Developing an Embedded Scaffolding Framework to Support Problem-Based Embedded Training (PBET) using Mixed and Virtual Reality Simulations

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ABSTRACT

With the U.S. Army's rollout of Future Combat Systems Family of Systems, there will be the introduction of radically new technologies to the field (Welch, 2003). Embedded training with mixed reality technologies is viewed as an innovative training approach that will enable the training of individual, crew, and leaders tasks on the assigned vehicles and equipment en route to a mission. Problem-based embedded training (PBET) has been introduced as an instructional methodology that will provide a systematic design framework for embedded training. As part of the development of this methodology, a scaffolding framework was developed to help learners in develop greater expertise in strategic planning, problem solving, leadership, and decision-making. Scaffolding, which are support tools designed to help learners develop greater expertise and self-reliance, are necessary to providing just-in-time support in learning environments that are cognitively and technologically complex. Thus, this scaffolding framework was developed for problem-based embedded training in a mixed reality learning environment it serves learners as well as instructional designers who are creating these types of environments. A heuristic evaluation was conducted on the framework, and the results of this evaluation are described as well as implications for future design and implementation within embedded training environments using mixed reality technologies.

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INTRODUCTION

Over the next ten years, the U.S. Army plans to roll out the transformational Future Combat Systems Force warrior. These programs will introduce radically new technologies to the field (Welch, 2003). Within the first increment of FCS, a family of manned systems will provide tomorrow's soldier with high battlefield mobility and unprecedented organic reconnaissance and surveillance capabilities. Yet today's Army "lacks an approach that will develop soldiers through educational decision-making tools and experiential learning that prepares them for operational experiences" (U.S. Army, ORD for FCS, Apr 14, 2003, p.38).

Thus, new training approaches and systems are needed to train all individual, crew, collective, and leaders' tasks on the assigned vehicles and equipment any time, any place including en route to a mission. These training systems will consist of embedded modeling and simulation training as well as mission rehearsal. These embedded full task and tactical simulation systems will provide the capability to train and assess Combat Critical Skills of soldiers, crew sections, dismounted soldiers, and multi-escheloned combined arm skills (U.S. Army, ORD for FCS, Apr 14, 2003).

Given the focus on embedded simulation, mixed and virtual reality technologies become important vehicles for providing more authentic and complex training environments through the *enhancement of reality*. Mixed reality is the experience of a blended virtual and real world (Hughes, 2003) through one of the five senses, most often visual displays and auditory devices. This includes a broad range of applications in which some elements of the real world (e.g., physical space, real objects, environmental conditions) are blended with digital objects. In order to demonstrate examples of training environments for each reality type, Kirkley et al (2003) developed a Reality-Virtuality Training Continuum with examples of training for each (see Figure 1). In virtual reality, the soldier is immersed in a virtual environment independent of the real world around them. The benefits of mixed reality are that the real world and real objects are used as part of the simulation and training, thereby adding a more authentic and realistic context.

Mixed reality consists of augmented reality, augmented vision, and augmented virtuality. In Figure 1, the augmented vision example shows a soldier viewing a checklist for a repair procedure on an umanned ground vehicle. The augmented reality (AR) example shows a soldier viewing underground utilities with an overlay of digital data shown via a heads up display. The augmented virtuality example shows a virtual background image of a city with real-world data superimposed over it; this would be used for mission planning.

Yet one of the challenges associated with embedded training is the need for an instructional methodology to provide guidance on how to appropriately design, deliver, adapt, and assess training in these contexts. Without such a methodology, embedded training may be inconsistently applied, and learning outcomes may not be maximized. Problem-based embedded training (PBET) has been developed specifically to support embedded training using mixed reality technologies (see Kirkley, Kirkley, Myers, Lindsay, & Singer, 2003 for a more detailed discussion). PBET provides a systematic process for designing and implementing training in a way that reflects the real environment in which soldiers perform. Central to the PBET approach are realistic mission-based scenarios with built-in capabilities for training managers to adjust enemy and environmental complexities. The PBET approach supports training for strategic planning, problem solving, leadership, decision-making, and basic soldier skills (e.g., cover and concealment). It also supports soldiers in learning how to operate equipment, while also training basic soldier skills (e.g., cover and concealment). While the PBET methodology was designed to support mixed reality learning environments, it also works for general classroom, online, and live in-the-field exercises. In fact, PBET is designed to support the seamless movement among these modes of learning.

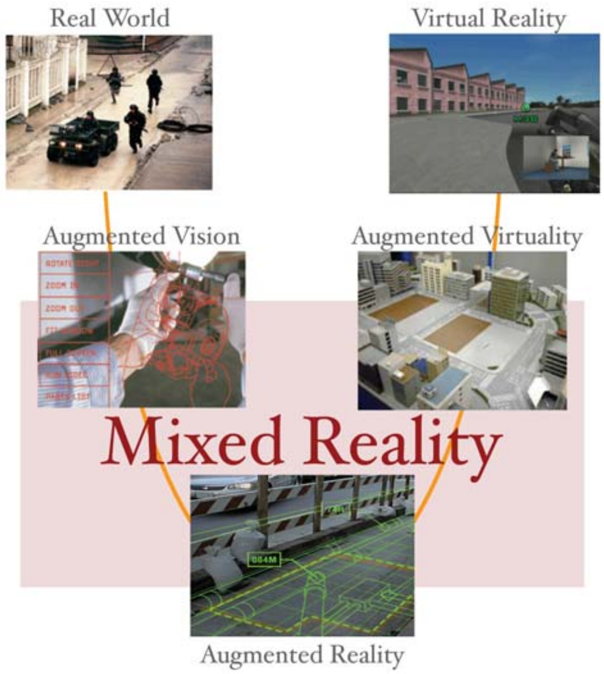


Figure 1. Kirkley et al's (2003) Reality-Virtuality Training continuum.

The PBET instructional model below encompasses four main components that outline the process a soldier or team of soldiers would follow in a training module:

- Mission - Written as an authentic military mission, this provides an overarching statement that helps learners conceptualize the various components of the situation, make links to real world issues related to the problem, and determine specific .
- Action Plan - Provides a guided approach for addressing the mission and implementing the solution; this supports mission planning, decision-making, and part-task training.
- Implementation – Provides a performance-based opportunity to implement the mission, such as an in-field exercise or on-the-job performance task.
- After Action Review (AAR) – Process that supports a team or individual soldier reviewing and assessing what was learned and what needs improvement.

As part of the development of the PBET methodology, a scaffolding framework was developed to provide guidance on how to support learners with managing their cognitive and metacognitive processes during the learning process. This is of particular importance in a cognitively and technologically complex learning environment where learners must deal with managing multiple resources, processes, and teams and interact with uniquely designed software applications as well as network processes.

DEFINING SCAFFOLDING

Scaffolding is a term used to describe pedagogical tools through which learners reach their goals and develop self-reliance via supports (Dennen, 2004; Winnips, 2001). First introduced by Wood, Bruner, & Ross (1976), this describes how a mentor mediates the learner's capabilities with the learning situation, task components, and steps to solving a problem in order to support learning and transfer of skills (adapted from Stone, 1993). The term comes from a metaphor related to the *scaffolding* used with building construction, which provides support and is removed gradually as the building is finished. Kirkley, Kirkley, Swan, & Sherwood (2003) define embedded scaffolds as systematically designed elements of support that are integrated directly within the learning environment. These are based on a performance support metaphor where the goal is to provide just-in-time, adaptive scaffolding via resources, learning tools and software, pedagogy, content, or the environment.

Traditionally, scaffolding has been viewed primarily as a set of instructional strategies used to provide assistance to learners as they develop self-reliance (Dennen, 2004). These strategies can be a directive or supportive. Directed scaffolding fits more closely with a teacher-centered model of learning where the instructor provides skills and strategies to teach content. Supportive scaffolding fits more closely with a learner-centered model of learning where the focus is on supporting the learner with the knowledge construction process (Dennen, 2004). The latter is in line with PBET-based approach.

Scaffolding is associated with sociocultural learning theory (Vygotsky' (1978) and cognitive apprenticeship (Collins, Brown & Newman, 1989; Lave and Wenger, 1990), which both view learning as situated within the activity, context and culture in which it occurs. Vygotsky's zone of proximal development focuses on the mediation between a learner and a more advanced teacher or mentor for the purpose of raising the learner's level of independent performance. Cognitive apprenticeship emerges out of situated learning theory (Brown, Collins & Duguid, 1989), which focuses on a knowledgeable mentor working with a novice learner, much like an expert craftsman would work with an apprentice (Lave & Wenger, 1991). There is an emphasis on authentic learning that is situated with the environment, community, and context in which it is used.

Within education, scaffolding research has focused on activation of prior knowledge (Anderson & Pearson, 1984), modeling of reading strategies (Walmsley & Walp, 1990), and cooperative learning strategies (Johnson, Johnson & Smith, 1991). In the past decade, there has been much research on the development and use of software-embedded scaffolding to support learning (Reiser, 2002). Designers have begun to create technology-based learning environments that embed scaffolding directly into the design of learning applications and systems. Some examples include Guzdial's (1993) EMILE system, which supports computer programmers in the programming process, and Bell & Davis's (2000) Mildred system, which supports students in developing reflection and argumentation skills.

Within the military, Hannafin, McCarthy, Hannafin, and Radtke (2001) have developed and tested a scaffolding framework for the Tactical Readiness Instruction, Authoring, and Delivery (TRIAD) project for the Navy. The goal of the TRIAD project was to investigate and improve the way that technical and tactical information is communicated throughout the US Navy fleet through resource-based scaffolds.

DEVELOPING THE PBET SCAFFOLDING FRAMEWORK

There are challenges with designing scaffolding for any technology based learning environments, and in particular, those that use mixed reality. Thus, the goal was to research and develop an embedded scaffolding framework to support learners in PBET environments using mixed reality simulations.

Within the PBET environment, where training is more contextualized and authentic, scaffolding needs to be specifically designed to meet a wide variety of training needs, contexts, and delivery methods. For example, soldier skill levels may be highly variable depending on their rank, prior experience, and aptitude. Soldiers may also be expected to perform individually or work in teams to execute operations. These operations may be conducted within a variety of contexts. Training or after action review may take place individually or in a classroom; further, a classroom activity may consist of team-based problem solving or of an individual examination. Simulation exercises may be completed via virtual simulations on a desktop computer, or within simulated, "real-world" environments outside of the classroom. A simulation, which "temporarily creates a set of things…and then relates them together through cause and effect relationships" (Lee, 1999). Yet they provide many technical as well as cognitive challenges, and soldiers need support so they can stay focused on the learning goals rather than trying to learn an interface or determine what it is they are to learn.

While the problem-based embedded training environment potentially provides many advantages (e.g., learning knowledge in context of application), there are also many challenges associated with providing necessary guidance and resources for learners. Hedberg (1993) states that in highly cognitive and complex constructivist environments, learners are often placed in the role of managing their own resources, a task which is difficult for some learners. Without appropriate support, learners may spend time on inappropriate tasks at the expense of learning or struggle to the point of frustration. To address these issues, cognitive and metacognitive supports (i.e., scaffolding) can be purposefully designed and embedded within the PBET learning environment to provide guidance.

Thus, the three goals for this framework are: 1) to provide instructional designers with a way to systematically design scaffolding supports for the PBET environment; 2) to provide cognitive support to learners using embedded in MR environments; and 3) to provide researchers with a consistent framework for evaluating the design and use of different types of scaffolds.

In developing the PBET scaffolding framework, we held the following assumptions:

- The PBET environment is designed to support meeting individual and team training goals via a problem solving, and when appropriate, a collaborative approach.
- The design of the PBET scaffolding framework focuses on a holistic training approach including

both out-of-field training (e.g., classroom or online) and in-field training. This means there are multiple types of scaffolding categories, functions, and possible scaffold forms.

- The scaffolding framework is designed to be used with mixed and virtual reality training environments.
- The focus of the PBET methodology is on using augmented-reality technologies via laptops, PDA and other computer-driven devices. The scaffolding framework may be used in these computerized scenarios to develop entire support systems; however, they may also be used to develop electronic job aids and manuals.
- The scaffolding framework is designed to assist trainers and instructional designers in developing scaffolds for more soldier-centric training and to support multiple training contexts as well as multiple input and output modes (e.g., PDA or audio).
- A variety of performance and training goals may be achieved by using the scaffolding framework as a guide for developing learner support systems.

To develop the PBET scaffolding framework, we began by examining Hannafin, Land & Oliver's (1999) scaffolding framework for open learning environments (OLEs). OLEs promote divergent thinking across problem solving contexts and value multiple perspectives. These characteristics are crucial for investigating "fuzzy, ill-defined, and ill-structured problems" (Hannafin et al., p. 120) such as those found in PBET environments.

Numerous learning support systems are available in OLEs, including the provision of enabling contexts, resources, tools, and scaffolding. Learners within complex environments such as OLEs often need specialized support for several reasons. For instance, they may bring varying knowledge sets and experiences into the situation; they may have different jobs or roles to perform; or the environment may require application of knowledge and specialized performance. Both OLE learning activities and associated scaffolding techniques exemplify an open-ended approach to learning. In this way, the OLE scaffolding framework further matches the values of the PBET learning environment.

Both the OLE and PBET methodologies support an immersiveenvironment in which the learner's experience mediates learning, experience-based problem solving activities are a means for negotiating understanding, and individuals continually interpret, evaluate, and respond based on ongoing assessments. Hannafin, Land, & Oliver (1999) provide four types of scaffolding in their classification:

1. Conceptual: This type of scaffold guides the learner in what to consider when the problem task is defined. It provides assistance related to generation of problem-relevant perspectives. Learners may be guided to apply current conceptions to a new problem area in and encouraged to organize their conceptual knowledge.
2. Metacognitive: This is related to management of individual learning processes and strategies. These scaffolds may help learners to better understand their task strategies and how they think about problems throughout the problem solving process.
3. Procedural: This helps the learner in using features of an OLE, for example, by providing help for accessing a system function.
4. Strategic: This provides assistance for approaching the task or problem. They enable learners to choose alternative approaches to problem solving, as well as support acts of decision-making, planning, and strategizing, allowing learners to relate new knowledge to existing knowledge.

Although the OLE framework provides a substantial base for addressing cognitive and metacognitive scaffolding from the point of view of supporting an individual learner's cognitive development, a PBET environment using mixed reality technologies requires an extension of the OLE framework for several reasons.

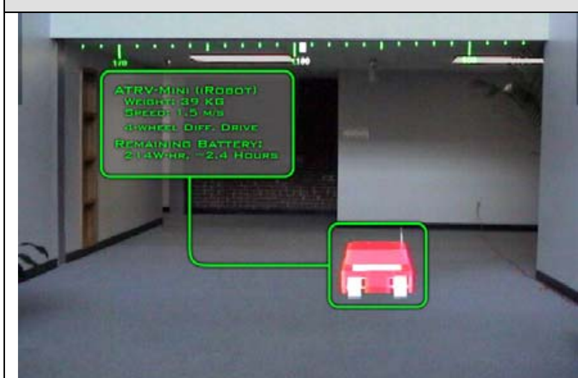
First, PBET learning environment is designed specifically to support meeting training goals through a problem solving process. In the design of the PBET instruction, problem solving is used as both a process and an interface to guide the learner through the definition, investigation, and development of a solution. By providing specific scaffolds to support various stages of the problem solving process, the soldier can better understand how to improve his or her own problem solving process. It is important to note that the problem solving scaffold could be generic based on the general steps to solving a problem (e.g., considering alterative solutions), or it may be based on unique categories of problems that are being solved (e.g., what is the best process for resolving an error while repairing an engine).

Second, PBET is designed to support scaffolding for both individuals and teams of soldiers. Therefore, a collaboration scaffold is provided to supply explicit scaffolding in how to work in a team. This scaffold may be generic (e.g., designate a project manager), or it may relate to specific types of team training events that require specific types of actions given the roles and tasks of each team member (e.g., how a fire team leader should maneuver an unmanned ground vehicle). The PBET scaffolding framework (see Table 3) encompasses six categories which address the majority of scaffold design options that can be used to design learner support systems.

Third, field-based exercises often require performance-based tasks, some of which are kinesthetic (e.g., the first aid task of applying a tourniquet). This sometimes requires physical participation in a procedure that cannot easily be trained through written instruction or visuals (e.g., applying a tourniquet). Some current types of scaffolding (e.g., instrumentation on a CPR dummy to indicate correct amount of pressure for chest compressions) can provide important support for learning touch and physical types of activities. Emerging haptic technologies as well as training that is embedded into equipment will increase the capability of supporting learners with kinesthetic scaffolds. The PBET scaffolding framework is presented in Table 1.

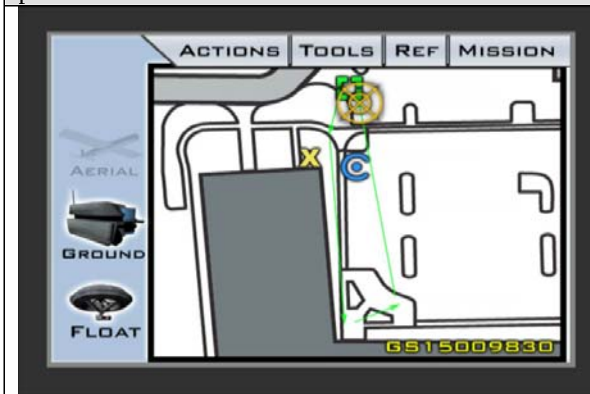
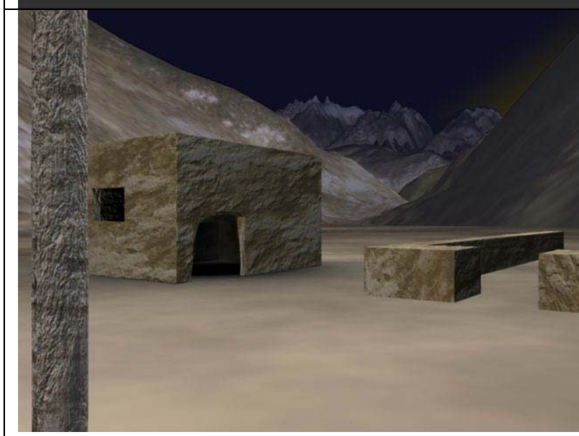
Table 1. Scaffolding framework for embedded training with mixed reality.

<table>
<tr><td colspan="2">PBET Scaffolding Framework
Note: These examples are not meant to be inclusive of all available types of scaffolding within a category. They can be expanded based on specific methods that emerge within these areas.
(*These types of scaffolds overlap with the Hannafin et al. (1999) framework.)</td></tr>
<tr><td>Scaffold Category and Examples</td><td>Scaffold Types
Example of Scaffold</td></tr>
<tr><td colspan="2">Cognitive
These are scaffolds that support knowledge development and understanding.</td></tr>
<tr><td>



</td><td>*Conceptual
Provides assistance related to generation of problem-relevant perspectives. Learners may be guided to apply current conceptions to a new problem area and encouraged to organize their conceptual knowledge.
Example
A soldier is trying to repair an SUGV and is having trouble completing the task. This pop up menu provides a short list as a reminder, and more info can be obtained by clicking on relevant sections.</td></tr>
<tr><td>

</td><td>Procedural
It aides a learner’s understanding of a process or procedure, essentially providing task completion support. Procedural scaffolds may be targeted at overall task process or at sub-processes which are tied to the higher learning task.
Example
This scaffolding provides a soldier a short list reminder on how to conduct recon with an unmanned system, such as a UGV.</td></tr>
</table>

***Metacognitive** Related to management of individual learning processes and strategies. These scaffolds may help learners to better reflect on and understand their task strategies and how they think about problems throughout the problem solving process.	
	***Strategic** These provide assistance for approach to a task or problem. They enable learners to choose alternative approaches to problem solving, as well as support acts of decision-making, planning, and strategizing, allowing learners to relate new knowledge to existing knowledge. **Example** A soldier is running a virtual simulation embedded in a desktop simulation. A metacognitive scaffold appears on the soldier's screen that helps him analyze his approach to placing the UGV within an area to conduct recon.
	**Transfer** Enables learners to bridge content/knowledge across contexts. Transitions may be to and from any number of training categories (e.g. virtual simulation → in-field exercise). The end result of a successful transfer scaffold will be that a learner is able to apply [common] knowledge to various problems within multiple contexts as well as transfer learning strategies/approaches between contexts when necessary. **Example** This type of scaffold supports the learner in relating or applying what was learned in one situation to another situation. For example, cover and concealment skills obtained for the urban environment could be applied (and adapted) for a new type of environment like a desert village through the use of virtual technologies.
Process These are scaffolding approaches to support both macro and micro processes found in problem solving and collaboration. A computer-based system could be designed specifically to support problem solving processes at the macro level or a specific activity within problem solving (e.g., defining a problem).	
(No image available)	**Problem solving** **Example** During a CTC training exercise, an instructor remotely triggers a simulated malfunction of the 120mm M256 main gun targeting system on an M1A2 Abrams Tank. The crew of the tank is given a "challenge" by the instructor to isolate the problem with the affected system and repair the system before the next offensive operation.
(No image available)	**Collaborative** **Example** During a CTC training exercise, an instructor remotely triggers a simulated malfunction of the 120mm M256 main gun targeting system on an M1A2 Abrams Tank. The crew of the tank is given a "challenge" to work together repair the system before the next offensive operation. Directions on specific roles and tasks are proposed by the simulation to demonstrate how an expert crew would work together.

Motivational

A motivational or supportive scaffold encourages learners to complete - or not complete - certain task actions. It may be provided during a training session, or may be assessed after a section of a training program is complete. A motivational scaffold may use either a positive or negative reinforcement mechanism.

Feedback

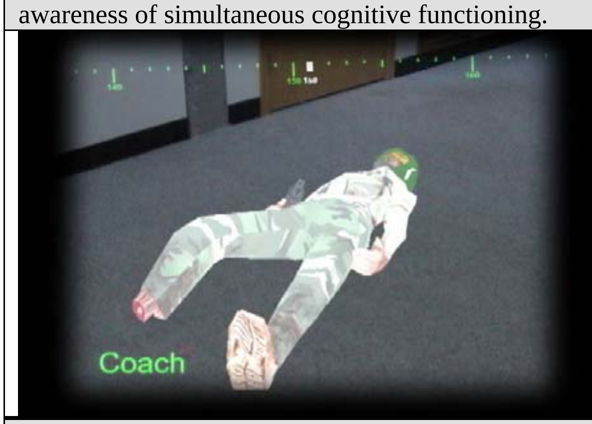
Provides information on how well a task was accomplished.

Example

A soldier is attempting to throw a grenade into a building in order to take out a terrorist. A basic form of motivation is providing feedback on success during the training event so the soldier can fine tune approaches and be motivated to perform better.

Kinesthetic

A kinesthetic scaffold guides a learner based on bodily or physical movement. Kinesthetic scaffolds may be separated into two sub-levels related to modes of body/cognitive processing: automaticity and physical. Automaticity scaffolds are appropriate for kinesthetically-related tasks that may be completed with very low cognitive demand; the learner should not think about the maneuver, but rather perform it in an automatic fashion. On the other hand, a physical scaffold requires the learner to physically perform tasks which require some awareness of simultaneous cognitive functioning.



Touch

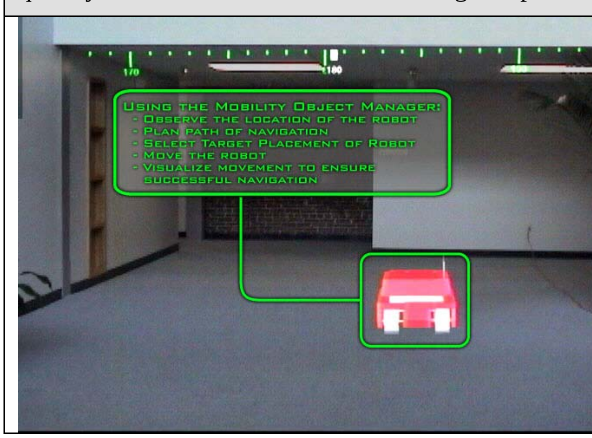
Provides response in regard to amount of pressure or weight.

Example

A soldier is practicing first aid task dealing with loss of limb. Using haptic technologies, he or she may work on a "dummy" that provides realistic feedback on touch and response to treatment. Also, a virtual coach is embedded to provide guidance on specific procedures..

Technological

A technological scaffold helps soldiers learn to use embedded training (ET) processes and components. ET systems are implanted within technology, issued weapons and equipment. A technological scaffold should help learners to quickly master various embedded training components and provide updates as needed.



Procedural

These scaffold aide the learner in using features of a technological system.

Example

This type of scaffold aides the learner in using features of a embedded training to conduct specific technological repairs. Changes in steps are maintained by that updates the procedural information on how to use the equipment.

EVALUATION OF THE PBET SCAFFOLDING FRAMEWORK

Six evaluators participated in a heuristic evaluation (Nielsen & Molich, 1990). Evaluators were research scientists with expertise in scaffolding as well as military training and simulation experts. To validate the PBET scaffolding framework, evaluators reviewed the following materials:

- A paper describing the development of PBET scaffolding framework.
- The PBET scaffolding framework with written descriptions of each type of scaffolding.
- Images from the robotics training scenario used to demonstrate each type of scaffolding that could be implemented in that particular scenario.
- An evaluation form with instructions for completing the evaluation.

From this evaluation, five of the six evaluators agreed that:

- The types of scaffolding described in the framework would help soldiers who are participating in complex, mission-based training environments.
- The types of scaffolding described in this framework would help soldiers who are training with mixed and virtual reality simulations.
- Using the different types of scaffolding would provide opportunities for soldiers to flexibly gain performance and skills for use in the battlefield.

Four of the six evaluators agreed that the scaffolding framework provided: a helpful approach for developing support for a range of different types of knowledge and tasks; advice on how trainers can design specific types of scaffolding; support for soldiers in preparing for participation in an augmented reality-based training simulation. One evaluator stated that the framework was too abstract to be evaluated. Other issues addressed by evaluators included the usefulness of scaffolding framework, the comprehensiveness of categories and suggested revisions.

Usefulness of Scaffolding Framework

All six evaluators agreed that the scaffolding framework was a useful framework for supporting learners in open-ended, complex learning environments. Several evaluators stated that the PBET scaffolding framework was useful, intuitive, and easy to use.

Comprehensiveness of Categories and Suggested Revisions to the Framework

Evaluators disagreed on whether the categories in the framework were comprehensive enough to address training in PBET types of environments using mixed and virtual reality. Four evaluators felt the categories were comprehensive enough, although one evaluator suggested some clarifications and elaborations be made and more obviously linked to research in human performance and cognitive science.

All six evaluators suggested a range of minor changes to the categories. One evaluator suggested that the cognitive scaffolding category be expanded to include goals of long- and short-term memory as well as a hierarchy of types of learning more akin to the Bloom & Krathwohl’s (1956) taxonomyThis evaluator also suggested that categories such as kinesthetic and technology do need to be part of the instructional consideration but they represent more operational concerns at a different

Advantages of Scaffolding Framework

Evaluators stated that the scaffolding framework would be of benefit to both soldiers using the PBET training environment and to instructional designers who are developing the PBET training modules. “It provides an organizing framework for the system development; for designers to design and soldiers to learn/think/train re: specific problems.” Specifically with regard to supporting learners, one evaluator stated that “the complexity of the learning environment is extreme and also very foreign to the learner. Such a scaffolding framework will be essential to organize instructional strategies as well as assess their effectiveness. Another evaluator stated that one big advantage would be the consistency brought on by such a framework. Another evaluator stated that this type of framework would be important for instructional designers who will create this type of training.

Additional recommendations made by evaluators were to provide some kind of tracking tools that help an instructor know what kinds of scaffolds soldiers are accessing. “These may provide insight into processes or procedures that need further attention and/or may highlight when a soldier is having a particular problem that needs to be addressed.” Also, several evaluators stressed the importance of testing the framework with soldiers in the field before making further refinements.

One evaluator stated that "by putting Soldiers into the effort during the early stages, you will reduce the number of revisions to the framework and develop a higher level of confidence with the program."

In summary, evaluators stated that the PBET scaffolding framework was a useful way to support soldiers within a PBET environment and to support instructional designers with creating PBET training scenarios. Although evaluators suggested a range of suggestions to improve the framework, they stated it was a useful way to conceptualize supporting learners in a PBET environment.

CONCLUSIONS AND NEXT STEPS

In this paper, we have presented a conceptual scaffolding framework to use for developing problem-based embedded training environments. These scaffolds should be designed to support the learner in simulation based environments using mixed or virtual reality. While the embedded scaffolding framework was deemed to be useful for conceptualizing a way to embed support into PBET-based training environments, there is still much design and testing to conduct with soldiers using this in mixed reality learning environment. However, this provides a useful first step in identifying the core components and types of resources that learners will need to perform.

Yet designing and implementing scaffolding demands that we consider how to design and deliver the components with multiple input and output modes. Also requiring consideration is the context, expertise, and background of the learner. These issues will present strong challenges for implementing this scaffolding framework. Yet the challenge will be found in providing an appropriate level of support to learners who are in the field and working within embedded training environments. This type of training calls for a holistic consideration of the aspects of learning and development that need to be scaffolded as well as the more holistic approach to understanding how to develop expertise (see Chi et al, 1988). Building on this, we also need to support learning by doing through cognitive design (Lesgold & Nahemow (in press). Integrating aspects of these approaches is the next step to be taken in the development of this framework.

Additionally, scaffolds will be need to be designed to be delivered via a wide range of devices, including embedded within equipment or via wearable computers, head worn displays, and haptic suits. Thus, scaffolding will have to be designed for multiple inputs and outputs, including video, audio, and haptic. There are a wide range of considerations to be researched in the effective delivery of scaffolds.

However, the next step is to evaluate the effectiveness of the scaffolding framework by testing it in a mixed reality learning environment. From this, design guidelines will also be developed to support instructional designers with developing scaffolds for these types of environments.

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