CHAPTER II

LITERATURE REVIEW

This chapter begins with the reasons for the proliferation of CAI effectiveness studies over the years. Next, salient features that differentiate CAI from traditional instruction are highlighted so that a comparison between the two can be viewed from a proper perspective. A review of previous research on CAI effectiveness is then presented, followed by a review of previous meta-analyses of CAI effectiveness.

Rationale for CAI Effectiveness Studies

In certain areas of technical education and training, the use of computers to assist instruction can help to overcome limitations imposed by conventional methods of instruction. In the case of maintenance training, Malek and Luszczak (1987) observed that the number of training systems that enable hands-on training of critical skills are insufficiently low to allow individual learners sufficient time on training tasks. They listed further limitations of using actual equipment for maintenance training, which include:

1. Such systems are not comprehensive due to their limited fault insertion capabilities.

2. Trainee performance is often difficult to evaluate objectively.

3. Individual performance in group-tasks are not easily measured or corrected.

4. Training often focuses on repair tasks rather than on the functional relationships that can increase the in-depth understanding of the system.

CAI has the potential to overcome the above limitations. For example, computer simulations can provide realistic representations of actual equipment that allow students to acquire a comprehensive understanding of the functional relationship between components. This greater understanding enables them to perform maintenance and troubleshooting tasks more effectively. Nevertheless, implementing a CAI program without evaluating its effectiveness is like building a ship without taking it to the water.

The effectiveness of CAI as compared to traditional instruction has been researched for decades. Various studies have been conducted at different educational levels and in various areas of instruction (e.g., Cohen & Dacanay, 1992; Johnson et al., 1992). Technical education and training is one area in which the question of CAI effectiveness has been researched (e.g., Gokhale, 1996; Jarunee, 1996). Military training is one other area where much of the advanced CAI effectiveness research has been conducted extensively (e.g., Lajoie & Lesgold, 1989; Regian & Shute, 1992).

Despite having a good rationale for conducting CAI effectiveness studies, these efforts have had their fair share of critics. Clark (1983) caused a stir among educational technologists by making the following argument: "The best current evidence is that media are mere vehicles that deliver instruction but do not influence student achievement" (p. 445). Clark concluded that the critical factor in determining student achievement is the instructional method, and not the medium such as the computer or instructor. Indeed, Clark's statement sparked a long-lasting debate on this issue. In defending CAI effectiveness research, Roblyer, Castine, and King (1988) refuted Clark's statement by arguing that:

> The point of this research should not be to make the computer instruction exactly identical to teacher instruction, but rather to determine whether the computer-based delivery system has inherent benefits over the teacher-based delivery

> system, for whatever reason. When viewed in this way, the computer may indeed be found to be responsible for making possible greater learning gains (p. 38).

Despite criticisms, CAI effectiveness studies have continued to proliferate over the past two decades. Why has such a great interest been generated? One possible explanation is that researchers are interested in finding ways that assist students in their learning process. Comparing the relative effectiveness of different instructional methods can help determine the method that produces greater learning and is thus deemed more effective. Additionally, results from these studies can help decision-makers in choosing the appropriate method of instruction for a particular educational or training program. Furthermore, since traditional instruction and CAI differ in many ways, one conclusive way to compare them is in terms of their relative effectiveness in producing learning.

Differences Between CAI and Traditional Instruction

This study employed meta-analysis, in which many primary studies were investigated that compared CAI to traditional instruction. Various forms or types of CAI have been used in the primary studies. Similarly, traditional instruction in the primary studies also had variations. A further differentiation beyond definitions is thus required to clarify differences between the two instructional modes. A clearer distinction will emerge if a comparison is made on features that are common in CAI against those that are common in traditional classroom instruction. Such a comparison was provided by Steinberg (1990), who observed that CAI and traditional classroom instruction differ in modes of communication, instructor-learner interactions, and environment. In the following sections, descriptions of some of these differences based on Steinberg’s factors are provided.

Modes of Communication

Live instructors use several modes of communication, mostly oral and physical. They use body language to give encouragement or indicate approval or disapproval where appropriate. In CAI, the dominant mode is visual. Although oral communication technology in CAI is available, it is not yet common. While noting that current technology allows for human speech to be incorporated into CAI, Steinberg (1990) observed that most CAI lessons are primarily visual.

While classroom students listen, read, and observe, CAI students are rarely expected to listen; they tend to only read and observe. Classroom students communicate by speaking or writing, while their CAI counterparts do so by typing, touching a display screen, or manipulating a tool such as a mouse.

Instructor-Learner Interaction

The way interaction occurs in traditional classrooms and CAI lessons also differs. In classroom instruction, only one student at a time responds overtly to the instructor, while other students in the class do it covertly, if at all. In CAI, lessons can be highly individualized, and every student has an equal chance of responding to every question.

Live instructors can attempt to assess students' learning by observing their behavior and then taking appropriate actions. However, the computer can only evaluate students' overt responses. In judging the responses, the computer is less flexible than the human instructor. Unless flexible judging is programmed into a CAI lesson, it cannot differentiate between responses that are similar in meaning. Additionally, a computer can only answer questions if it is programmed to do so. On the other hand, a human instructor can answer just about any question or suggest resources for finding the answer.

Traditional classroom instruction is usually group-paced. The teacher sets the sequence of instruction, and instruction is usually linear, with every student following the same path. CAI, on the other hand, is usually individually-paced with branching paths. The computer, learner, teacher, or some combination can control instructional sequence.

Environmental Factors

Steinberg (1990) noted that environmental factors are common knowledge in one mode but not in the other. For instance, in the traditional classroom instruction, it is often self-evident for students to know how well they are doing. This capability in CAI is only possible when the lesson is designed to do so. In terms of learner-learner interaction, learners usually interact with other learners in the traditional classroom while CAI students seldom do. Repetition of identical lessons is readily available in CAI but not easy to produce in the traditional classrooms.

Theoretical Framework

The use of a theoretical framework for a meta-analysis is different from its use in an individual or primary study. Any attempt to establish a theoretical framework for this meta-analysis should be linked to its purposes. There are two major purposes of this meta-analysis. First, determining the overall effectiveness of CAI in technical education and training, and second, determining how differences in CAI effectiveness are related to various features of the primary studies. These features and their corresponding categories can only be determined after selected studies have been examined in detail. The aforementioned approach has been practiced in many previous meta-analyses (e.g., Kulik et al., 1986; Roblyer et al., 1988). The presence of variations within categories of study features help to explain variations in the observed differences in CAI effectiveness. For example, it might be determined at which educational level is CAI most effective. Another possible focus could be the determination of a CAI type that is most effective.

It is obvious that the different types of CAI selected for this meta-analysis have been based on different theoretical underpinnings. Nevertheless, it can be said that CAI is designed from two broad theoretical perspectives -- behaviorist or cognitivist. The choice of one theoretical basis over the other is dependent on several factors such as educational level and outcomes of instruction. Being a study at the macro level, it is appropriate for this meta-analysis to describe a framework for CAI from the two different perspectives in its broadest sense.

<u>Theories of Learning in CAI</u>

Chambers and Sprecher (1983) examined the major theoretical representations of learning, ranging from low-level to high-level learning. They noted that conditions agreed by most theorists as necessary for learning to occur are contiguity, reinforcement, and repetition. Regarding contiguity and reinforcement, most theorists agree on the importance of reward (i.e., positive reinforcement) immediately following a student's correct response to a problem in a learning situation. Regarding repetition, theorists generally agree that repeated occurrences of the response followed by reinforcement are necessary for learning and retention. Apart from knowing where common ground exists, it is also important to understand the different perspectives of these theories that have produced the schism in educational research.

<u>Behaviorist Theory</u>

Chambers and Sprecher (1983) noted that the renowned behaviorist B. F. Skinner believed that immediate positive reinforcement following a correct response is important in learning but he differentiated between learning a response and maintaining it. For Skinner, once a predetermined level of responding is reached, one should move away from constant reinforcement towards variable reinforcement. This could be reinforcement after fixed periods of times (fixed interval), reinforcement after variable periods of time (variable interval), reinforcement after fixed number of correct responses or behavior (fixed ratio) or reinforcement after a variable number of correct responses or behavior (variable ratio). The purpose of these variable schedules of reinforcement is to avoid weakening the reinforcement. In this regard, Skinner’s views are directly applicable to the drill and practice forms of CAI, and have been used successfully in this area for many years. Chambers and Sprecher also observed that Skinner’s theory is being applied to the tutorial type of CAI. Good tutorial programs put students in control of learning while the computer facilitates learning by presenting materials, questioning, providing help messages, and providing reinforcement for the correct answers.

Cognitive Theory

From the cognitive perspective, Simonson & Thompson (1997, p.41) stated that CAI “needs to be organized and delivered in a way that complements the cognitive structure and level of sophistication of the learner.” They noted that behaviorists emphasize outcomes, while cognitivists place greater importance on the learner. They further listed the following guidelines from the cognitive perspective for the design of CAI.

1. Activation is needed to get instruction started, maintenance is needed to keep it going, and direction is needed to prevent it from being astray.

2. The material to be learned should be optimally organized based on the concept that the understanding of abstract material requires adequate realistic experience. “Children cannot understand a computer-generated drawing of a flower unless they have first experienced real flowers” (p.42).

3. Sequencing of materials is important because learners have different cognitive styles based on factors such as their level of field dependence and level of visual processing. CAI lessons should permit students to learn in a way that best suits their cognitive styles.

4. Feedback should be incorporated into a CAI lesson in its correct form and timing so that information can be used when and where it is needed in order to make progress in the lesson.

5. Discovery learning is a powerful technique that provides learners the chance to explore a lesson in a way that is most appropriate for them. It is based on the assumption that with minimal assistance, students will learn more by discovering the lesson found in the situation. An example of the incorporation of discovery learning is LOGO, a computer language created by Samuel Papert at Massachusetts Institute of Technology.

Advances in technology in the workplace are demanding that students be prepared to engage in higher order thinking. Consequently, instructors and trainers in the field of technical education and training need to emphasize these level of thinking in their instruction.

Higher Order Thinking

Resnick (1987) noted that although higher order thinking cannot be defined exactly, it can be described using the following features: (a) nonalgorithmic -- the action path is not fully specified in advance, (b) complex -- the thinking path is not "visible" from any single vantage point, (c) yields multiple solutions rather than unique solutions, (d) involves uncertainty -- not all information needed to solve a problem is readily known, (e) involves self-regulation of the thinking process, and (f) effortful -- requires considerable mental work in making elaboration and judgements.

Theories of learning have been used in designing CAI that engages students in higher order learning, both in the military and civilian sectors. Examples of CAI systems that have been used to provide this type of learning include (a) operating a space capsule, (b) flying a plane, (c) managing a nuclear reactor station, and (d) repairing a missile system (Shlechter, Bessemer, & Kolosh, 1992). Some of these systems have been evaluated in a controlled manner in order to determine their effectiveness.

CAI Effectiveness Studies

Intelligent Computer-Assisted Instruction (ICAI) or Intelligent Tutoring Systems (ITS) is a form of CAI that could provide higher order learning for students. ICAI possesses greater "intelligence" than the typical or conventional CAI program, and thus enables students to exercise their higher order thinking with the computer. ICAI is based on three kinds of "knowledge and problem solving expertise programmed in a sophisticated instructional environment" (Burns & Capps, 1988, p.1). These knowledge foundations are expert knowledge, student diagnostic knowledge, and curricular knowledge.

The Technical Troubleshooting Tutor is an example of an ICAI that is grounded in learning theory and has been subjected to a controlled evaluation to determine its effectiveness (Johnson et al., 1992). It was developed to simulate troubleshooting scenarios for students to practice troubleshooting faulty aircraft electrical systems. This ICAI incorporated the cognitive apprenticeship model of instruction, which enables it to (a) coach students through difficult situations, (b) sequence learning experiences based on individual performance, (c) fade into the background as student ability improves, and (d) help students develop automaticity through practice. Johnson and his colleagues found that “students who worked on the Technical Troubleshooting Tutor became more effective and efficient troubleshooters than those students who did not have the same opportunity” (p. 51).

Much research on the teaching of knowledge and skills to students through intelligent tutoring systems has been conducted in the military (e.g., Gott, 1995; Lajoie & Lesgold, 1989). This research has been a massive undertaking in terms of effort, time, and money. The expertise of experienced personnel in the subject matter of interest was elicited in the development of these tutoring systems. In the case of SHERLOCK, an ICAI for teaching the skills of troubleshooting test stations for F-15 jets, expert mental models were embedded in the tutor. These mental models were developed through a process called cognitive task analysis where experts document their understanding of the workings of a complex system and their procedures for troubleshooting such systems. In order to determine its effectiveness, SHERLOCK was evaluated using avionics technicians in the military. It was found that students who learned through SHERLOCK “displayed more expert-like problem-solving steps, and made fewer inappropriate or bad moves” (Lajoie & Lesgold, 1989, p. 21).

Lessons learned from the evaluation of SHERLOCK were used in the improvement of the ICAI to produce SHERLOCK II. The newer version was also evaluated in a controlled manner and it was found that students who learned through SHERLOCK II significantly outperformed their control counterparts (Gott, 1995). More strikingly, the performance of apprentice subjects having about three years of Air Force experience was equivalent to those of Master technicians having 10 years of experience in F-15 avionics maintenance.

Gokhale (1996) evaluated the effectiveness of computer simulation for enhancing higher order thinking. The CAI type used by the experimental group was predominantly a simulation program while the control group was given instruction in a laboratory format. Instruction was in the area of electronics where students were tasked to build a small signal amplifier. Gokhale concluded that students who used the simulation software performed significantly better on problem solving tests than control students. In explaining the effectiveness of the simulation, Gokhale noted that the computer simulation offered students the opportunity to engage interactively with the computer on experiments with electronic theories and devices. Thus, they were able to focus on mental activities. On the other hand, laboratory students had the additional task of dealing with laboratory equipment and so had to focus on both physical and mental activities.

As mentioned earlier, not all results of CAI effectiveness studies favored CAI. In assessing computer drill and practice on the performance of secondary school students in an agriculture program, Ogle, Birkenholz, and Stewart (1989) found that it has no significant effects. The results of this study prompted Ogle et al. to raise questions concerning the effects of CAI on student achievement. Yuill (1991) conducted a study on the effects of computerized problem-solving simulations on critical thinking skills of baccalaureate nursing students. The CAI and control groups both participated in the same nursing coursework but the CAI group received computerized patient care simulations as a supplement. CAI activities include assessing a patient's condition through his or her nursing history, obtaining information from a physical examination, identifying a patient's problems, and planning appropriate nursing care. After the experiment, the Watson-Glaser Critical Thinking Appraisal Test was administered to measure gains in critical thinking ability. It was found that the computer simulations had no effect on critical thinking ability. Gains in cognitive knowledge were also measured by the course grades from a test given after the experiment. The CAI students did not perform significantly better than their control colleagues.

Spotts (1992) studied the effectiveness of a multimedia CAI in teaching the fundamental of pneumatics to employees of an automotive manufacturer who were randomly assigned to the experimental (multimedia CAI) and the control group. The same materials were used for instruction in both groups, and the same total instructional time of eight hours was allocated. The multimedia CAI program allowed branching of learning paths, provided remedial lessons, tracked students' performance, and provided feedback. Achievement was measured by the amount of new information acquired and retained after training. From the results of a posttest that measured declarative knowledge, it was concluded that no significant difference on achievement gains was found between the groups.

Thus it can be seen that results from previous CAI effectiveness studies in the field of technical education and training are mixed. The equivocal results from these numerous CAI studies provide researchers with the opportunity to synthesize and integrate the findings through the meta-analytic procedure in order to determine conclusively the extent of CAI effectiveness.

Meta-Analyses of CAI Effectiveness

Kulik (1994) observed that at least a dozen meta-analyses on CAI effectiveness have been performed. He reviewed these and discovered that they were conducted by different researchers at eight different research centers, and further discovered the following points:

1. Students usually learn more in CAI classes as compared to traditional instruction. Achievement effect sizes in the meta-analyses range from 0.22 in elementary and high school science courses to 0.57 in special education classes.

2. CAI students learn in less time as compared to students taught in the traditional way. Savings in time range from 24% in adult education to 34% at the college level.

3. Students like their classes more when taught through CAI.

4. Students in CAI classes develop more positive attitudes toward computers.

5. There were no differences in attitude toward subject matter between CAI students and students taught in the traditional manner.

Kulik summarized his review by saying that “adding computer-based instruction to a school program, on the average, improves the results of the program. But the meta-analyses differ somewhat on the size of the gains to be expected” (p.13).

Meta-Analyses of CAI Effectiveness in Technical Education and Training

Fletcher (1990) conducted a meta-analysis of the effectiveness of computer-controlled interactive videodisc instruction at three different settings: higher education, industrial training, and military training. He found the overall effect size for military training to be 0.39, indicating an improvement in student performance from the 50th percentile to the 65th percentile for the computer-based group. The corresponding effect sizes for industrial training and higher education were 0.51 and 0.69 respectively.

A more recent review by Fletcher (1997) found that time to train is saved by an average value of 30%. He cited Orlansky and String (1979) and Fletcher (1990) as among the researchers who found such results in military settings. One benefit from savings in training time is it enables personnel to be available for operational duty longer, thus producing an indirect cost savings. This indirect cost savings may far outweigh the direct costs in training time (Fletcher, 1997).

Fletcher (1997) cited a study by Fletcher, Hawley, and Piele (1990) that used the cost-effectiveness ratio as a comparison between CAI and other modes of instruction. It compared the costs to increase mathematics scores by one standard deviation through several methods: using peer-tutors, reducing class size, increasing instructional time, and providing computer-based instruction. The most cost-effective method was found to be computer-based instruction and peer tutoring.

The military is regarded as being in the forefront of computer-based training research. This is evident from the various effectiveness studies on such method of training. One example is in the area of flight training. From these studies, Hays, Jacob, Prince and Salas (1992) conducted a meta-analysis of the effectiveness of flight simulation training. They divided the 26 selected studies into jet experiments and helicopter experiments. The major finding was that the use of simulators combined with real aircraft training consistently produced improvements in training for jets compared to real aircraft training only. No significant finding was observed from the helicopter experiments.

CAI effectiveness studies have also been performed in health professions education area. Observing that little had been done to quantitatively summarize the several dozens of effectiveness studies in computer-based instruction in this field; Cohen and Dacanay (1992) proceeded to perform a meta-analysis. As a result, they found an overall effect size of 0.41 from 37 studies that reported achievement outcomes. They further noted that this value is “not as impressive as that found by Hmelo (1989-1990), who located 33 comparative studies on computer-based instruction in health professions education” (p.275). Although Cohen and Dacanay regarded their effect size as not being greatly different from Hmelo’s value of 0.63, they went on to suggest several factors that might cause this difference i.e., inclusion criteria, locating studies, coding study features, and analyzing results. For example, they noted that of the 33 studies cited in Hmelo’s review, only five met their inclusion criteria. Another finding from Cohen and Dacanay’s meta-analysis was that published studies showed statistically significant and larger achievement effects than dissertations and theses.

In their meta-analysis, Kulik et al. (1986) found that CAI in technical training produced an overall effect size of 0.42 from 18 studies that were conducted between 1964 and 1979. Although they found that none of the study features were related to achievement effect size, two features were very close to being statistically significant i.e., type of computer-based instruction and source of study. The effects of computer-based education were found to be almost significantly greater in published studies than unpublished ones and dissertations. This result is similar to the finding from the meta-analysis by Cohen and Dacanay (1992) in the health professions.

Summary

Effectiveness studies provide useful information for selecting the most appropriate method of instruction for a particular situation. Many studies have been conducted in the general field of education as well as the specific field of technical education and training. These studies have compared the relative effectiveness of CAI to traditional instruction. As the results of such studies were equivocal, they have been quantitatively synthesized and integrated by meta-analysts to obtain an overall conclusion. Generally, the meta-analyses have shown positive effects of CAI over traditional instruction but the magnitude of these effects varies according to features of the individual or primary studies. Study features that have previously been investigated include CAI type and educational level and thus will be among those investigated in this meta-analysis.