# Infusing Simulations with Expert Mental Models, Adaptivity, and Engaging Instructional Interactions

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## ABSTRACT

While many simulation-based training systems focus on following procedures, experts report that when they follow procedures, they apply their conceptual knowledge of the system to assist them. This conceptual knowledge, often referred to as a mental model, helps technicians overcome confusion from ambiguous instructions, reinforces information in the procedures, assists in recovering from mistakes, and provides a functional understanding of the equipment in case technicians need to troubleshoot. Psychological studies show that conceptual knowledge can lead to greater accuracy in following procedures. Thus, for procedural tasks, training should incorporate the underlying conceptual knowledge and help students to build accurate mental models.

This paper will illustrate how a simulation that was designed to train procedures was enhanced to foster the development of mental models. First, we worked with experts to determine the mental models that should be taught. Second, we designed the instruction to be adaptive so that students only got the content that they needed. Otherwise the instructional content is an unwelcome and unhelpful interruption. Third, we designed the instruction to be interactive to engage students in the construction of their own understanding.

This paper will report formative and summative results from a study comparing the performance of technicians using the standard procedural training system and a training system enhanced to train the conceptual knowledge as well. Students using the enhanced training system scored 24% better on post-test performance, even though the additional time for the training only increased overall training time by approximately 1%. The study was conducted over a 12 day instructional block, and produced a 1.3 standard deviation improvement on the post-test, which was statistically significant, $p < .05$.

## ABOUT THE AUTHORS

**Robert Pokorny** has worked primarily in the areas of instructional environments and simulation since graduating with a Ph.D. in Experimental Psychology. His first post-graduate experience was at the Air Force Research Laboratory, where he focused on simulation-based Intelligent Tutoring Systems and cognitive task analysis for expert systems. At Intelligent Automation, he has worked on visualization instruction, and directed projects in simulation-based battlespace information training systems for teams, integrated content development and knowledge management, assessments of cognitive readiness from cognitive process and from simulation-based assessments.

**Jacqueline Haynes** is co-founder and Executive Vice President and Director of the Education and Training Technology Group at Intelligent Automation, Inc. Her background combines education and psychology with artificial intelligence applications. She received her Ph.D. from the University of Maryland in Curriculum and Instruction, and did post-doctoral work there in artificial intelligence and intelligent tutoring systems. Previously she was a faculty member at the University of Maryland, College of Education. Her research interests include research-based instructional design, tools for Web-based instruction, and reading comprehension.

**Sherrie Gott** is a cognitive/educational psychologist with over 25 years experienced in (a) analyzing expert and novice performance in complex domains, (b) developing tools for assessing cognitive processes in such environments, and (c) developing tutoring systems based on principles of artificial intelligence to accelerate the acquisition of complex skills. At the Air Force Research Laboratory, she led a project which led to field testing of one of the first large-scale Intelligent Tutoring Systems, Sherlock. She received her Ph.D. in Educational Psychology from the University of Texas at Austin in 1979.

**Michelene Chi** is a psychologist who has studied conditions that foster learning. Currently she is a professor at Arizona State University. Michelene Chi is a psychologist who is a Foundation Professor at Arizona State University's Mary Lou Fulton Teachers College. She is also the Director of the Learning Sciences Institute at ASU. Her research focuses on understanding how students learn difficult science concepts; finding ways to promote students' engagement with learning materials by defining 4 levels of "active learning," and providing concrete ways for teachers to enhance their activities from one "active" level to the next higher "active" level of engagement.

**Mary Hegarty** has been on the faculty of the Department of Psychological & Brain sciences, UCSB since 1988. Her research is on spatial thinking in complex activities such as comprehension, reasoning and problem solving. Her current research projects include individual differences in navigation, the roles of internal and external visualizations in reasoning about physical systems, and the use of visualization versus analytic problem solving strategies in scientific problem solving. Her current research is funded by the National Science Foundation. Mary Hegarty received her Ph.D. in Psychology from Carnegie Mellon University in 1988.

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Students can learn from simulations in which they safely practice difficult and dangerous tasks. Students can learn more when the simulation is part of a training system that not only provides a practice environment but also provides instruction that is tailored to a student's needs. For example, while a student is practicing tasks in a simulation, the training system can also present instruction to teach underlying conceptual knowledge to support good decision making. This paper describes design principles for transforming a procedural simulation-based practice environment into one that fosters development of mental models. The transformed environment leverages expert mental models, is adaptive to student needs and engages students in instructionally efficient interactions.

The use case we will examine to showcase these design principles is maintenance training. Simulations for maintenance technicians provide a practice environment for executing and learning maintenance procedures. Simulations mimic the real environment; technicians practice executing procedures on the simulation that they will later execute on the real equipment. Training environments for technicians include classroom instruction and practice on equipment and/or simulated equipment. In our work, we investigated how to enhance the simulation-based practice environment so technicians could learn how to visualize and conceptually understand the operation of the equipment and the corresponding maintenance procedures.

Applying instructional theory to develop training for simulations is a complicated design process. The same principles applied in different contexts would result in very different training. Job requirements, simulation capabilities, and training context affect how training simulations should be designed.

1. The nature of performers' jobs. Do the performers need to execute steps automatically and with great speed? Is their job solely to follow rules? Is their job to make decisions in accordance with principles?
2. The capabilities of the simulation. Does the simulation allow the student to explore the environment? Does the simulation force students to perform steps correctly?
3. The structure of the comprehensive training environment. Does the simulation supplement classroom or practical training on a real device? Is the simulation the primary teaching platform?

An effective learning environment incorporating simulation-based training (SBT) can be designed by following some simple guidelines: (1) Include conceptual models to support learning with understanding; (2) Adapt the learning environment to student learning requirements, and (3) Develop rich instructional activities that engage students and extend the learning beyond experience of the simulation. We have applied these guidelines to enhance a specific practice environment. The effectiveness of the learning environment is discussed based on results from formative and summative evaluations. Lesson learned and how they can be applied to designing future simulations and training requirements will be discussed.

## THEORETICAL APPLICATIONS OF LEARNING SCIENCES TO SIMULATIONS

Student learning is affected by how a SBT environment (a) focuses on conceptual understanding, (b) adapts to student needs, and (c) engages students in instructional interactions that help them construct their knowledge.

### Learning With Conceptual Understanding

Do technicians need to have mental models to visualize and understand the equipment they work with? To answer this, we look to learning theory, psychological studies, expert technicians' observations, and current maintenance practice.

In *How People Learn* (Bransford, et. al, 2000), sponsored by the National Academy of Science, the authors point out how "learning with understanding" aids performance: it helps students know when to apply their knowledge; and it helps students transfer knowledge from one environment to another.

Psychological studies also support that learning conceptual knowledge and building mental models helps performers follow procedures. Smith and Goodman (1984) compared the value of providing users only procedural steps, and procedural steps with supporting conceptual knowledge. They reported that participants without the conceptual support were more likely to make mistakes that would divert them completely off the correct procedural path. Once this happened, these participants required guidance to recover to the correct procedural path; participants given conceptual support required less intervention to complete the task.

Interviews with expert technicians revealed that they generally find the procedural specification of maintenance activities (frequently Electronic Technical Manuals) very helpful, they can follow the procedures better when the procedures are consistent with their knowledge of the systems and how the systems should be tested. Most practical training programs appreciate the importance of conceptual knowledge and theory, and teach it to support job performance. However they tend to teach it in a disconnected way that does not help students build their own mental models.

In current maintenance practice, understanding the conceptual knowledge behind procedures helps technicians in three ways. First, understanding assists memory when following instructions. For example, if a procedure says "conduct a continuity test between component Power Supply PS2, J15, pin 3 and Signal Processing Computer C5, J2, pin 1," a technician who already knows the components uses that framework to remember the components and jacks, and only needs to remember the pins. Technicians who do not have the conceptual framework must remember pins, jacks, and components. Technicians who rely on memory are more likely to make mistakes (Baddeley, 2002). Second, technicians who know more about the equipment operation and its functions will be able to recover from errors or glitches more easily, as did participants in the Smith and Goodman study (1984). If the procedures do not yield results exactly as specified, or if the technicians need to interpret the procedures, then understanding the equipment and their operation enables technicians to make reasonable next steps. Finally, understanding the concepts of underlying tasks enables technicians to transfer their knowledge to related domains and situations.

### Adaptivity

An adaptive training system changes to suit the needs of students. Such a system will present content that is neither too complicated nor too simple for the learner. In learning theory, this is presenting content within a student's "Zone of Proximal Development" (Murray and Arroyo, 2003). Presenting content that matches a student's current skill level contributes by (a) presenting content that a student needs, and (b) resulting in positive affect, as the student is neither bored nor overwhelmed during the training.

Adaptive training can take many forms, and use multiple levels of sophistication. Some adaptivity is built into a curriculum by adding more complexity as students progress. Some adaptivity mechanisms look at prior performance before assigning more complex tasks. More sophisticated mechanisms monitor performance during training, make assertions about student strengths and weaknesses, and use those assertions to adapt future instruction within a scenario.

### Engaging Instructional Activities

Within a comprehensive training environment, the instructional activities can cover a broad range of complexities. Simple instructional activity examples include experts lecturing students, or students reading lessons. Slightly more complex instructional activities are homework/practice problems, or worksheets in which students answer questions about content. A SBT can provide a rich practice environment but the instruction should also include activities that engage students and help them learn the required conceptual knowledge.

Engaging students in instructional activities for learning is not intuitive to most. The most commonly observed form of instruction is telling someone what they should do or what they should know. For example, if I know something, I normally presume that I can simply tell someone else what I know; naively, I think the person I told now knows what I said. Learning science suggests a more complicated story for producing effective student learning.

Instructional interactions should guide learners to construct his/her own knowledge. A recent framework for studying instructional activities was presented by Chi (2009). Chi's framework distinguishes overt behaviors, which can be observed, from cognitive processes, which cannot be directly observed. We can hypothesize cognitive processes when students are asked to perform specified behaviors. Chi classifies learning activities as (a) passive, (b) active, (c) constructive, and (d) interactive. Passive actions require no response, such as watching a video. Active learning activities require the learner to take actions as a result of the instructional activity. Examples include underlining important sections of text while reading, or manipulating videos to re-watch certain sections. Constructive activities result in new products. To illustrate how constructive learning is more complex than active, consider the example of reading text. Underlining important segments while reading is active; a constructive response would be articulating a summary of a segment. The constructive task results in new products. Other examples of constructive activities are drawing concept maps, taking notes, asking questions, comparing and contrasting cases, or constructing answers to questions. Constructive activities contain information that has not previously been presented to the student. Interactive activities require dialogue between individuals. For a conversation to be interactive, both participants must make substantive contributions. These distinctions are important, as analyses of experiments show that learning increases as the instructional activity become increasingly engaging, from passive to active to constructive to interactive.

Why do more engaging activities help students learn? Constructive learning activities will frequently guide learners to apply processes which enable them to infer new ideas, create new insights, reason analogically, and integrate new knowledge with old. Processes that yield new products allow learners to see new connections they had not been aware of earlier, and lead learners to revise their knowledge structures. Interactive learning activities include constructive processes, and add processes in which a learner constructs new ideas with a partner who is engaged in the same exploration. The discussion produces richer explanations (not simply explanations to oneself, but explanations created with an effort to persuade), and provides exposure and analysis of another's ideas. The intent for a learning system should be to engage the student in activities that yield efficient learning, promoting cognitive processing that increases depth of processing within the limits of the training environment.

The practical goal of instructional activities has three guidelines: First the activities should be deployable in a SBT environment. Second the preferred instructional activities should be as engaging as practical, e.g., aim first for active, then constructive, then interactive. Third, the activities should be affordable. While we have not previously addressed the affordability of instruction, instruction must be affordable, or it will not be selected or implemented.

To summarize, learning environments should support conceptual understanding, adaptivity, and engaging instructional activities. In the next section we discuss how to implement these elements in SBT.

## ENHANCING A SPECIFIC SIMULATION-BASED TRAINING ENVIRONMENT

We applied the learning principles described above to enhance a SBT environment for maintenance technicians.

## Maintenance Training

Before applying the learning principles, we first had to understand the nature of the technician's job and the nature of the maintenance training. We began by interviewing expert technicians to explicate the nature of their jobs and the primary learning challenges they faced.

Technicians in these maintenance jobs follow procedures (sometimes presented electronically, sometimes presented on paper). The simulation provided an environment in which students could practice the procedural steps.

While expert technicians agreed that procedures were normally clear, they also understood that they used their own understanding of the procedures' intent ("the goal of a troubleshooting procedure") and rationale ("the logic of the procedure"). Expert technicians said that when they understood the rationale of the procedures and how tests affected the flow of these procedures, the procedures were easier to follow. However, when technicians did not understand the intent and rationale of the procedures, the procedures were more difficult to follow. Technicians conduct tasks by following procedural steps in conjunction with their own understanding of equipment structure and function.

## Conceptual Knowledge: The Application

While conceptual knowledge is frequently presented to students via lecture or background reading as "theory of operations," it can also be presented within the context of a simulation. Students can learn conceptual knowledge when that knowledge is pertinent to a simulated activity, and made explicit to the student. As an example, consider how a technician might learn about continuity tests. Conceptual knowledge underlying a continuity test can be presented in lectures or background reading. When a simulation is available, the same conceptual knowledge can be presented when conducting a continuity test.

Our aim was to present conceptual knowledge to the student within the context of simulation. Before students use the simulation, training modules are constructed that contain conceptual knowledge pertinent to specific steps of the procedure. When a student reaches a step for which conceptual knowledge is pertinent and modules have been constructed, the training system interrupts the student's flow of executing steps, and presents a training module. After the training module is completed, the training system returns to the simulation, and the student executes the next step. If students hear a concept in the classroom and then see it related in a job-relevant simulation, students can more easily see the connections between theory taught in the classroom and practice.

Thus, in our training, conceptual knowledge will be presented to students in a simulation by interrupting the flow of procedural steps, and presenting relevant concepts.

## Adaptivity: The Application

To adapt content to student needs, the system must track (1) each student's capability with topics that have targeted conceptual knowledge modules and (2) the complexity of the concept in each module. When a student reaches a step of the procedure that has a conceptual training module, the system compares the student's scores on that conceptual knowledge with a score of the complexity of the content presented in training modules. If the student's score indicates that the student knows the content, the content presentation is skipped. If the student's score indicates the student can benefit from the content, the training module is presented.

## Engaging Instructional Activities: The Application

To present conceptual content to students, the learning system begins each instructional interaction with a question to the student. The question is constructed so that answering the question requires reflecting on the intent or rationale of the procedures. The student then compares his/her answer with an expert's answer.

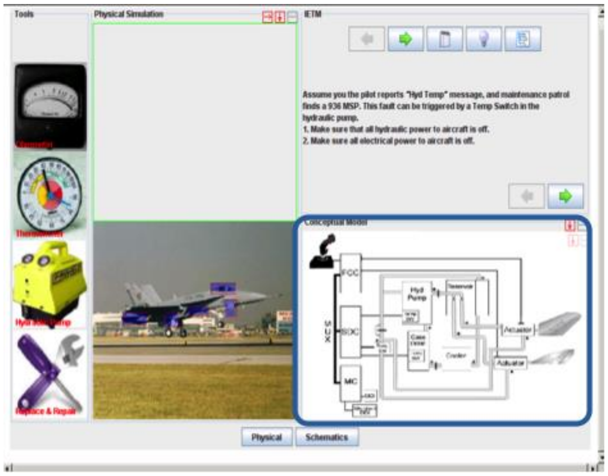
These learning activities focus on content areas that experts have determined to be important. We have generated categories of questions about conceptual knowledge that students need to learn. Further, the format of the interactions has been created. With these formats, developers can focus on the specifics of the content that needs to be presented. Engaging instructional activities are informed by the types of content that students need to learn and use established formats of learning interactions.

## The Maintenance Training Environment

We designed a prototype SBT environment for F-18 maintenance technicians. Many features of the SBT environment are illustrated in Figure 1, which shows the basic windows of a general procedural training system. One window shows the simulated equipment. A second window shows the procedures to be executed. While these are the two basic windows, other windows are available as well. A third window provides access to documentation for the system, including block and schematic diagrams, and principle of operation. This documentation window can be toggled with a fourth view, an expert's mental model of the equipment that is kept up to date given the user's actions on the equipment.

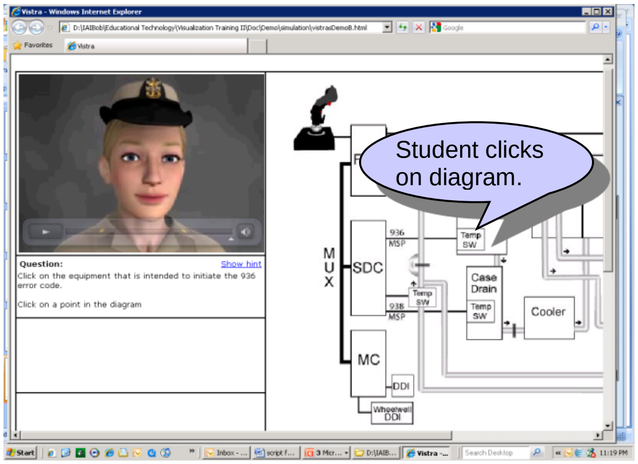
In the training environment, the student executes specified steps on the simulated equipment. Occasionally, the procedures are paused, and the student is presented with a training module. The module leads the student through an activity in which the student constructs an answer. Constructing an answer to a question helps the student develop conceptual understanding of the equipment and how the test procedure works.

The questions can take one of three formats. As shown in Figure 2, the student can be asked to point to some section of equipment which has been described in the question. By considering the question and identifying where to click, the student is constructing knowledge of the equipment. As shown in Figure 3, the student can be asked to provide a text answer. Constructing an answer to open text questions again requires the student to explain a process. As shown in Figure 4, the student can be asked to respond to a multiple choice question and provide a text justification.



Assume you the pilot reports "Hyd Temp" message, and maintenance patrol finds a 936 MSP. This fault can be triggered by a Temp Switch in the hydraulic pump.
1. Make sure that all hydraulic power to aircraft is off.
2. Make sure all electrical power to aircraft is off.

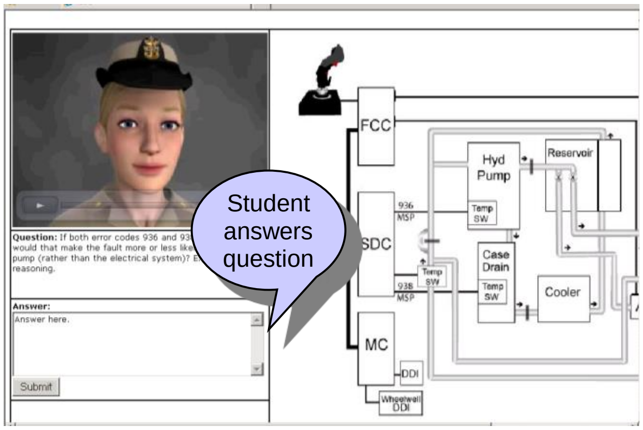
**Figure 1. Simulation with procedures and diagrams**



**Question:**
Click on the equipment that is intended to initiate the 936 error code.

Click on a point in the diagram

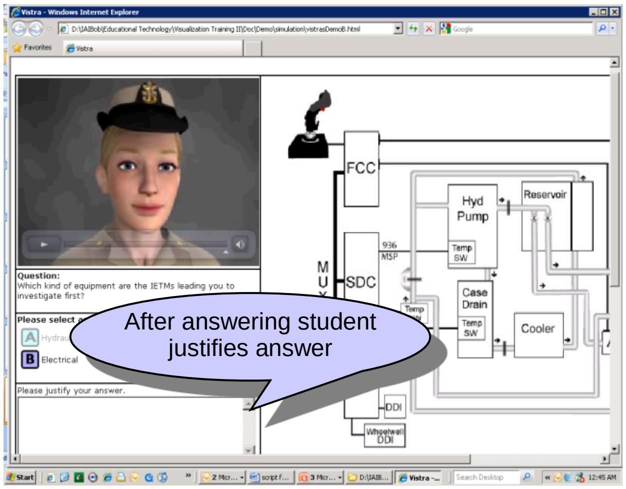
**Figure 2. Training module with hotspot**



**Question:** If both error codes 936 and 93
would that make the fault more or less like
pump (rather than the electrical system)? E
reasoning.

**Answer:**
Answer here.

**Figure 3. Training module with text answer**



**Question:**
Which kind of equipment are the IETMs leading you to investigate first?

**Please select a**
A Hydrau
B Electrical

Please justify your answer.

**Figure 4. Training module with multiple choice answers**

## Practical Methods to Foster Conceptual Knowledge

To develop instruction to foster conceptual knowledge we implemented the following steps:

1. Content was developed by following a routinized interview process. In this process, a SME and learning scientist walked through a maintenance procedure. The process began with the SME dividing the procedure into meaningful segments. The SME drew pictures (at the insistence of the interviewer) to show what was accomplished by each segment. Text descriptions of the function of segments were also collected. These pictures and text descriptions became candidate content for the training modules.

2. For each segment identified in step 1, SMEs and learning scientists created a training module for that segment. Factors considered included (1) Did the segment address the heart of the procedure, or was it ancillary? (2) Would understanding the function in the target process assist performance on the job? Questions to help answer question 2 were “Did technicians have trouble completing this segment?” and “Would the concept considered provide test rationale and intent?”

3. After identifying segments which should have training modules, potential questions were drafted. The questions were typically identified as falling into one of a few categories including:
    a. To what configuration was the equipment set based on technician action (manual or software)?
    b. How did results from a test constrain the fault to a subset of equipment?

4. We considered how many training modules should be presented for each procedure. More training modules provided more learning opportunities. But more training opportunities interfered with completing the task of executing the procedure, which many technicians saw as their primary mission in the simulation. Simple procedures had as few as four training modules. Complicated procedures had up to twelve training modules.

## Practical Methods to Incorporate Adaptivity

An adaptive training system presents training modules only to those students who could benefit from them. To support this process, the training system has “student variables” that reflect a student’s grasp of content. Some variables are module specific; some assess cross-module concepts. In addition to student variables, each module has a variable reflecting module complexity. If the comparison of student variables with the complexity variable indicated a student would benefit from seeing the content, the module was presented; if the student would not be expected to benefit—if the student had previously demonstrated knowledge of the same content, the module was skipped. After each question, student variables were updated based on student performance.

### Practical Methods to Construct Engaging Instructional Activities

To incorporate learning theory into the training system, we held a workshop with learning theorists and domain experts to create engaging instructional activities that foster conceptual knowledge. The results were templates of interactions which lead students through activities in which they construct response, and compared their response to experts' responses. Maximizing affordability would be achieved by having one template for all modules. Maximizing level of engagement would be achieved by developing a format for each module. We balanced these goals by designing a few templates with learning theorists. The specific content for each module used one of these templates and was created by a SME working with a task analyst. This arrangement balanced affordability with level of engagement.

To elicit content from SMEs for insertion into training modules efficiently, we held a second workshop to conduct a cognitive task analysis process. The process had the following three stages. First, experts reviewed a procedure with an instructional developer, and divided the procedure into meaningful segments. The SME was asked to use his first impression of dividing procedural steps into segments. Second, experts sketched the relevant equipment operation, and described in text the operation of the equipment during this segment. Third, the content was transformed into one of the templates previously specified for guiding learning. In deciding what should be included in a training module, two fundamental questions were addressed.

- How much theory needed to be included in the module? The answer to this question is based on the initial interview with expert technicians: they said it was important to understand the intent and rationale of the procedure. The content included in the modules is guided by providing students with the intent and rationale of the procedure.
- How much detail should be included in graphics? The level of detail was guided by the intent (and subsequent rules) to label (a) all components in the documentation for the procedure, (b) components named in the procedure, and (c) any components named by the experts in their description of the current segment's process. These rules improved the development of training module words and graphics.

### Summary: Maintenance Trainer Enhanced to Foster Conceptual Knowledge

The application of current learning theory to maintenance training resulted in the enhancement of a SBT. Students not only practiced following procedural steps, but they also received training modules in which they learn the concepts underlying the procedures and build a mental model. As the instructional designer and the SMEs developed training module content, patterns of questions and answers became apparent, and led to a taxonomy of training module content. The categories of content in previous training modules informed the development of new content.

## TRAINING EFFECTIVENESS RESULTS

The enhanced maintenance training was tested qualitatively with formative methods, and quantitatively with summative methods.

### Formative Test Results

The training modules were incorporated into a SBT environment used by maintenance technicians of complex electronic equipment. Formative studies were conducted with students who received upgrade training. Students receiving upgrade training had field experience ranging from a few months to 15 years. Thus, the formative studies had the advantage of feedback from students with various expertise levels. The results from these formative tests revealed both how technicians believed their performance would be improved by this instruction, and how instructors and instructional developers should improve the development of training modules.

Technicians participated in formative tests by working through simulations with training modules in groups of two. Students universally reported that the training modules were helpful. Comments from three of the 10 technicians who were part of this test included:

- "Good to have questions, so you know what you're doing"
- "Pauses help you stop and think about what you're doing"
- "Diagrams are absolutely perfect for new guys"

The instructors for the course strongly supported the use of training modules with simulations. The instructors for the upgrade courses had been involved in the development of the instruction. They were anxious to receive feedback from students. After the students completed the simulations with training modules, the instructors reviewed student answers, and suggested the following ways the instructional interactions could be improved:

1. One problem is that students sometimes interpreted questions differently from the interpretations intended and expected by the instructional developer and SMEs. To guide the students to address the intended question, we generated a fill-in-the-blank answer form. These fill-in-the-blank answer forms more clearly showed the kind of information that the technicians need to incorporate in their answers. The fill-in-the-blank answer forms did not ask students to provide short phrases, or simple facts. Rather the fill-in-the-blank answers still required sufficient text construction so students needed to understand the content to answer the question.

2. Students sometimes exhibited a strong misconception about how the equipment worked. For instruction to effectively address a student misconception, the remediation should first address the misconception, giving some reason for its attractiveness, and relating an explanation of the correct explanation. Simply presenting the correct answer, without addressing the misconception, was not effective. When technicians are believed to have a misconception based either on formative studies or instructor experience, the remediation must first address the misconception, and then present the experts' answers with excellent support of the accurate rationale.

3. Different students reacted similarly to training modules. The implication is that testing training modules with just a few students can illustrate the reactions that many students will have. Given this similarity across different students, trying questions out with students will greatly benefit training quality.

### Summative Test Results

A quantitative test of the enhanced maintenance training was conducted with a class of 12 students. The effectiveness of the instructional modules was tested during a 12-day block of instruction. To support this instruction, the training used both hands-on training on a version of the real equipment, and computer-based simulations. Maintenance procedures on the equipment were partitioned into "checks." Each check on the real equipment takes between 1 hour and a full day, with many procedures on the real equipment requiring two technicians. Each check focuses on one aspect of maintaining the equipment.

The class was divided into two groups of six students by instructors who were directed to randomly assign students to each group. Six students received the existing training and executed procedures on a complex simulation (the control condition). The other six students executed procedures that were elaborated with training modules on four of the checks (the treatment condition). Conducting these checks with training modules increased the overall time by approximately one hour. As this time was distributed across four checks, this slight increase course duration resulted in no structural change to the course.

A test for individual students was prepared for the block of instruction by instructors. The existing assessment for this block was a group, hands-on assessment. For the purpose of assessing the effectiveness of the instruction, instructors created a test for students to take individually. This test had question types relevant to actions maintainers would make during deployment. One type of question described results indicating a fault in the equipment, and asked students to identify components that were suspects in the fault. Another type of question asked students to select good actions to take given a set of results from completed procedures on the equipment. Results of this test are shown in Table 1.

**Table 1. Results comparing groups with and without training modules**

| Groups | n | Post-test | |
|---|---|---|---|
| | | Mean | S.D |
| Treatment | 6 | 31.8 | 4.3 |
| Control | 6 | 25.7 | 4.5 |

The difference between groups was statistically significant: T-test $p < 0.05$. The effect size > 1.3 Standard Deviation.

## DISCUSSION

Simulation-based training environments can be enhanced to teach students not only "how" to complete procedures, but also the conceptual knowledge underlying the procedures (the "why"). To do this, learning theory suggests that SBT environments help students build mental models, are adaptive to individual student needs and engage students in instructional activities.

To be effective not only instructionally but organizationally, one must consider the larger goals and context of the overall training environment. Instructional developers must consider how students will perform their jobs in the field, and constraints of the simulation in the training environment. Job environment features to consider include:

- What access will the technician have to technical experts at the deployment site? If the technician will have to work unassisted, the technician's training will be different than if the technician will always be able to teleconference with an experienced technician.
- What is the usefulness (and access to) the documentation?

Constraints of the simulation that should be considered include:

- At the training center, can the simulation be stopped between actions?
- Does the simulation allow free play?
- What is the evaluation system like (if it has one)?
- How are the simulations and its evaluation system used in the training environment?

The instructional design described in this paper focused on the development of mental models, adaptivity, and engagement of students in instructional interactions. While these are important principles, other instructional design principles must also be addressed which include:

- Clear, simple writing and graphics
- Involvement of instructors in design

Content needed to be simple, clear, and unambiguously correct. Content creation is painstaking. Once it is created, it is best to pilot test the instruction with students to check for clarity and possible misinterpretations. The content includes narration and graphics. Both need to be immediately graspable, so students can use their cognitive resources on understanding concepts, and not on interpreting poorly synthesized speech or images that are not clear and consistent.

Instructors need to be involved in students' use of the simulation. Instructors need to access students' answers. Instructors benefit by seeing what students understand and what they do not. Students benefit by receiving feedback from instructors, and by increased motivation from knowing their work will be reviewed by instructors. Making student answers available for instructor review aids students and instructors.

The instruction needs to be affordable and maintainable. Creating great instruction that is too expensive to create and maintain is interesting research, but not practical, deployable, or beneficial. More elaborate interactions could be created, but the cost of creating elaborate interactions could make generating and maintaining the instruction too expensive.

This report has focused on the application of current learning theory to enhance procedural SBT. A learning system that focuses on conceptual understanding of procedures has the advantage of knowing the steps a user should take, what has preceded the current step, and the rationale behind the steps of the specified procedure. In non-procedural SBT, students select their own actions rather than following specified actions. Developing instruction for this kind of simulation would require the instructional system to know how an expert would understand the current situation, given what actions have been taken and what the results were, and to assess the quality of actions that the student might choose to take given the current situation. An example of an assessment system that easily assesses student performance in complex environments was presented by Pokorny, Haynes, and Gott (2010).

### Next Steps

The principles applied in this project are core contemporary learning theory. For simulations to be as effective as possible, learning principles need to be applied to SBT. Applications need to consider not only learning theory, but also the situation to which they are applied. This paper clarifies design considerations so that the core learning theory principles can be applied to other simulations. Applying learning theory principles in complex real world environments and simulations will benefit students and organizations. Our goal has been to offer suggestions in integrating core learning principles with real world constraints to show how students and organizations can benefit from simulations that teach procedures and concepts.

## ACKNOWLEDGEMENTS

We thank our collaborators on the NavAir Training System Division who worked with us on F-18 maintenance, and all personnel who contributed their time and efforts to the investigations. We also thank the late Paul Radtke of NAWCTSD for supporting the early research on adaptive visualization training.

Most of all, we thank the instructors and technicians who shared their thoughts and practices with us.

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