A COGNITIVE APPROACH TO STUDENT-CENTERED *E*-LEARNING

Frank L. Greitzer
Pacific Northwest National Laboratory
Richland, WA 99352

Like traditional classroom instruction, distance/electronic learning (*e*-Learning) derives from largely behaviorist computer-based instruction paradigms that tend to reflect passive training philosophies. Over the past thirty years, more flexible, student-centered classroom teaching methods have been advocated based on the concepts of "discovery" learning and "active" learning; student-centered approaches are likewise encouraged in the development of *e*-Learning applications. Nevertheless, many *e*-Learning applications that employ state-of-the art multimedia technology in which students interact with simulations, animations, video, and sounds still fail to meet their expected training potential. Implementation of multimedia-based training features may give the impression of engaging the student in more active forms of learning, but sophisticated use of multimedia features does not necessarily produce the desired effect. This paper briefly reviews some general guidelines for applying cognitive science principles to development of student-centered *e*-Learning applications and describes a cognitive approach to *e*-Learning development that is being undertaken for the US Army.

INTRODUCTION

In traditional approaches to education and training, the burden of communicating course material rests with the instructors. Over the past thirty years, more flexible, student-centered teaching methods have been advocated, inspired by the concepts of "discovery" learning (Bruner, 1966; Hermann, 1969) and "active" or "autonomous" learning (e.g., Johnson, Johnson & Smith, 1991). These instructional approaches propose replacing or complementing traditional lectures with active learning experiences such as role-playing, simulations, self-paced or team-based exercises, and other types of open-ended problems requiring critical or creative thinking. While these methods have been successfully established in many educational settings, their benefits have not been automatic and have been realized only through substantial effort (Felder & Brent, 1996).

The field of distance learning, or electronic learning (*e*-Learning) has had a similar progression. Deriving from largely behaviorist computer based instruction paradigms, *e*-Learning applications still tend to reflect passive, rather than active, student-centered training philosophies. Originally following a substantially linear process, computer-based training approaches are becoming more student-centered as a result of new methods and computer technologies that allow greater flexibility in the design and delivery of instructional material. Nevertheless, many training applications that employ state-of-the art multimedia technology that allows students to interact with simulations, animations, video, and sounds still fail to meet their expected training potential. Implementation of multimedia-based training features may give the impression of engaging the student in more active forms of learning, but sophisticated use of multimedia features does not necessarily produce the desired effect. As Michael Allen (2002) observes in a well-articulated article advocating discovery-based *e*-Learning: "Lurking behind many of today's slick delivery systems are shop-worn, passive learning paradigms that Socrates spurned in the fifth century B.C." Arguably, many *e*-Learning applications suffer from the traditional linear, expository teaching method in which material is presented for students to read, followed by testing for rote memorization, and then the cycle is repeated. It is not uncommon for students to breeze through such computer-based training without really learning the material, particularly when they can take advantage of user-centered features like quizzes that allow them to take another guess or casually link them back to review the material containing the correct answer. Such features are good, but not sufficient to overcome the drawbacks of otherwise passive learning formats. What is lacking is an active learning paradigm—grounded in principles of cognition—that helps ensure that students learn the functional value of the material by working directly with the content.

The purpose of this paper is to briefly discuss principles that form the foundation of a cognitive approach to student-centered, interactive *e*-Learning, and to describe specific methods and techniques that have been employed in developing an *e*-Learning application based on these principles.

BACKGROUND

Cognitive Principles

Research on cognitive processing—how information is stored, retrieved, and represented (e.g., Atkinson and Shiffrin, 1968; Tulving and Donaldson, 1972; Lindsay and Norman, 1977)—points to the importance of helping students develop well-connected knowledge structures. When the knowledge structure for a topic is large and well-connected, new information is more readily acquired; the richness of connections facilitates information retrieval. We tend to organize and categorize new information in terms of what we already know (i.e., our knowledge about the world, or semantic memory). Because information that ties in easily with semantic memories is easier to understand and to remember, presentation of new material in training situations should seek to tap into the learner's existing semantic knowledge structures. Showing how the new information or procedures relate to one's experiences—the "real world"—will facilitate this classification/memory storage process and improve retrieval of the information.

Cognitive theory holds that human memory comprises a very limited working memory (Miller, 1956), and effectively an unlimited long-term memory (Atkinson & Shiffrin, 1968). Associative processes and organizational processes play an important role in learning and memory. It is well known that humans exploit relationships among items being memorized, and that material being recalled tends to reflect these relationships regardless of whether or not the material was organized when presented (Anderson & Bower, 1973). Knowledge can also be viewed as schemas representing relationships among facts and concepts; knowledge structures contain schemas that may vary in their degree of automaticity (Kotovsky, Hayes & Simon, 1985). Schemas allow many elements of knowledge to be treated as a single element in working memory, which reduces demands on working memory compared to controlled, conscious processing that requires higher cognitive loads (Schneider & Shiffrin, 1977; Shiffrin and Schneider, 1977).

If a learner has acquired appropriate automated schemas, cognitive load will be low; but if the material has not become organized into structured schemas, then cognitive load will be high, as the many elements that comprise the material must be considered discrete. In short, learners have difficulty with instruction unless they are already fairly acquainted with the material—which leads to a paradox (Carroll, 1987): "To learn, [users] must interact meaningfully with the system, but to interact with the system, they must first learn." (p. 77). Research on "minimalist training" aimed at addressing this paradox suggests that an effective approach is to encourage learners to work immediately on meaningful, realistic tasks; to reduce the amount of reading and other passive activity; to use prior knowledge to advantage; and to help make errors less traumatic and pedagogically productive (Carroll, 1987; 1990).

Interactive experiences in applying what has been learned should be, to the greatest extent possible, presented in realistic contexts. When carefully designed, quizzes and interactive exercises can provide unique and valuable opportunities for learning through exploration and discovery. The key to this enhanced type of performance testing is incorporating student-centered activities involving manipulation of objects to solve problems (i.e., working directly with the content rather than answering factual questions that only require rote learning). Problem-centered training helps to instill learning experiences that are intrinsically rewarding, relevant, and enjoyable for the student (Wilson, Jonassen & Cole, 1993). Engaging learners in problem-solving activities, rather than passively digesting course content, not only increases motivation but also compels them to think about, organize, and use the information in ways that encourage active construction of meaning, help build lasting memories, and deepen understanding of the material.

These cognitive principles lead to the following student-centered training guidelines that guided our development approach:

- *Stimulate semantic knowledge*. Relate material to the learner's experiences and existing semantic knowledge structures to facilitate learning and recall of the information.
- *Manage the learner's cognitive load*. Organize material into small chunks, and build up gradually from simple to complex concepts.
- *Immerse the learner in problem-centered activities.* Provide opportunities for learners to work immediately on meaningful, realistic tasks.
- *Emphasize interactive experiences*. Develop problem-centered activities that require manipulation of objects to encourage active construction/processing of training material to help build lasting memories and deepen understanding.
- *Provide frequent and varied practice*. Implement a variety of interactive problems for practice, exercises and tests that aid understanding.

Application

We have specifically attempted to address these principles in the design and development of a training application for the US Army's Combat Support System Automated Information System Interface (CAISI). The CAISI provides a wireless communications capability that allows various Army systems to communicate across the battlefield through their classified tactical packet network (Colacicco, 2001). The CAISI Project Office at Ft. Belvoir, VA, has developed training content and is conducting classroom training as part of the CAISI fielding activities. In this two-tiered course, CAISI operators receive classroom training that prepares them to set up, transport, break down, operate and maintain the CAISI both in garrison and in the field. CAISI administrators, or System Support Representatives (SSRs), receive the operator training plus more in-depth instruction on additional network administration, security, and maintenance/troubleshooting responsibilities (the full course requires 40 hours of classroom training). This is very much a hands-on experience. Taught in a "lab-like" setting, approximately twenty soldiers work with actual equipment in small teams of two-to-four soldiers. To pass the CAISI course, students must demonstrate the ability to set up the CAISI and make it operational in a timed test.

Concurrent with the CAISI fielding and classroom training development, the Pacific Northwest National Laboratory (PNNL) is developing an *e*-Learning application for CAISI operator sustainment training. This Web-based CAISI training system is also distributed on CD for use on individual computers, and material developed for the computer-based course is also available for use in the classroom.

APPROACH

Multimedia Tools

Tools to construct three-dimensional renderings of objects and flash interactions allow us to add to our collection of training aids (already comprising more traditional items such as photos, video, sounds, etc.). When teaching procedural knowledge (such as equipment maintenance and operation as in the CAISI application), high-fidelity object representations such as those developed here help establish well-connected knowledge structures. These more sophisticated interaction elements can be used effectively to support simulated interactions, demonstrations of relationships among objects, and basic building blocks for interactive student-centered learning. Multimedia tools used include Alias/WaveFront Maya, MacroMedia Director, ShockWave Studio, Apple QuickTime, and Totally Hip LiveStage Pro. Maya was used for 3-D modeling and rendering; Director, ShockWave, QuickTime and LiveStage Pro were used to build engaging, interaction elements and scenarios.

Interaction Elements

The emergence and maturation of electronic media-based technologies in recent years has made it increasingly feasible and cost-effective to apply the cognitive principles and student-centered training concepts to *e*-Learning development. Our cognitive-based, student-centered approach created a specific set of training features to form a foundation for the *e*-Learning development. Since they are focused on student-centered/active forms of training, we refer to these features as *interaction elements*.

Stimulating semantic knowledge structures. One type of interaction element links to general facts about the world (relating to semantic memory) that may be identified with parts of the training content. Sometimes referred to as "factoids," this information is not critical to understanding the material but may help to enrich the student's experience and strengthen the memory representations of the material. We use the label ***Did You Know?*** to identify these interaction elements (Figure 1 shows a ***Did You Know?*** Interaction element that describes an earlier version of CAISI).

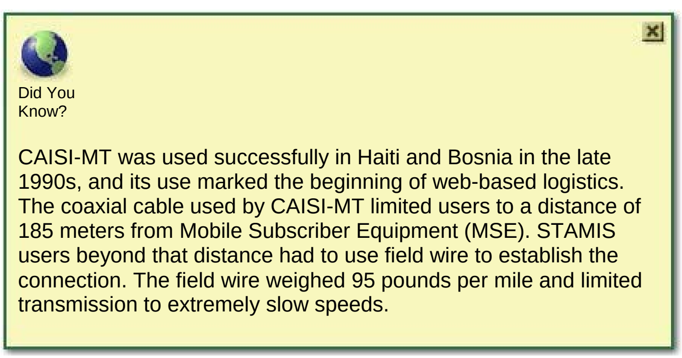

Figure 1. A *Did You Know?* interaction element that pops up when its icon is clicked.

Another type of interaction element helps to strengthen semantic knowledge and aid retrieval by pointing out concepts that are especially relevant or important, particularly those that will come up again in subsequent training lessons. Such associations are called out for the student as a ***Heads-Up*** that the information will have particular significance. Lesson objectives and higher-level module objectives are made available through similar types of interaction elements.

Managing the learner's cognitive load. The challenge of reducing the learner's cognitive load during training was a specific focus of our training system design. One aspect of our approach was to begin with simpler material and gradually move to more complex materials. A related strategy is to train in small chunks, guide student practice, and incorporate worked examples (e.g., Carroll, 1994). We implemented these types of features in highly focused sample problems (***Checkpoint*** interactions) on material that was just presented. ***Checkpoint*** interactions promote practice in manipulating objects to produce a correct outcome; feedback is provided and the learner can repeat problems as desired.

Immersing the learner in problem-centered activities. The highly-focused, interactive examples implemented as ***Checkpoint*** interaction elements provide opportunities for learners immediately to practice applying concepts with multimedia objects that simulate the real equipment. Figure 2 shows a sample ***Checkpoint*** interaction that allows learners to exercise their knowledge about the proper procedure for assembling a wireless antenna. When each step in the process is selected, the corresponding assembly activity is displayed as a multimedia movie.

The interaction elements are all identified with distinct icons that alert the student that these training aids are available, accessible simply by the click of a mouse. Rather than forcing such material on the student, these aids are discretionary/optional in our user-centered format in which students control their own navigation, and levels of exploration, through the course.

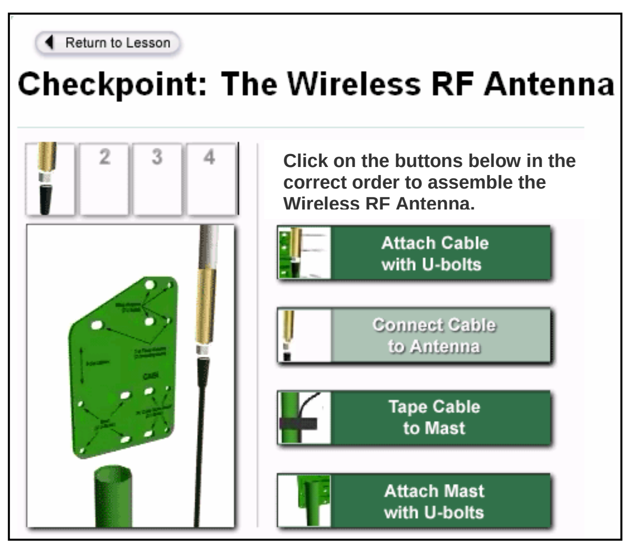

Figure 2. Sample Checkpoint interaction on assembly of wireless antenna.

Integrated Practical Exercise

Emphasizing interactive experiences. Interaction elements provide the foundation for problem-centered activities that promote deeper understanding of the material. Feedback and unconstrained access to interact with the problems implemented within interaction elements help the learner see and experience the correct solution. A distinct aspect of our approach was to implement interaction elements as building blocks to support problem-centered activities that grow in complexity from simple test of facts to more complex application of concepts and procedures in solving problems. We incorporated simple interaction elements into this strategy by using them individually when specific concepts are introduced and then re-using and combining them later to support more complex concepts that require integration of knowledge and skills. Many basic interaction elements were re-used to provide interactive quizzes and module tests (an example is shown in Figure 3).

Further, interaction elements were combined to create more complicated tasks that comprised sequences of activities and application of knowledge/skills in context, as required by integrated practical exercises. Implemented as extended scenarios, these integrated practical exercises test the extent to which students can apply knowledge and procedures learned in earlier lessons and modules to realistic problems, such as setting up, operating, and troubleshooting the equipment. In essence, the integrated exercises are composed of a series of interaction elements that are stringed together within a given context, as defined by a scenario that is described. Each step in the extended example tests critical knowledge.

Providing frequent and varied practice. To provide more varied practice, steps in the integrated practical exercise scenario are chosen randomly from a pool so that specific performance requirements change as the scenario details unfold when the exercise is repeated. These non-static, realistic, complex interactions provide interesting and useful practice working with the equipment and applying troubleshooting procedures, which helps prepare learners for actual on-the-job experiences and responsibilities. Because the complex interactions are engaging, challenging, and relevant, we expect that learners will be more motivated to try them out repeatedly to improve their skills.

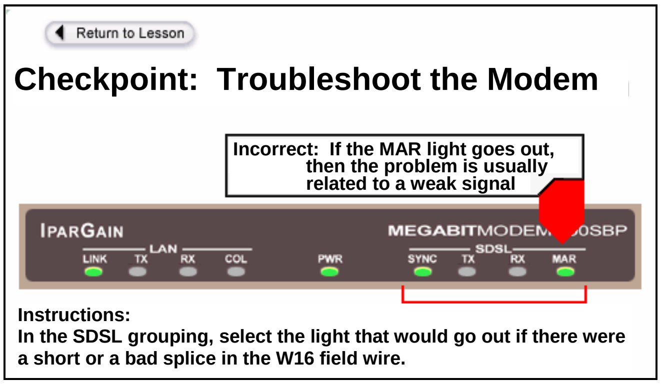

Figure 3. Interaction element used in a Checkpoint, a quiz, and incorporated into an integrated exercise.

RESULTS TO DATE

The classroom version of the training was fielded in spring 2002 and the US Army CAISI Project Office continues to make enhancements and improvements. The *e*-Learning application development necessarily lags behind the classroom instructional design/development. Because of changes to the equipment and modifications to the course content, the *e*-Learning application will be available in late summer 2002.

Initially, the *e*-Learning application will be provided as a resource that is available following the initial fielding and training—this will support refresher training (sustainment training) that is available to previously trained personnel as well as new personnel who arrive after the initial fielding. Beyond this, once the web-based training is available, it is expected that some of the classroom instruction can be eliminated as a blended training delivery concept is achieved.

To date, we can see that the implementation of multimedia interaction objects and features is beginning to influence the materials used for classroom instruction. The impact is expected to be a reduction in the time required to conduct the classroom training, which has been strained to fit within a 40-hour time limit.

Some features developed for the CAISI *e*-Learning application have been incorporated into the classroom-based training to help reduce classroom instruction time and to augment or enhance the classroom experience. For example, because rendered still images tend to provide higher-quality representations than photographs, rendered images have been substituted for photographs in the classroom training materials. This is particularly advantageous when photographs of equipment contain cluttered backgrounds or poorly lighted objects. Interaction objects such as 3-D renderings, multimedia movie files, and animated .gif files developed for the *e*-Learning application are also available for use as classroom demonstrations. Examples include multimedia files that demonstrate unpacking, packing, and assembly of equipment, as well as animated graphic files to illustrate conditions associated with troubleshooting procedures. These multimedia demonstrations, when incorporated into the classroom presentation, can complement or supplement actual equipment demonstrations in the classroom, as well as provide opportunities to view examples of problems that may be difficult or impossible to create with actual equipment in the classroom.

CONCLUSION

An effective interactive training application should create activities that exploit the associations and relationships within the material. It should compel the learner to organize and structure responses to problems, so as to develop a deeper understanding. We believe that creative employment of cognitive-based interactive features throughout instructional delivery fosters understanding of underlying concepts and development of practical knowledge that transfers to real-world on-the-job performance. Applying these cognitive principles leads to a training experience that is more interesting, relevant, and effective—not only for electronic learning, but also for traditional classroom-based instruction.

Ultimately, in addition to serving a sustainment training role, the *e*-Learning version of the course could be used to supplement classroom training and deliver training content prior to fielding, thus reducing the amount of classroom time that will be required. Generally, for *e*-Learning, students tend to complete the training in less time compared to equivalent classroom instruction (typical "compression ratios" are in the range of 40-60%; Hall, 1997). Therefore, an economic advantage could be realized both in terms of instructor cost savings and reduction of student labor hours. Costs of *e*-Learning delivery compare favorably to classroom instruction as the number of students to be trained increases (the lower delivery cost of *e*-Learning offsets its higher development cost). Blended learning environments might be employed such that, for example, with approximately 16 hours of *e*-Learning accomplished by students at their convenience, the CAISI classroom-based instruction could be reduced from five days to less than one day (comprising hands-on activities). One question that must be answered is whether the *e*-Learning application will yield equivalent outcomes to classroom training. A survey comparing classroom and distance learning outcomes found that a large number of studies reported no significant differences in the amount of learning or skills that students acquire through classroom and distance learning (Russell, 1998). For the CAISI classroom instruction application, the performance criterion is 80% correct on test items and satisfactory completion of a hands-on, timed performance test. If it can be shown that the *e*-Learning application yields equivalent results, a good argument can be made about increasing the role of the *e*-Learning application. Plans are underway to conduct a study to compare the effectiveness of both forms of the CAISI training.

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