubal, 2009). In the current operating environment, different versions of equipment may be in use in a single unit. Also, units may be falling in on different equipment versions than were used for their training. If the system maintainers do not understand the functionality of the diagnostic equipment available to them in the field for the weapons systems in their units, then unit readiness suffers and logistics costs rise.

Traditional maintenance training is designed for a specific weapons system using the TMDE allocated to that system. Unfortunately, novice unit maintainers have not adapted to the variations in TMDE and systems in the operational environment. Implemented separate training for each possible system that the maintainers might face in the field is no longer a feasible approach due to constraints on training schedules and the rapid introduction of new system variants (Wilson & Helms, 2003).

Evidence of the Need for Adaptive Maintainers

The U.S. Army Ordnance Electronics Maintenance Training Directorate (OEMTD) performed a skills transfer study involving some 94E (i.e., radio and communications security repairer) and 94F (i.e., special electronic devices repairer) soldiers. Each group of soldiers had to perform maintenance on a SINCGARS radio in a context (e.g., aviation or non-aviation) that was different from what was learned and that used different actual (but functionally equivalent) TMDE, but that otherwise involved the same principles. According to several OEMTD instructors, a large number of soldiers were unable to complete the transfer task.

Adapting to Different Equipment Configurations

The U.S. Army Signal Center recognized the need for adaptive maintenance training when multiple variants of a system are in the field. For example, the Signal Center designed a group of five courses for training tactical satellite ground station operator/maintainers (Waters et al., 2008) on four variants of a tactical ground station: the AN/TSC-85C, AN/TSC-93C, AN/TSC-85D, or AN/TSC-93D. Figures 1 and 2 illustrate some of the differences in the 85 and 93 systems. The 85 is a multi-channel system that is carried on a heavy vehicle, while the 93 is a single-channel system that is mounted on a High Mobility Multipurpose Wheeled Vehicle (HMMWV). These differences in channels are implied by the greater number of the signal entry ports on the side of the shelters. The differences between the C and D models refer to variations in the equipment mounted in the vehicles.

Figure 1. AN/TSC-85C Tactical Satellite Communications Terminal

Figure 2. AN/TSC-93C Tactical Satellite Communications Terminal

The primary objective of the tactical satellite operator/maintainer courses is to train adaptive soldiers who can install, operate, and maintain multiple TACSAT terminal configurations.

VIRTUAL MAINTENANCE TRAINING

The Signal Center's tactical satellite operator/maintainer courses required a maintenance training simulation running on a personal computer that could support the following:

- Residential training for qualifying satellite ground station operator/maintainers.
- Sustainment training for Reserve and National Guard units that were using different equipment versions than active-duty units.
- New equipment training for units that were upgrading from the C version to the D version ground station.

The Signal Center required a virtual operator/maintainer environment that supported deliberate practice of installation, diagnostic, and operation skills for multiple vehicle configurations and TMDE. Figure 3 shows a typical virtual maintenance training application, where the learner (i.e., student) is practicing with cover between two generators for a satellite ground station. The high voltage and current levels of the generator make this a dangerous process in a live environment, but one that can be practiced safely in a virtual environment.

Figure 3. Virtual Maintenance Training Allows Soldiers to Practice Dangerous Diagnostic Skills Without Fear of Failure

Benefits of Virtual Training

An established benefit of virtual training is that soldiers become familiar with the equipment in a virtual environment, thereby enabling them to recognize the equipment before they have to perform potentially risky processes in a live environment (Helms, Hubal, & Triplett, 1997). This recognition can instill confidence and provide important visual and audible cues that a soldier is performing a procedure correctly. In addition, this process and equipment recognition allows for significant improvement of the time that it takes for soldiers to perform these procedures.

A second established benefit of virtual training is the potential for deliberate practice of skills (Clark, 2005).

Risks of Virtual Training

Although the realism of virtual environments provides a powerful set of cues to aid students in learning maintenance skills, one risk of using a virtual environment based on a single system variant or tool set is that students will become dependent upon the cues provided by the system or tool and be ineffective with other systems and tools or in other situations that are not explicitly covered by the training scenarios. This risk places a burden on instructional designers to develop virtual training methodologies and practice scenarios that train adaptive operator/maintainers.

TRAINING ADAPTIVE MAINTAINERS

The U.S. Army Training and Doctrine Command (TRADOC) has adopted the Familiarize, Acquire, Practice, and Validate™ (FAPV) methodology to provide the incremental development of the skills and knowledge required of the target audience (Frank et al., 2003). This methodology provides opportunities for training adaptive maintainers. The Signal Center uses the FAPV training methodology for MOS 25U (signal support systems specialist) qualification, as well as MOS 25S (satellite communication systems operator/maintainer). These training courses are typically divided into modules for System Overview; Install; Power Up; Preventive Maintenance, Checks, and Services (PMCS); and Troubleshooting.

We have focused on developing measures and tools for estimating the coverage of training requirements by different combinations of lessons. This analysis benefits the learner by ensuring exposure to different environments while limiting the number of lessons that the learner has to take. This allows the training to reward skilled students with shorter training times while providing less-skilled students more time for practice on basic skills.

Familiarization with System Variants

Familiarization Mode lessons provide the learner with a free-play virtual environment to explore the systems that he or she is operating and maintaining. These lessons also provide guidance in terms of the terminology used for these components and the definitions of the functions of these components.

The MOS 25U training covers the Force XXI Battle Command Brigade and Below (FBCB2) system and its various configurations in multiple vehicles. For the FBCB2 maintenance training, different virtual environments were created for variant installations of the system, but only one interactive practice simulation was created for the Install module. Figures 4 and 5 show the SINCGARS radio systems in two different vehicle configurations. In Figure 4, the two SINCGARS radios of the FBCB2 system are shown in a HMMWV retransmission vehicle. The same radios are in the center of Figure 5, but are in a Stryker command vehicle environment.

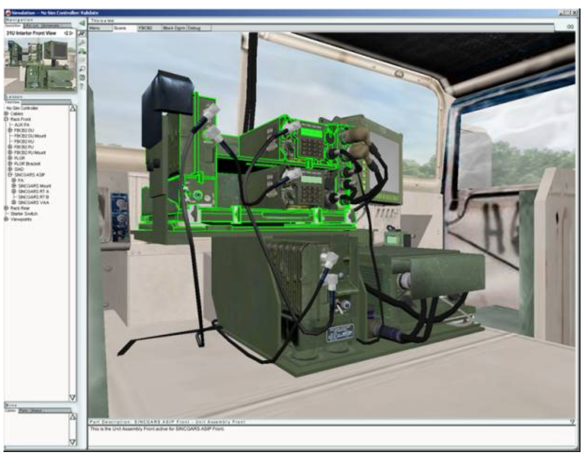

Figure 4. Familiarization with SINCGARS Radios as Components of an FBCB2 in a Retrans Vehicle

Selected Scenarios for Acquiring Skills

The 85/93 tactical satellite course includes the modules listed above, as well as a Link Establishment module. For each module, lessons are arrayed across the FAPV modes and cover the different system versions. Acquire Mode lessons walk the learner sequentially through each step of the procedure being trained. For the tactical satellite course, the power-up process is taught using the 85C and 85D systems; however, the learner can practice the power-up process on any configuration. Once the learner has learned a power-up procedure in an 85 terminal (the larger of the two), that knowledge can be transferred to a 93 terminal because the terminals use the same components, but the 85 terminal has more copies of some components. There are, however, major differences in the components and also the power-up procedures of the C and D model terminals; thus, they have separate Acquire Mode lessons.

Figure 5. Familiarization with SINCGARS Radios in a Stryker Command Vehicle

Deliberate Practice in Multiple Environments

The maintenance training systems described here can randomly select the next practice lesson from a library of similar scenarios. All the scenarios in a library have the same learner assessment criteria, but vary the vehicle configurations, required frequency or network specifications, or initial fault conditions. The learner is required to pay attention to the environment to recognize these changes. For example, the frequency and network requirements for establishing a satellite communications link are specified in a cut sheet that is provided as a tab in the simulation. The learner must understand what information is presented where in the cut sheet and must also know how the cut sheet specifications change the settings that are required in the equipment. This type of situational awareness is critical for adaptive maintainers, just as it is for adaptive leaders (Tillson et al., 2005).

Exams to Validate Adaptive Skills

To validate adaptive operation and maintenance skills, the Validate Mode lessons in the 85/93 operator/maintainer courses (or performance exams) require that the learner demonstrate different skills on all four system variants. Although the exams are selected randomly from a library of scenarios, they always include scenarios from each of the modules and scenarios for each of the vehicle variants.

GENERALIZATION AS AN EXPERT SKILL

Research on the effectiveness of learners in transferring knowledge from one type of problem to another has shown the need for both specific contextual and conceptual information in the learning process. Key conclusions from the National Research Council's *How People Learn* publication on learning transfer research include the following:

- Skills and knowledge must be extended beyond the context in which they were learned to be transferrable to other situations.
- Transfer is facilitated when learners understand how problems are similar and different. Developing a knowledge representation of the relationship of the parts to whole is instrumental in this comparison.
- Learning must be based on principles because rote memory rarely is transferrable.

Experts' abilities to transfer knowledge from one situation to another to solve problems are based upon how they organize information and their mental representation of the problem (Bransford et al., 1999).

An Experiment on Knowledge Representation of TMDE

Design principles for virtual training of adaptable maintainers are informed by research on knowledge representation about TMDE by experts and novices.

An experiment to elicit the knowledge representation used by novice and expert maintainers was conducted with the U.S. Army OEMTD located at Ft. Gordon, GA (Hubal, 2009). The intent was to model the structure of knowledge and skills exhibited by electronics maintenance personnel and to identify differences between experts' models and novices' models of TMDE. This research was motivated by the lack of adaptive thinking by newly qualified electronic system maintainers.

Experiment Design

The experiment surveyed a total of 83 participants. Twenty-one novice participants had just begun the basic electronics course and were residents at Ft. Gordon for only a few weeks. Thirty-nine intermediate participants were already part-way through their MOS-specific training and had been residents at Ft. Gordon for an average of about 4 months. Twenty-three expert participants were OEMTD instructors and Warrant Officers with years of operational experience, including deployment experience. The experiment classified these experts into three different types. The first type of experts, labeled "diagnosticians," grouped test equipment based on the outcomes of using test equipment. Experts of the second type, labeled "appliers," grouped the test equipment based on the systems being diagnosed, such as for radio communications versus radar applications. The third type of experts, labeled "functional," grouped the test equipment based on its function.

For the intermediate and expert participants, the focus was on three MOS: 94E (i.e., radio and communications security repairer), 94F (i.e., special electronic devices repairer), and 94R (i.e., avionic radar repairer). All data gathering occurred at Fort Gordon.

The research team generated an initial list of 53 possible stimulus items that included three types of items: TMDE identifiers (e.g., OS 303/G), TMDE descriptors (e.g., oscilloscope, power meter), and diagnostic functions (e.g., voltage measurement, power measurement). Data were gathered using an online tool that allowed the participant to drag and drop from a list of stimulus items into participant-generated (i.e., open sort) categories.

Results of the Experiment

The results of this research verified that novices classify TMDE in terms of names and visual characteristics, while experts categorize TMDE in terms of functions of the equipment and how the equipment is used for troubleshooting. The categories used by the different types of experts (i.e., diagnosticians, appliers, and functional) suggested different approaches for training adaptive maintainers.

TRAINING TO GENERALIZE

Referencing General Maintenance Concepts

Training adaptability requires training the learner to recognize common concepts presented in varying circumstances. These common concepts provide guideposts to help the learner adapt to unfamiliar circumstances. Below, we discuss two types of common concepts: maintenance processes and diagnostic principles.

Training Common Maintenance Processes

A common high-level structure for troubleshooting and maintenance of equipment is the following high-level structure for the task:

- Validate the fault
  - Diagnose the fault that caused the symptoms
  - Isolate the fault to contain any damage or side effects and to narrow the possible fixes

- Fix the root cause
- Validate that the fix eliminates the symptoms.

These process steps provide natural "chunks" that allow learners to assimilate concepts gradually into their mental models (Ambrose et al., 2009).

Training Common Diagnostic Principles

An important aspect of training adaptable maintainers is showing how basic laws of physics can be used in many maintenance situations. Recent research emphasizes the need to interleave practical applications of the laws of physics with education on those laws (Rittle-Johnson and Koedinger, 2009).

An early research project on using virtual reality on a personal computer for maintenance training posed a diagnostic problem based on Ohm's law (McMaster Grantlin, & Holloway, 1997):

$$E = I * R \quad (1)$$

The fault to be repaired was a frayed battery cable in a 1957 Chevrolet automobile (see Figure 7). The initial information provided to the learner was that the car will not start. However, the learner can test that although the starter will not turn over, the radio works. The learner must combine tacit knowledge (the radio requires less current than the starter motor) with Ohm's law (the fraying increases the resistance in the cable) to find the problem, replace the cable, and then validate that the car starts. An after-action review (AAR) of a learner's performance links the learner's correct actions first to the process and second to the diagnostic tests that are suggested by Ohm's law. The challenge for the instructional designer is grouping the practical exercise scenarios with the basic principles that they illustrate.

Figure 7. Frayed Battery Cable in 57 Chevy Virtual Maintenance PC Simulation

A similar form of generally reusable concept was used in the maintenance training for the strategic satellite ground stations (Cooper et al., 2004). These satellite systems have built-in redundancy, with different forms of redundancy used in different subsystems. This redundancy is designed to mask faults so that they do not prevent the system from functioning. However, the masking makes the identification, isolation, and verification of the fault difficult. Therefore, common process themes are the following:

- Finding appropriate ways to defeat the redundancy to detect and isolate the fault.
- Ensuring that the redundancy is restored at the conclusion of the maintenance process.

The training simulation reinforced these concepts as part of preventive maintenance lessons, with scenarios where the system is functioning but the redundancy has been defeated, making the system vulnerable to single faults.

Lesson Sequencing

The military typically uses the concepts-before-procedures (i.e., concepts-first) training approach, where domain principles are taught for an extended focused period prior to procedural training on a particular system. However, recent research is challenging the concepts-first lesson sequencing advocated by some cognitive theories. This research examined the ability of math students to gain and transfer knowledge using a concepts-first approach compared to an iterative concepts-procedural approach. When the students iterated between concepts and procedural lessons, they developed a greater knowledge of the arithmetic procedures, including the ability to transfer that procedural knowledge to new novel problems. As the authors note, these results were "impressive given that all participants completed the same lessons; only the order of lessons differed" (Rittle-Johnson and Koedinger, 2009).

Experience with the FBCB2 training system supports the sequencing strategy of interleaving concepts and applications (Frank et al., 2004). For the Install module lesson, learners interleaved an abstract block diagram lesson (e.g., compare the cable connections in Figure 7 with the virtual cables shown in Figure 4) that focused on an abstract view of cable connectivity and a realistic simulation in a virtual environment that was specific to the HMMWV.

We have been developing an Intelligent Tutoring System (ITS) that interleaves conceptual and procedural lessons to help facilitate the transfer of knowledge. The basic concept is to link conceptual lessons to the critical tasks or performance measures that are assessed during practice lessons on maintenance procedures. These conceptual lessons are used to remediate specific tasks or performance measures. For example, the FBCB2 is a system of systems, including a global positioning system (GPS), multiple radio components, and a computer. An end-to-end, power-up practice lesson will include assessment of performance on critical tasks for each of the components. If a learner succeeds in initializing the PLGR GPS unit but does not succeed in establishing communications with the SINCGARS radio, then a conceptual lesson on SINCGARS radio operational concepts is recommended to the learner. This interleaving of conceptual and practical lessons is facilitated by "chunking" a long lesson into shorter sequences, as discussed below.

Choice of Scenarios for Interaction

The FBCB2 prototype incorporated a lesson-chunking method in which longer procedural lessons were sub-divided into smaller teachable components. This has been expanded into a current research effort that focuses on the use of an Intelligent Tutoring System (ITS) that dynamically sequences the lessons based upon an assessment of a learner's progress within the training. Key to effectively mediating student learning is the ability to identify which student errors are due to an inability to generalize experience or a lack of procedural understanding and then providing the appropriate remedial lessons.

Research has established that "chunking" training is effective in getting the learner to internalize the knowledge and transfer the skills from the training environment to the operational environment (Ambrose et al., 2009).

Educational Scaffolding

Visual representation of information is an import aspect of linking the conceptual and procedural learning. For example, a schematic is an abstraction of the relationship of components within complex systems. A block diagram is an abstraction of the system at a higher level. Figure 8 shows how this concept abstraction method could be used so that learners installing the FBCB2 components could view the linkage between the block diagram and virtual equipment. In this case, as the learner connects the processing unit, he/she is able to see that component highlighted in the upper left corner.

Another aspect of developing this linkage between the principles of operations and the applied procedural training is inclusion of interactive smart books as a mechanism for providing context-specific information. The purpose of the smart book is to provide background material for the student to access to assist in the completion of the training. The smart book contains information, such as doctrine, standard operating procedures, examples, diagrams, and technical specifications, which is organized into categories to facilitate quick access. This type of information becomes more meaningful to a student the in context of working through solving a problem.

Both of these mechanisms can be extended to effectively train generalized maintenance skills to novice soldiers. A linked taxonomy of the novice and expert knowledge representations would allow the novice to identify the equipment and procedures in a manner that conforms to his/her knowledge categorizations while moving the novice more quickly to identifying the equipment in ways similar to the expert.

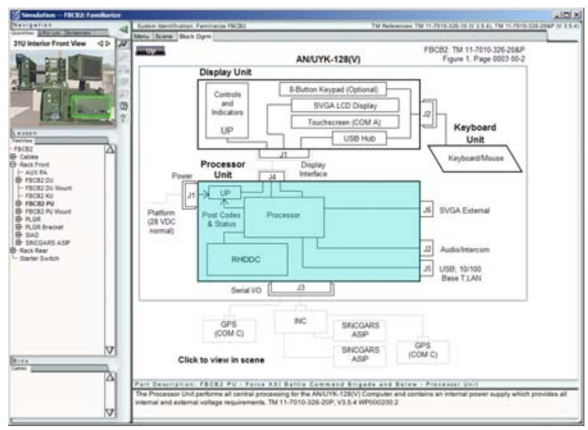

Figure 8. Block Diagram from FBCB2 Install Practice Lesson

After-Action Review (AAR) Visualization

A common formalism for diagnosis or troubleshooting is a diagnostic decision tree. Kizakevitch et al. (2007) describe using diagnostic decision trees as a visualization for AARs that compare student diagnoses with diagnoses prepared by Subject Matter Experts. Figure 9 shows an AAR for triage, with the school solution on the left and the student solution on the right. The student has made the correct first decision, but has not progressed to the appropriate leaf of the decision tree. This AAR visualization links student actions to the general diagnostic concepts that are the basis for adaptable maintainers.

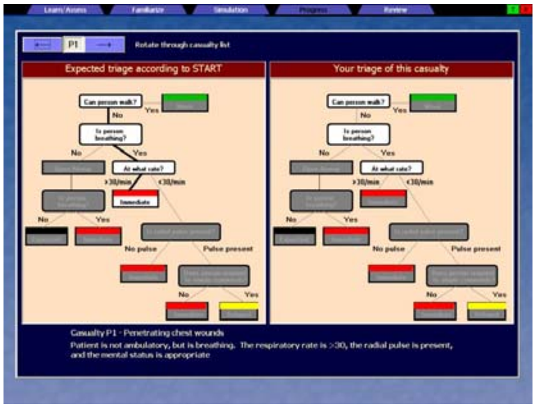

Figure 9. After Action Review Visualization Using Diagnostic Decision Trees

CONCLUSIONS

There is a growing need for adaptive system maintainers who can apply general principles for using a variety of diagnostic tools (i.e., TMDE) with common functions to diagnose a variety of equipment with common capabilities and faults. This observation is supported by experimental evidence collected by OEMTD that indicated that maintainers were having difficulty using TMDE available in their operational assignments that was not used during their training.

Instructional designers face many challenges in developing succinct, cost-effective training for adaptive maintainers. Designers need to provide training across the variety of equipment and tool sets that are in use in the field and to train maintainers to deal with a broad range of faults in a limitless set of environments. In addition, they need to train maintainers to apply common procedures and use the universal principles of physics to deal with unfamiliar situations. Finally, they need to provide effective training for maintainers with a diverse set of skills, ability, and experience.

In this paper, we have presented several strategies that can help instructional designers meet those challenges. We also have described how the FAPV-distributed training framework can be used to facilitate these strategies. Finally, we have described how to incorporate rules into an Intelligent Tutoring System that will enhance adaptive maintenance skills.

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