A META-ANALYSIS OF OUTCOMES FROM THE USE OF COMPUTER-SIMULATED EXPERIMENTS IN SCIENCE EDUCATION

By
JOHN VAN LEJEUNE

Submitted to the Faculty of the Graduate School
Texas A&M University-Commerce
in partial fulfillment of the requirements for the degree of
DOCTOR OF EDUCATION
August, 2002

UMI Number: 3058170

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

A META-ANALYSIS OF OUTCOMES FROM THE USE OF

COMPUTER-SIMULATED EXPERIMENTS IN

SCIENCE EDUCATION

Approved:

________________ Adviser

____

____

____

____

Dean of the College

____

Dean for Graduate Studies and Research

ABSTRACT

A META-ANALYSIS OF OUTCOMES FROM THE USE OF COMPUTER SIMULATED EXPERIMENTS IN SCIENCE EDUCATION

John Van LeJeune, Ed.D.
Texas A&M University – Commerce, 2002

Advisor: Robert L. Windham Jr., Ed.D.

The purpose of this study was to synthesize the findings from existing research on the effects of computer simulated experiments on students in science education. Results from 40 reports were integrated by the process of meta-analysis to examine the effect of computer-simulated experiments and interactive videodisc simulations on student achievement and attitudes. Findings indicated significant positive differences in both low-level and high-level achievement of students who use computer-simulated experiments and interactive videodisc simulations as compared to students who used more traditional learning activities. No significant differences in retention, student attitudes toward the subject, or toward the educational method were found. Based on the findings of this study, computer-simulated experiments and interactive videodisc simulations should be used to enhance students' learning in science, especially in cases where the use of traditional laboratory activities are expensive, dangerous, or impractical.

ACKNOWLEDGEMENTS

I wish to express appreciation for the guidance and encouragement given by the members of my advisory committee: Dr. Robert Windham Jr., Dr. Robert Munday, Dr. Sue Espinoza, and Dr. Ben Doughty. A very special thank you goes to my wife of 24 years, Mary Ann LeJeune, for her continued support throughout my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

The introduction of modern computer technology into the classroom has made possible many new and rich learning environments (Lee, 1999). Among the most innovative uses of the microcomputer in the science classroom is the implementation of interactive videodisc-based simulation (IVD), and more recently, computer simulated experiments (CSE). Computer simulated experiments are computer programs written for the microcomputer which model real world phenomena or duplicate traditional laboratory activities (Armstrong, 1991). One or more CD-ROMs containing computer simulated experiments and laboratories are now routinely packaged with the ancillary materials of most currently published secondary science textbooks produced by major vendors. Interactive videodisc and computer-simulated experiments often include such multimedia features as audio and animated video to represent aspects of the school laboratory. Test tubes, beakers and flasks containing various reagents, mechanical apparatus, electrical circuits, and even virtual animals to be dissected are components of modern interactive videodisc and computer-simulated experiments. Students commonly use the computer mouse or keyboard to control, interact with, and manipulate the simulated components to conduct experiments and record data. The increased availability and use of computer-simulated experiments has prompted increasing controversy among science educators over their effectiveness and appropriate use (Lee, 1999).

Many science educators regard the use of computer simulated experiments and interactive videodisc-based simulations as valuable adjuncts to the regular science laboratory, supporting their use in addition to, but not in place of, genuine laboratory experiences (Clariana, 1988; Gerhold 1985; Ignatz & Ignatz, 1987; Kosinski, 1984; Moore & Thomas, 1983;).

Supporters of the use of computer simulated experiments point out that computer simulated experiments have advantages over real world laboratories in that they reduce the complexity of the task and automate repetitive activities, allowing the student to focus on the most important variables in the learning situation (Kelly, 1998). Advocates of computer-simulated experiments also indicate that simulations promote higher-order thinking skills such as problem solving (Woodward, Carnine & Gersten, 1988) and the study of scientific processes of thinking (Jackman, Moellenberg, & Brabson, 1987; Lunetta & Hofstein, 1981; Rivers & Vockell, 1987). Okey and Oliver (1987) stated that computer simulations are important because they allow interaction with difficult, dangerous, expensive, or time-consuming events. Additionally, computer-simulated experiments allow students to make choices and observe and act on consequences; provide a way to study cause and effect, to make predictions, and to draw conclusions.

Pena and Alessi (1999) preferred certain computer simulated experiments over traditional laboratory activities in some cases because simulations allow students to slow down, speed up, or even halt the time frame of events, allowing them to see events more clearly. They also allow students to observe otherwise unobservable features in a problem situation, such as the exact pattern of light rays and at what points they converge and diverge in a lens. The authors suggested that, most importantly, computer simulated experiments encourage a "what if" inquiry approach to science. Kelly (1998) favored computer-simulated experiments when factors such as danger, cost, and length of time might prevent the real activity from being conducted in the classroom.

The use of computer-simulated experiments has not been relegated solely to the elementary and secondary science classroom. Simulations in training health science professionals present several benefits over the normal clinical rotations. Clinical simulations allow the learner to experience key aspects of reality without risk to the patient. Simulations allow exposure to unusual cases not otherwise available to a particular learner, allow alternative solutions to be attempted without risk to a patient, and allow re-usable standardized opportunities for evaluation of the health care professional (Jones & Kieth, 1983). Waugh et al. (1995) advocated the use of cardiology simulations for use by medical students. While there is no question that the programs are poor substitutes for interaction with human patients, Waugh explained, medical students could experience a wide range of cases which may not present themselves during the student's cardiology rotation.

Humanitarian reasons for using computer simulated experiments and interactive videodisc dissections exist as well. Rather than maintain large colonies of abnormal animals for use in training veterinary students, interactive videodisc and computer simulated experiments technology have been used since the late 1980s, to train students in abnormal physiology and anatomy (Branch, Ledford, Robertson, & Robison, 1987). Animal dissection has been used in biology classrooms since the 1920s, and has become a routine laboratory activity, even though student aversion to the act of dissection appeared in the research literature as early as 1940. The dissection of dead animals has been the reason stated by many biology students as the reason for being "turned off "to biology (Orlans, 1988). Pennsylvania, Florida, and California have passed legislation defending the right of any public school student from Kindergarten to the 12th grade to refuse to dissect an animal in the science laboratory, leading many schools to consider computer simulated and interactive videodisc dissections as viable alternatives (Tylinski, 1994).

Researchers such as Schrock (1984), Samsel et al. (1994), and Offner (1993), support the traditional laboratory activities, maintaining that laboratory work using a computer simulation may not be as effective as hands-on experiences for learning specific science concepts. According to Schrock, "No computer simulation, whether cookbook or one with result, predetermined with ranges of variation, or loaded with random variation, possess the spontaneity and truth-in-detail of a real lab." Schrock also believed that computer simulations did not help students develop values from reality, but further isolated students from real value-producing experiences. Samsel et al. (1994) agreed that simulated labs were inferior to traditional laboratories because a computer simulation could only contain specific outcomes; students could learn no more than these. Samsel argued that while random biological variation could be introduced into the program, most such approaches were rather artificial and cosmetic, and did not bring any new information to the learning experience, such that animal viability could. Samsel concluded that the real point of experiments is that students will have to apply their knowledge carefully in the future, and have to remember exactly how quirky the mammalian physiology could be. Offner (1993), an advocate of dissection in high school biology laboratories, contended that no model, diagram, video, or movie could duplicate the fascination, sense of discovery, wonder, and even awe that students felt when they found real structures in their own specimens. Offner argued that when the specimen was real, the students' attention was heightened and what they learned was registered in their long-term memory. MacKenzie (1988) suggested that even though computer simulated experiments were safe, simple and self-contained, they suffered by their abstract presentation of real world phenomena. Students might develop a false sense of reality or security in the simulation of situations that are complex or potentially dangerous.

As interest concerning the value and use of computer-simulated experiments increased during the 1980s and 1990s, an increase in the number of both qualitative and quantitative studies describing their use and effectiveness emerged. These research studies produced varied and sometimes contradictory findings on the effectiveness and appropriate utilization of computer-simulated experiments. Researchers and educators remain divided on the effectiveness and appropriate use of computer-simulated experiments and interactive videodisc-based simulation in the science classroom.

Statement of the problem

Numerous research studies examining the instructional value of computer-simulated experiments and interactive videodisc simulations have been conducted with conflicting results. A meta-analysis investigating the effectiveness of computer simulated experiments compared to traditional instructional methods and an analysis of the features of the simulation related to its effectiveness has not been previously performed. The problem of this study was an examination and synthesis of research relating to outcomes from the use of computer simulated experiments and interactive videodisc simulation in science education.

Purposes of the study

The purpose of this study was the synthesis, through the use of meta-analytic methodology, of the findings of research literature related to the effectiveness of computer-simulated experiments in science education. Specifically, the study employed meta-analysis to examine the effectiveness of simulation features and implementation strategies of computer-simulated experiments and interactive videodisk technology in terms of the following five student outcome measures:

1. achievement requiring low-level thinking skills such as recall of facts, comprehension, and application;
2. achievement requiring high-level thinking skills such as problem solving, processing skills, or transfer of learning;
3. retention of material at least two weeks after the treatment;
4. attitude toward the instructional method; and
5. attitude toward the subject matter.

Research questions

Five research questions were developed in an attempt to synthesize from existing studies what role computer simulated experiments have in science education.

1. What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to low-level thinking skills?
2. What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to high-level thinking skills?

3. What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to retention of material for at least two weeks after treatment?
4. What are the differences between the use of computer-simulated experiments and traditional learning activities on student attitude outcomes relating to attitudes toward the subject matter?
5. What are the differences between the use of computer-simulated experiments and traditional learning activities on student attitude outcomes relating to attitudes toward the method of instruction?

Significance of the study

The first documented instructional use of a computer was in 1950 with a computer-driven flight simulator used to train pilots at MIT (Roblyer & Edwards, 2000). Since that time, computer simulations have become increasingly common in science laboratories as both computer hardware and simulation software has become more sophisticated and capable. The introduction of microcomputers, such as the Apple II in 1977 and the IBM PC In 1981, into the classroom started a revolution in educational technology that has not subsided to this day. Several major research reviews as well as nearly 1300 individual articles, opinion papers, and research studies on the effectiveness of computer-assisted instruction and more specifically computer-simulated experiments have been written since 1977.

Early reviews of the research literature concerning computer simulation prior to 1977 were generally unfavorable toward the use of computer simulation (Pierfy, 1977). As microcomputers and simulation software improved during the early 1980s, opinions on the effectiveness of computer simulation began to become less decisively negative, and more indeterminate. Studies conducted by Bredemeier and Greenblat (1981), McKenzie and Padilla (1984), Bangert-Drowns, Kulik and Kulik (1985) and Waugh (1985) indicate mixed results on the effectiveness, but offer only limited support for computer simulations in education.

The years between 1983 and 1987 represent years of great change in both computer hardware and software development. The year 1983 saw the development of the CD-ROM, the two-button mouse, and the development of C++ programming language. Microsoft introduced the Windows operating system in 1985, and both Apple and IBM unveiled much more capable and greatly improved computer systems (the Apple Mac II and The IBM PS2/386DX respectively) in 1987. Computers and software have continued to improve during the last decade of the twentieth century, and more recent literature reviews and meta-analyses indicate more positive outcomes of computer simulation in education, especially in scientific fields (Lee, 1999).

Armstrong (1991) performed a meta-analysis on the outcomes of educational simulations in all subject areas on 55 research studies from 1984 to 1990. Of these 55 studies, 15 were either computer-simulated experiments or interactive videodisc simulations. The author did not submit these studies to individual analysis, but included their effect sizes in the more general study. Armstrong found that there were positive effect sizes for low-level recall of facts, an effect size of +0.31; high-level thinking skills, +0.28; and for retention of facts after two weeks, +0.27. Negative effect sizes were noted for attitudes toward the subject, -0.32, and for studies that grouped students for the simulation, -0.09. Attitudes toward the method of instruction were positive with an effect size of +0.4. Armstrong concluded that the reason for this highly positive result was due to the highly interactive nature of some of the simulations.

Stratford (1997) conducted a review of computer-based modeling and simulation research for pre-college science classrooms. Stratford's reviews of studies by Brna (1987, 1991) on kinematics, Gorsky & Fiengold (1992) on mechanics, and White (1993) led the author to conclude that computer simulations can help students identify and revise scientifically inconsistent conceptual understandings. Stratford's review of eight studies on genetics simulators, found that genetics models could generate realistic problems for students to solve and realistic data to analyze. Slack and Stewart (1990) found that the simulation, while providing a realistic problem-solving environment, did not elicit good problem solving skills from the students. They concluded that the simulation did not develop adequate connections between conceptual knowledge and problem-solving strategies. The authors recommended that genetics concepts, hypothesis generation and genetics testing strategies be taught before the simulation. The issue of appropriate placement of simulation into the lesson cycle tends to be a continuing concern of researchers, and might explain some of the conflicting results of similar studies such as those conducted by Stewart, Hafner, Johnson and Finkel (1992). Students in these studies were successful in model revising and problem solving and were able to produce genetic models that were compatible with accepted theory. The authors claimed that an advantage of simulations is that they allow the students to engage in knowledge production in the classroom, significantly increasing the amount of research they can do as compared to actually crossing fruit flies.

Ronen, Langley, and Ganiel (1992) conducted a study of 300 physics lessons using computer-simulated experiments in 50 physics classrooms with 18 teachers. Resulting teacher opinions were that simulations contributed favorably to students' achievement, interest and involvement. These teachers made a number of suggestions relating to the appropriate time and method to incorporate simulations into the lesson cycle. Appropriate uses included initial subject presentation, exploration during teaching, drill and practice, assisting laboratory work, and summary and review.

Stratford's (1997) review of Feurzeig (1992) study on a cardiac simulation, and Richards, Barowy, and Levin's (1992) study on a bouncing ball simulation reported favorably on the ability of simulations to improve problem solving strategies and inquiry skills. Muffoletto and Knupfer (1993), however, reported no significant differences in students' science reasoning skills when groups using simulations were compared to groups using traditional biology laboratory activities. Stratford concluded that simulations were useful in confronting students with misconceptions and "promising" as it concerns the acquisitions of conceptual knowledge. The author also concluded that simulations are effective at developing student problem solving, theory building, and inquiry skills.

Lee (1999) performed meta-analysis similar to the study completed by Armstrong six years previously. Like Armstrong, Lee did not isolate studies concerning computer-simulated experiments or interactive videodisc simulations, but included such studies in the larger meta-analysis. Lee's meta-analysis analyzed 19 studies on computer simulations, 10 of which were related to science subjects. The effect size calculated for academic achievement of students using simulations as compared to students using traditional educational methods was positive (+0.41). The effect size for attitude toward the use of simulation was slightly negative (-0.09).

Over 1300 studies have been published regarding the use of computer simulation in science education. Of these studies, the majority of the early findings from the 1970s to the early 1980s were negative, perhaps owing to the limitations of computer hardware and a lack of sufficiently effective software simulations. Since the middle 1980s, however, reviews of simulations in science classrooms have reported conflicting, but generally favorable student outcomes. Meta-analyses by Armstrong (1991) and Lee (1999) on the outcomes of computer simulations in a variety of subjects have reported positive effect sizes in several student outcomes, but negative effect sizes in others. Additionally, the effectiveness of several implementation features such as type of simulation, presentation mode, and amount of expository instruction used in the simulation need further study. A meta-analysis specifically investigating computer-simulated experiments and interactive videodisc simulations in science classrooms has never been conducted.

Since the introduction of the microcomputer into the science classroom in 1977, science educators have utilized this technology to simulate laboratory investigations. Numerous research studies examining the instructional value of computer-simulated experiments and interactive videodisc simulations have been conducted with conflicting results (Lee, 1999). There is a need to investigate the source of conflicting outcomes on the effectiveness of computer-based laboratory simulations by integrating related primary studies in a systematic way.

Method of procedure

This study utilized meta-analysis, a data collection and analysis technique developed by Glass (1976), designed to synthesize results from a large collection of studies for the purpose of integrating the findings. The purpose of the meta-analysis is to draw useful conclusions from the findings of previous studies as well as to synthesize those data in order to make new discoveries and relationships (Rosenthal, 1984). The capacity of the meta-analytical technique to investigate relationships among significant features of many studies and their outcomes is among the strengths of this approach.

Hunter and Schmidt (1990) pointed out that rather than resolve an issue, large numbers of studies on a particular topic increase the number of conflicting results. At this point the need is not for conducting further studies, but attempting to resolve existing studies (Hunter & Schmidt, 1990). According to Glass (1976), meta-analysis is the appropriate method to accomplish that goal, by drawing generalizations from findings presently available and providing insight about what remaining research needs are.

Specific procedures of the meta-analysis technique used in the study were as follows:

1. Identifying and collecting the studies;
2. classifying, and coding the studies;
3. quantifying the findings on a common scale; and
4. analyzing the data.

Identifying and collecting the studies

The identification of related literature and previously conducted studies began with an on-line search of computer databases such as ERIC, UMI ProQuest Digital

Dissertations, and Wilson Select Plus. The abstracts of resulting citations were viewed, and pertinent studies were obtained. As these articles were collected, references cited within these articles were considered for collection. This method continued until no further pertinent research articles were found.

Classifying, and coding the studies

Relevant features and characteristics of the analyzed studies were coded by a panel of three judges with expertise in the fields of educational computing, and entered onto a coding sheet as well as a computer database, as recommended by Lipsey and Wilson (2001). Seven major variables identified by preliminary examination of previous meta-analyses and literature reviews were coded, and those were related to five outcome effect magnitudes related to student achievement and attitude. The seven variables to be coded were:

1. simulation type (interactive video-disc, computer-simulated experiments)
2. instructional mode of the simulation (exploratory, confirmatory),
3. subject matter (biology, chemistry, physics, environmental science, earth science),
4. grade level of students,
5. length of treatment.
6. gender of students, and
7. the year of publication of the study.

The five student outcomes to which these variables were related were:

1. low-level thinking skills,
2. high-level thinking skills,
3. retention,

4. attitudes towards the subject being studied, and

5. attitudes toward the simulation.

Quantifying the outcomes on a common scale

The meta-analytical technique requires that a common scale be used to compare the outcome measures of individual studies included in the body of research. This commonality of scale was accomplished by calculating a statistic called the effect size. The effect size for each individual study included in the meta-analysis is calculated by dividing the mean difference between experimental and control groups of that study by the pooled within-group standard deviation of that study (Glass, 1976).

Analyzing the data

Once calculated, the effect size for each individual study was then included in a calculation of an overall mean effect size for the entire body of studies.

The overall mean effect size indicated whether the treatment had an overall positive, negative or no effect for each of achievement and attitudinal constructs.

In addition to the primary research questions, additional features of the related studies were coded and subjected to meta-analysis. Studies containing similar coding were grouped for the purpose of determining if studies with similar codes contain similar results, leading to a clearer understanding of outcomes.

Definition of the terms

The following terms, used in the study, may be operationally defined as follows:

Computer simulation. Computer-simulations are "computer programs that allow the user to interact with a computer representation of either (a) scientific model of the natural or physical world, or (b) a theoretical system" (Weller, 1996)

Computer-simulated experiments. Computer-simulated experiments are computer simulations that provide learner-centered environments and allow students to explore systems, manipulate variables and test hypotheses. These include procedural simulations involving manipulation of screen icons to emulate the assembly and utilization of equipment, and process simulations involving models of invisible phenomena that have mathematically interrelated variables that can be manipulated to observe changes. (Windschitl & Andre, 1998).

Instructional simulation. Instructional simulation is a simulation intended to result in a predetermined learning outcome. (Armstrong, 1991).

Meta-analysis. Meta-analysis is known as an "analysis of analyses", and refers to the application of a quantitative method applied to descriptive studies. The technique involves the synthesis or integration of numerous studies on a single topic by combining probabilities across studies. (Glass, McGaw & Smith, 1981)

Limitations of the study

Meta-analysis methodology was utilized in this study to summarize previously reported research literature. Because this study's findings were based on prior research, the investigations of features relating to the implementation and effectiveness of computer-simulated experiments were limited to those features investigated and reported in the literature. In addition, the validity of meta-analysis is dependent on the degree to which the collected data represent the total research.

Delimitations of the study

The decision to include the studies contained in this meta-analytical synthesis was determined using the following guidelines.

1. The study must have contained sufficient data for the calculations required in meta-analysis.
2. In the case of the results of a primary study appearing in more than one publication, the more complete study was used.
3. The simulation type must have been presented on PC, Macintosh or videodisc technology.
4. Each study must have been published within the period of January 1983 to December 2001.
5. The simulation must have been pre-programmed and produced for the purpose of instructional simulation in the science classroom, as opposed to simulations produced by students or simulation games.
6. The study must have employed a true or quasi-experimental design.

Assumptions of the study

The meta-analytic technique employs statistical analysis to synthesize the results from many primary research studies into a single overall effect size. No two studies, however, measure exactly the same outcomes, or use exactly the same instruments. The meta-analytical technique assumes that even though the primary studies are not identical, they are similar enough to synthesize into a single general outcome measure. Since meta-analysis relies upon the findings of prior research, the selected studies were assumed to be methodologically sound. In addition, studies used in the meta-analysis were assumed to be representative of all studies relating to the use of interactive videodisc and computer-simulated experiments in science education.

Organization of chapters

Information for this study is presented in five chapters. Chapter 2 consists of a review of literature pertaining to the use of computer simulated experiments in science classrooms, reviews of previous studies on the use of computer simulated experiments, and other literature related to the field, as well a review of the studies contained in the meta-analysis. Chapter 3 provides a detailed description on the methodology used in this study, and chapter 4 consists of a presentation of findings and an analysis of the results of the study. Conclusions concerning the results of the study and recommendations for future research are contained in chapter 5.

Chapter 2

LITERATURE REVIEW

The review of literature begins with a brief history of the personal computer, followed by a summary of theoretical and non-experimental literature concerning computer-based simulations. The following section reports on the findings of previous meta-analyses and literature reviews of instructional simulation. The final sections present a brief summary of each of the studies included in the meta-analysis procedure and summarize the review of literature.

A brief history of microcomputers

According to Veit (1993), the first true microcomputer was the IBM 5100 ®, developed by IBM in the early 1970s. This $10,000 machine had a five-inch screen and stored programs and data on a cassette tape. While the IBM 5100 ® was the first true microcomputer, the first practical microcomputer was developed by a tiny garage-based computer firm, Apple Computers, which produced Apple I ® 1976, and quickly followed with the Apple II ® in 1977 (Roblyer & Edwards, 2000). Apple computers became the standard in microcomputer technology and were found in thousands of homes and classrooms across the country. IBM re-entered the microcomputer market in 1981 with its IBM PC Jr. ®, a machine based on the Intel 8088 ® processor, and using a DOS (Disk Operating System) developed by Microsoft Corporation.

The years between 1983 and 1993 represent years of great changes in both computer hardware and software. The CD-ROM, the two-button mouse, and the C++ programming language were all developed in 1983. Microsoft introduced the Windows ® graphical interface in 1985, and both Apple Computers and IBM unveiled much more capable and greatly improved computer systems (the Apple Mac II ® and The IBM PS2/386DX ® respectively) in 1987. Also during this period, Phoenix Technologies Ltd. Corporation produced the Phoenix BIOS ®, a virtual equivalent to IBM's patented BIOS (Basic Input Output System), allowing other computer manufacturers to produce "IBM compatible" computer systems based on the Intel ® 80386 processor, and later, on the 80486 processor (Gockhale, 1989).

The second major era of microcomputer advancement began in 1993 with the introduction of the Pentium ® processor by Intel Corporation. Ncarly twice as fast as previous processors, the new Pentium ® machines allowed sophisticated and realistic graphics and audio to be incorporated into programs. Realistic and highly interactive simulation games became increasingly popular consumer products, including a growing number of educational simulations. No longer limited to purely textual or unrealistic graphical feedback, simulations of all types improved dramatically with the development of the Pentium ® family of processors (Roblyer & Edwards, 2000).

Theoretical and non-experimental literature

Scientific Inquiry

Scientific inquiry refers to the diverse ways that scientists study the natural world and propose explanations based on the evidence derived by their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world. (National Research Standards, 2000, p.23.)

In his address to the American Association for the Advancement of Science in 1909, John Dewey contended that teachers of science often gave too much emphasis to the accumulation of information and not enough to science as a way of thinking and an attitude of mind. Dewey stated that science was more than a body of knowledge to be learned, there was also a process or method to learn as well (Dewey, 1910).

Schwab (1960, 1966) argued that the study of science should be viewed as conceptual structures to be revised as the result of new evidence. Schwab suggested that teachers should present science as inquiry to learn science, looking first in the laboratory and then later in the classroom. Schwab (1960) recommended three approaches to their laboratories:

1. teachers could use laboratory manuals or textbook materials to pose questions and describe methods to investigate the questions;
2. teachers could use instructional materials to pose questions, but allow the students to determine the methods and answers; and
3. teachers should allow students to use an open approach, without textbook or laboratory based questions.

Students could ask questions gather evidence, and propose scientific explanations based on their own investigations.

Constructivist theory

While Dewey and Schwab concerned themselves with mostly practical aspects of the inquiry method, cognitive psychologists including Piaget, Bruner, Kuhn, and others were developing theories, known as constructivist theory, which supported the ideas of the inquiry method. The premises of constructivism, according to the Physics Education Research Group (2001), include the following:

1. knowledge is constructed, not transmitted;

2. prior knowledge impacts the learning process;

3. initial understanding is local, not global; and

4. building useful knowledge structures requires effortful and purposeful thought.

According to Piaget (1969), learners evolve through four stages of cognitive development: sensorimotor, preoperational, concrete operations and formal operations. Learners are able to evolve from one stage to the next through the processes of maturation, experience, social transmission, and equilibration. Equilibration, the most fundamental factor in the process, is a motivation for attempting to pose order and meaningfulness on experiences. Equilibration can be accomplished in two ways, assimilation and accommodation.

Assimilation occurs when students use existing concepts to understand new phenomena. Kuhn (1962) called these existing concepts "paradigms," which help students to define problems, indicate strategies for dealing with them, and specify criteria for what counts as solutions. Assimilation does not force the learner to confront conceptions that are different than those that are preexisting or "preconceptions".

If the existing cognitive structure is unable to process the event, a crisis occurs. The new concept, an anomaly, has to be dealt with in some way; the existing structure must be modified to fit the environmental demands in a change called accommodation. Accommodation requires that the learner be dissatisfied with the existing concept structure, and want to overcome this disequilibrium. These cognitive conflicts provide an essential factor in constructing new knowledge, and an opportunity for higher-level knowledge construction.

According to Hewson and Hewson (1983), once dissatisfaction of a learner's preconception has been achieved, it is necessary to present the new material in such a way that the learner wants to exert the effort to accommodate the new data. The new concept must be presented in a fashion that is intelligible, plausible, and fruitful. Unless the new concepts are sensible, understandable, believable, and useful in solving problems, learners may not see the benefit of accommodating these conflicts at all.

Yerrick (1996) explained that simulations could construct worlds that can be changed, observed, modified, and manipulated in ways that the physical worlds cannot. There is no way, for example, to design a physical experiment that is totally uninfluenced by the forces of gravity and friction, yet these conditions may be necessary for eliciting dissatisfaction in a learner. Once dissatisfaction has been accomplished, the intelligibility, plausibility, and fruitfulness must be established. According to Yerrick, intelligibility can be enhanced by comparing simulations of student held conceptions with scientifically established paradigms so that the two can be contrasted as competing explanations of the same simulated event. The ability of the simulation to repeat the accepted explanation many times, along with graphical and numerical feedback, helps the learner to accept the alternative view as plausible. The fruitfulness of simulations can be demonstrated by the ability of the simulation to be edited and performed again and again producing instantaneous data. This allows students to ask and answer questions of real events in short time frames. Simulations may also aide in testing the fruitfulness of a scientific concept in predicting new events. Each of these options, according to Yerrick, within simulation software provide ways to bring into question students commonsense notions, establish dissatisfaction, and make the scientific explanations more intelligible, plausible, and fruitful as avenues of research.

Simulation and cognitive change

Several studies have been conducted to determine if computer-simulated experiments are effective at presenting learners with conflicting paradigms, and capable of facilitating assimilation or accommodation. Hakerem, Dobrynina, and Shore (1993) conducted a case study on the effect of interactive three-dimensional simulations of the interactions of water molecules on the thought processes of four high school science students. These students were chosen from a pool of 245 high school students based on the misconceptions that the subjects held about the nature of water molecules. In a series of "think aloud" interviews before, during, and after an interactive simulation of water molecule interaction, the researchers tracked the progress of the students as they discovered their misconceptions and accommodated them, becoming able to visualize the interactions of molecular particles. The conclusions reached by the researchers were that the interactive simulations afforded a much better method of allowing the students to "see" the world at the molecular level, and develop an understanding of the nature of the behavior of particulate matter.

Monaghan and Clement (1999) conducted "think aloud" interviews with three high school post-physics students after they had interacted with a relative motion computer simulation presented in a predict-observe-explain format. The simulation displayed the relative motion of a black car, a white car, and a plane from different frames of reference as follows: the ground, the white car, the black car, and the plane. The student first observed the speeds using the ground as a frame of reference. The student was then asked to predict the speeds of the objects from a different frame of reference. After the prediction, the simulation would be run, and the student would be asked to explain the prediction and why it was either correct or incorrect. This procedure was repeated for each of the frames of reference and for each of the three subjects. The researcher analyzed results of the three cases, and found significant improvement in dynamic imagery use in two of the three subjects. The researcher concluded that simulations such as the one used in that study were promising as instructional tools. The students were able to understand the visual representations of the simulations draw appropriate analogies to new situations and make inferences. Monaghan concluded that a simulation can:

1. Provide an experience that produces dissonance;
2. Provide an initial example of the behavior of a system that stimulates students to construct an explanation of the behavior;
3. Provide a framework for the visualization that can allow the student to transfer ideas to similar but different problems; and
4. lead to the formation of a schematic model that relies on mental simulation rather than computer simulation.

Windschitl and Andre (1998) investigated the effects of exploratory (before initial instruction) vs. confirmatory (after initial instruction) instruction in a study conducted on 250 non-biology major undergraduate students. Prior to either treatment, students were given a survey concerning their epistemological beliefs concerning objectivism and constructivism. The confirmatory group received a computer simulation on the cardiovascular system that was reduced to a step-by-step cookbook approach. The exploratory group used a simulation that allowed students to freely create, test and evaluate their own hypotheses about the human cardiovascular system. After treatment, the researchers found that students with objectivist beliefs preferred the confirmatory simulation, while the students with constructivist beliefs preferred the exploratory simulation. These results indicate that simulations may be beneficial in the confirmatory role for concepts that fit within the learners pre-existing conceptual framework, as well as in the exploratory role for those concepts that must be accommodated.

Zietsman and Hewson (1986) conducted an experiment with 34 students taking high school physics, on the effectiveness of a computer simulation to change students' conceptions of Newtonian motion. The experiment addressed three critical areas of the effectiveness of computer simulations on conceptual change. The first part of the experiment compared a computer simulation with a mechanical device, a Towbridge and McDermott's apparatus. The second phase of the experiment used simulations as a diagnostic instrument, to determine which students had misconceptions concerning Newtonian motion. The third phase of the experiment assessed the effectiveness at remediation on those students with misconceptions about Newtonian motion. The researchers found that there was no difference in the students' response to the simulation or the mechanical apparatus. They also found that there was no significant effect of the simulation on the students' misconceptions during the diagnostic section of the experiment. There was, however, significant conceptual change in student understanding of Newtonian motion after the remediation simulation. These results indicate that while the use of simulations might not be superior to traditional laboratory demonstrations, simulations are more effective at remediation than traditional methods.

In a similar study, Weller (1995), studied the effectiveness of computer simulations to diagnose and assist in the remediation of students' misconceptions of motion and dynamics. Using a five-step process, Weller interviewed students, developed a diagnostic program, and performed two pilot studies to arrive at the most common student misconceptions and the instruments with which to identify those misconceptions. Weller then produced a computer simulation designed to counter those misconceptions and administered the simulation after a pre-test of students' dynamics conceptions. The results of a posttest administered immediately after the simulation indicated a significant change in students' conceptions about motion. A delayed posttest was administered six weeks later, and students again showed a high level of achievement on the measure of motion concepts. Follow-up interviews revealed that features of the simulation which would not have been present during an actual experiment (vector arrows), helped students understanding of motion.

Advantages and disadvantages of simulation

While both traditional laboratory activities and simulations are forms of inquiry which engage the learner in the process of observing, hypothesizing, experimenting and forming conclusions and relationships among data, computer-simulated experiments are considered to be, by some authors, superior to conventional laboratories as inquiry tools (Mintz, 1993). In addition to many practical advantages, computer-simulated experiments have a number of instructional advantages. Mintz (1993) listed the following advantages of computer-simulated experiments:

1. Various types of research problems which cannot be addressed by conventional experimentation, such as prediction and forecasting, can be presented to the learner through simulation;
2. Simulations can provide immediate input and output, allowing students to see immediate connections between hypotheses and experimental results. Immediate responses to "what if" questions encourage students to examine various systems states and investigate as many hypotheses as they desire without fear of error and without having to repeat their experiments;
3. Isolation and control of variables enable students to assess the effect of each individual variable as well as their combined effects, promoting clearer understanding of this key aspect of inquiry work; and
4. Simulations can display information in a variety of formats, improving student ability to interpret and organize data.

Min (1995) presented a more complete and detailed list of advantages offered by computer simulation. Advantages listed include such considerations that many pieces of the apparatus necessary to be able to carry out an experiment in reality is too expensive; and often this apparatus can only be operated by specialists, if it can be obtained at all. Furthermore, the process to be investigated might take place so quickly in reality that it cannot be examined through the traditional experiment, such as certain chemical processes. On the other hand, the process to be examined can proceed too slowly in the real world, such as biological processes involving multiple generations. Other processes, such as ecological systems, may be too complex to examine through traditional laboratory investigations. Processes such as planetary movements in space, or molecular motion may be either too large or too small to investigate in a traditional fashion. Some processes such as nuclear reactions or the physiology of a human body, or certain disease processes can be irresponsible to research from an ethical point of view through traditional experiments. Since simulation often goes hand-in-hand with visualization, Min also recommended the use of simulation to introduce trainees to a new subject, as students often need some insight before they are able to learn and understand a new concept. Computer simulations allow the student to insert those parameter values that he or she thinks will produce a result that is of interest to him, as well as allow a student to choose how he or she wants to approach a simulation or experiment. Computer simulation also allows the student to repeat the experiment how often he or she wants to repeat the experiment and to determine to which degree he or she wants to intervene. Finally, Min stated that if well designed, learning how to operate a computer simulation program generally requires little effort, and offers the student the advantage that they perceive that not everything can be used as input. Disadvantages are also connected with the use of computer-simulated programs in education. Limitations are in some cases the result of the wrong or inappropriate use of such programs. Min (1995), listed several possible limitations of a general and educational kind are as follows:

1. Simulation concerns the manipulation of a number of variables of a model representing a real system. However, manipulation of a single variable often means that the reality of the system as a whole can be lost;
2. A computer simulation program cannot develop the students' emotional and intuitive awareness that the use of simulations is specifically directed at establishing relations between variables in a model;

3. Computer simulation cannot react to unexpected 'sub-goals' which the student may develop during a learning-process;
4. Computer simulation programs may function well from a technical point of view, but they are difficult to fit into a curriculum;
5. Often a computer simulation program cannot be adapted to take different student levels into account within a group or class; and
6. during the experience of interaction with a computer simulation program, the student is frequently asked to solve problems in which creativity is often the decisive factor to success.

Review of non-experimental studies

In a study conducted by Kinnear (1986) on the use of computer simulation in a high school genetics class, 68 undergraduate biology students used computer-simulated experiments to virtually mate fruit flies and other species to simulate genetics principles. These virtual genetics experiments were designed to mathematically replicate the number and types of offspring that would have been produced in the real world, only at an immensely accelerated time frame. From the computer-generated results, the students were asked to deduce the underlying genetic principles and explain how the resulting numbers of offspring were produced. The researcher found that these types of simulations could encourage students to think "productively" rather than "reproductively". Kinnear concluded that simulations facilitated meaningful, rather than rote learning of genetic concepts.

Okey and Oliver (1987) conducted an experiment investigating the types of tactics and strategies that students used in working with computer simulations. Subjects in this study were 50 students enrolled in three sixth-grade classes, from three different schools. A pretest measuring logical thinking ability was administered to the students before treatment began. Students used a survival strategy simulation to exercise problem-solving techniques and develop higher order thinking skills. Students from two of the schools worked in a computer laboratory with two students assigned for each compute,, while students at the third schools worked in groups of four or five throughout the day on a single classroom computer. Students working in the laboratory setting completed approximately one hour of time on the computer per day, while students in the single-computer classroom only used the computer 20 minutes per day. After treatment, students completed a survey to determine their attitudes toward computing, and a test of their ability to transfer simulation skills to new topics. Researchers conducted interviews with selected students throughout the study and made tape recordings of several groups of students as they used the simulation. Researchers found that students working in pairs scored higher on measures of attitude toward computers than did the students working in larger groups. Findings also included a high correlation between scores on the measure of logical thinking ability and on ability to transfer skills to new topics. The authors concluded that computer simulations allow interaction with difficult, dangerous, expensive, or time-consuming events, and allow students to make choices and observe and act on consequences, provide a way to study cause and effect, to make predictions, and to draw conclusions.

Mintz (1993) conducted a qualitative study on a pond life ecosystem simulation developed at Tel Aviv University in Israel. Observations were recorded for nine pupils, aged 14-15, as the students ran the simulation for a total of six one-hour lessons over a period of three weeks. The simulation was an unguided, pre-instructional activity in which students controlled the amount of food added to a pond ecosystem, the maturation age of the fish, and the number of offspring possible to each fish. The students observed the number of fish increase or decrease through several generations as a response to their strategies. The number of fish did not increase infinitely, however, due to space limitations, as the size of the pond was finite. The task of the students was to come up with an appropriate hypothesis and inquiry strategy to determine the best possible strategy for increasing the fish population to its maximum level. By the end of the sixth session, all students successfully found the relationship between the variables, and completed the assignment. Mintz found that the computer simulation expanded and improved classroom inquiry work in the areas of posing hypotheses, conducting experiments, observing and recording data, and drawing conclusions. Mintz reported that the students displayed motivation and interest while working with the simulation, and concluded that simulation can compliment the conventional laboratory in enabling students to improve scientific process-experimentation.

Khoo and Koh (1998) conducted a survey of 28 undergraduate education majors enrolled in an advanced university chemistry or physics course. Students were presented with a series of lectures on molecular dynamics and the crystal structures of molecules before being trained on the use of the simulation software. Students were asked to build construct simple molecules varying the bond angle, bond lengths and varying energy minimizations. Students were to then construct crystals starting from these molecules using correct unit cells. Students were then allowed to rotate these crystal structures and in different orientations and to explore the effect of varying temperatures on these crystals. After the simulations, a simple questionnaire was administered to solicit feedback regarding the students' understanding and visualization of the concepts learned in the molecular dynamics and crystal structure simulations. Results of the survey indicated that students rated their ability to visualize and build crystal structures highly. Responses to the use of the simulation as a learning tool resulted in positive results from all subjects. Additional evidence to support the highly significant positive results of the simulation's effect on students' ability build molecular models and crystal structures was observed when students were able to correctly write flow charts and FORTRAN computer programs about the steps with hardly any supervision. The authors concluded that computer simulations were an effective and less costly method of teaching molecular modeling. The authors noted that the simulations offer the possibility of posing totally new problems or solutions. Students could, for example, produce and explore hypothetical compounds totally impossible to produce in a "wet" laboratory.

Eylon, Ronen, and Ganiel (1996) conducted a study using an optics simulation on a group of 32 high school physics students. The control group consisting of 29 students was taught by a different teacher and received no treatment. The program simulated the refraction of rays of light as they encountered differently shaped lenses and mirrors. The researchers found that the experimental group scored significantly higher ($p < 0.005$) on a post-test administered to the experimental and control groups. The second phase of this study examined the achievement of a group using the simulation program with a structured workbook and compared them with a group using the structured workbook and using paper and pencil rather than the simulation program to draw ray diagrams, and a group with neither simulation nor a workbook. The group with the structured workbook and simulation performed significantly better than either of the other two groups, leading the researchers to conclude that while the simulation environment promoted student understanding of geometrical optics, that the student also requires guidance to overcome conceptual difficulties.

Previous reviews and meta-analyses

In his review of primary research studies pertaining to computer-based simulation research in pre-college science classrooms, Stratford (1997) analyzed 11 primary research articles dating from 1988 to 1995. From these primary research articles, the majority of which were qualitative, Stratford found the following:

1. computer simulations can help students identify and revise scientifically inconsistent conceptual understandings;
2. generate realistic problems for students to solve and realistic data to analyze;
3. allow students to engage in knowledge production in the classroom;
4. significantly increase the amount of research students can do;
5. contribute favorably to students' achievement, interest and involvement; and
6. contribute favorably to students' problem solving strategies and inquiry skills.

Finally, Stratford concluded that while simulations could be successfully integrated into appropriate theory building and inquiry activities, the actual large-scale integration into schools had proved to be difficult.

Dekkers and Donatti (1981) conducted an analysis of 93 studies involving computer-based as well as non-computer based simulation studies completed prior to 1979. Even though the researchers considered this synthesis to be a meta-analysis, it should be considered a literature review as is it contained studies that were not based on true or quasi-experimental research designs, nor were effect sizes reported for the primary studies. They concluded that simulation instruction was equal to traditional instruction methods in terms of achievement and retention, but more effective in terms of attitudinal factors.

As part of a larger meta-analysis, Kulik and Kulik (1989) reported on five studies using computer-based simulations in a wide variety of educational subjects, including science, and found that simulations were more effective for the science and technology simulations than for other subjects. The effect size for achievement outcomes for computer simulations combined with other computer enrichment programs was + 0.26 overall. The effect size for pre-college students was +0.10, while the effect size for students at the post-secondary level was +0.34. In addition to finding significantly different effect sizes based on the student grade level, Kulik and Kulik also discovered that effect sizes tended to be larger for studies lasting less than four weeks, and for studies that were unpublished.

Unfortunately, these early attempts at synthesis offer little insight into the effectiveness of computer simulation in classrooms today. Becker (1986) critiqued the early meta-analyses of computer-based learning and found that in out of the 284 studies he reviewed, only three studies utilized microcomputers in use in schools of that era (Apple II and IBM PC). Kulik and Kulik (1986) also noted the limited applicability of earlier reviews:

> Computers have changed dramatically since that time. They have become smaller, less expensive, more reliable, and quicker in their operations. Communication has become easier with them and their output has become more

> readable and attractive. These developments have influenced not only the ways in which computers are being used in college teaching today, but also to the subject areas to which they are being applied. (p. 83)

Armstrong (1991) performed a meta-analysis on the outcomes of educational simulations in all subject areas on 55 research studies from 1984 to 1990. Of these 55 studies, 15 were either computer-simulated experiments or IVD simulations in science subjects. The author did not submit these studies to individual analysis, but included their effect sizes in the more general study. Armstrong found that there were positive effect sizes for low-level recall of facts, an effect size of +0.31, high-level thinking skills, +0.28, and for retention of facts after two weeks, +0.27. Negative effect sizes were noted for attitudes toward the subject, -0.32, and for studies that grouped students for the simulation, -0.09. Surprisingly, attitudes toward the method of instruction were positive with an effect size of +0.4. Armstrong concluded that the reason for this highly positive result was due to the highly interactive nature of some of the simulations.

Lee (1999) performed meta-analysis similar to the study completed by Armstrong six years previously. Lee, like Armstrong, did not isolate studies concerning computer-simulated experiments or IVD simulations, but included such studies in the larger meta-analysis. Lee's meta-analysis analyzed 19 studies on computer simulations, 10 of which were related to science subjects. The effect size calculated for academic achievement of students using simulations as compared to students using traditional educational methods was positive (+0.41). The effect size for attitude toward the use of simulation was slightly negative (-0.09). In addition to the effect sizes previously reported, Lee concluded the following:

1. Within the presentation mode, the guided simulation is much more effective than the unguided simulation.
2. Simulations are almost equally effective for both the presentation and practice mode if the guided simulation is used.
3. Specific guidance in simulations seems to help the student perform better.
4. When students learn in the presentation mode with unguided simulation, they showed a negative attitude toward simulation.
5. Even in the practice mode students showed very little preference to simulations
6. Science seems a very fit subject for simulation type learning.

Reviews of studies used in the meta-analysis

Barker (1988) compared the effectiveness of interactive videodisc to lecture-demonstration in teaching physical therapy students the sliding board transfer skill. Students were randomly assigned to two groups, a control group and an experimental group, of 15 students each. The control group received a lecture-demonstration, and the experimental group received an interactive videodisc simulation. Students in both groups were graded on their performance on a demonstration of their ability to perform a sliding board transfer. In addition to this demonstration of low-level recall of facts, both groups completed a 10 question multiple-choice test immediately after treatment and again in a delayed posttest four weeks later. Students in the experimental group scored significantly higher than did students in the control group on all measures. Barker concluded that since interactive videodisc instruction was at least as effective as lecture/demonstration in teaching the sliding board transfer, interactive videodisc simulations could be useful in replacing the traditional technique especially in self-paced courses or in patient education.

Barnea and Dori (1999) compared a computerized molecular modeling simulator with traditional methods of teaching molecular structures to students in high school chemistry classes. Two tenth-grade chemistry classes performed traditional laboratory activities using plastic models and served as the control group for this investigation, while three classes used the computerized simulator and served as the experimental group. After the administration of pretests to determine students' spatial ability and understanding of chemistry concepts, students in both groups received either conventional or computer-simulated treatment. On a posttest administered after treatment, students in the experimental group scored significantly higher on both the test of spatial ability and understanding chemistry concepts than did the students in the control group. The researchers concluded that students in the experimental group had a better understanding of bonding and of three-dimensional perception of molecular structure due to the interactive nature of the simulation.

Berlin and White (1985) investigated the effectiveness of computer-simulated experiments as compared to the manipulation of concrete manipulative objects in helping students internalize concepts through abstract representations. The subjects of this study were 113 second-grade and fourth-grade students from different socioeconomic backgrounds. Students performed 28 tasks over a three-week period, using either concrete manipulative activities or computer-simulated experiments. At the end of the treatment period, two measures of abstract thought were administered, and the results of those instruments were analyzed. Researchers found that students using computer-simulated experiments, regardless of race or gender, achieved significantly higher scores on a measure of abstract thought than students who used concrete manipulatives. The researchers concluded that while traditional methods affected students of particular racial characteristics or gender differently, the computer-simulated experiments were more successful in facilitating the transformation from concrete thinking to abstract thought of all students.

Branch, Ledford, Robertson, and Robison (1987) conducted a study on the effectiveness of an interactive videodisc simulation to teach heart auscultation to students in their first year of veterinary school. Students were randomly assigned to either a control group, which used traditional taped recordings of heats sounds and murmurs, or an experimental group, which used an interactive video-disc simulation that presented heart sounds as well as simulated blood flows and cardiac lesions. In spite of the visual enhancements included in the simulation program, when tested, students from both groups performed equally well at recognizing and diagnosing abnormal heart sounds. Despite the apparent equivalence in teaching heart auscultation, the authors promoted the use of computer-simulated experiments and interactive videodisk dissections for humanitarian reasons. The authors reasoned that rather than maintain large colonies of abnormal animals for use in training veterinary students, interactive videodisk dissections and computer-simulated experiments technology could be used to train students in abnormal physiology and anatomy.

Brant, Hooper, and Sugrue (1991) conducted an investigation to determine the instructional effectiveness of computer-simulated experiments both before and after genetics instruction. The subjects in this study were students enrolled in an animal science course at a large Midwestern university. Students were randomly assigned to a C (control) group, a B (before) group, and an A (after) group. Students in the C group did not participate in a simulation, but performed more traditional genetics problem solving activities. Students in the B group received training through the use of computer-simulated experiments before starting the lesson in genetics, and students in the A group received computer-simulated experiment treatment after the genetics lesson. After treatment, all students completed a test of practical animal breeding concepts. Students in the B group scored significantly higher on the test than did students in either the C or A treatment groups. There was no significant difference between the scores of students in the C and A groups. The researchers concluded that computer simulations are most effective when used to confront students' misconceptions and offer opportunities for them to explore possible solutions before formal instruction, especially in the types of subjects that involve complex problem-solving skills.

Buttles (1992) investigated the effectiveness of computer-simulated experiments as compared to students receiving traditional instruction on their ability to apply the scientific method to an experiment on plant growth. Students enrolled in the Fall, 1990, semester were considered to be the control group, while students taking the same course in the Spring, 1991, semester received the simulation treatment and were considered to be the experimental group. Both groups took the same midterm exam, and the results of questions concerning the scientific method from both groups were compared. The mid-term exam scores for students in the experimental group were very significantly higher than the mid-term scores of students in the control group. In addition to the midterm exam, both groups took a follow-up laboratory exam four weeks after the mid-term.

Again, the scores of students in the experimental group were very significantly higher than scores of students in the control group. Buttles noted that while a few of the students in the class were biology majors and planned to continue to work with real plants, many students were non-majors with little prior success in science. Buttles concluded that computer-simulated experiments were an effective addition to the teaching of biology, and that it allowed students to achieve a degree of success and understanding in the classroom.

Carlsen and Andre (1992) investigated the effectiveness of computer-simulated experiments to promote conceptual change among college students who held erroneous preconceptions concerning basic electrical circuits. The subjects of this study were college psychology students with no previous physics background. Students were randomly assigned to either a control group, which were taught about electrical circuits using conceptual change texts, or an experimental group, which used a computer-simulated experiment on electrical circuits for three one-hour treatments on three consecutive days. After treatment, a test of conceptual understanding of electrical circuits was administered to both groups. Scores of students in the experimental group were significantly higher than scores of students in the control group. The researchers concluded that simulations were beneficial in helping students overcome incorrect preconceptions and to acquire a more developmentally advanced model of series circuits that the control group acquired.

Choi and Gennaro (1987) compared computer-simulated experiments with traditional laboratory activities to determine their effectiveness in promoting students' understanding of the volume displacement concept. Subjects were 128 students enrolled in eighth-grade earth science at a middle school in Roseville, Minnesota. Subjects were randomly assigned to a control group or an experimental group based on gender. The students in the control group studied the volume displacement concept using hands-on laboratory equipment, while students in the experimental group explored the concept using computer-simulated experiments. At the end of the treatment, both groups were tested on their understanding of the volume displacement concept, with no significant difference between the groups. The groups were also tested after a period of 45 days for retention of the concepts learned earlier, with similar results. Upon analyzing the performance of students with respect to gender, researchers discovered that females were found to score much better after participating in the computer-simulated experiments, and males performed better after hands-on laboratories. The researchers concluded that computer-simulated experiments are as effective as traditional hands-on laboratories, and that computer-simulated experiments could be used as replacement for traditional labs.

Chou (1998) investigated the effectiveness of computer-simulated experiments as compared to traditional laboratory activities on the misconceptions of students in the field of electro-magnetism. Students studying college physics were randomly divided into two groups of 28 each, and given a pretest on physics achievement. Students in the experimental group participated in a computer-simulated laboratory experiments for a period of six weeks, while student in the control group performed or traditional electro-magnetism laboratories for an equivalent period of time. At the end of the treatment period, a posttest was administered to both groups. Students in the experimental group scored significantly higher on the posttest than did students in the control group. Chou concluded that the results from computer-simulated experiments were easier to analyze than conventional E&M laboratories, allowing students to develop a clearer understanding of relationships between variables.

Dewhurst, Hardcastle, Hardcastle, and Stuart (1994) compared the effectiveness of a computer-simulated experiment on the transport mechanisms of intestinal epithelial tissue to a traditional physiology laboratory. Subjects in this study were students in an undergraduate physiology class. The control group, consisting of 8 students, worked in the laboratory for over 35 hours to complete a series of experiments on intestinal tissue to determine transport parameters of epithelial tissue. The experimental group, consisting of 6 students, used a computer-simulated laboratory to cover the same material. No significant difference was found on the mean scores on an achievement test administered to both groups after treatment. The average time spent by the members of the experimental group, however, was approximately 19 hours as compared to 35 hours for the control group. The cost of the computer-simulated experiments was five times less than the conventional labs. The researchers concluded that while some students require learning laboratory skills involving animal tissue, most do not, and computer-simulated experiments are equally effective for these students. The researchers also preferred the use of computer-simulated experiments because laboratories involving animals are staff intensive, have a high recurring cost, and raise concerns of students who generally dislike using animals to demonstrate known principles.

Faryniarz and Lockwood (1992) investigated the effectiveness of computer-simulated experiments as compared to lecture on the ability of students to engage in environmental problem-solving activities. Subjects were 58 students enrolled in a junior-college biology class in Waterbury Connecticut. After all students took a pretest of problem processing skills, the control group of 24 students received instruction through the lecture method. The experimental group, consisting of 34 students, completed three computer-simulated experiments concerning environmental problems. At the end of the treatment, both groups took a posttest on problem processing skills. The experimental group scored significantly higher on the posttest than did the control group. The researchers concluded that students benefited from the opportunity for active learning, and that the simulations allowed students to think about and work through environmental problems.

Fawver, Branch, Trentham, Robertson, and Beckett (1990) compared interactive videodisc simulated laboratory on animal physiology with a traditional cardiovascular physiology lab to determine the effectiveness of the computer-simulated experiment. Subjects in this investigation were 85 students in their first year of veterinary school. Subjects were randomly assigned to a control group, which participated in six live-animal demonstration labs, or an experimental group, which participated in an interactive videodisc simulation of similar concepts. At the end three weeks, both groups were given an achievement test on the principles covered in the laboratories. No significant differences were found in the achievement test scores of these groups on the cardiovascular laboratory test; but the results of the fibrillation laboratory, however, showed that the students in the experimental group scored significantly higher than did the students in the control group. The researchers concluded that the use of live animals was not necessary foe efficient student learning of physiological concepts. Even though this particular study produced mixed results, the researchers noted that live animals did not always respond characteristically every time in the laboratory, while computer-simulated experiments may show a variety of characteristic responses depending on the stimulus used by the instructor.

Friedler, Merin, and Tamir (1992) investigated the effectiveness of computer-simulated experiments as compared to traditional biology experiments in six high schools including 200 students enrolled in a high school biology class. Students were divided into control and experimental groups, given a pretest on biology concepts and problem solving, and either taught using conventional laboratory exercises or computer-simulated experiments. After four double-length class periods, students were again tested on biology concepts and problem solving. In addition to a comparison of experimental treatment to conventional treatment, the researchers grouped the test results by gender. Overall, the students in the experimental group scored significantly higher on the posttest than did students in the control group. No significant differences were noted between students on the basis of gender. The researchers concluded that computer-simulated experiments broadened and deepened students' knowledge as well as help expose difficulties in conceptualization.

Geban, Askar, and Ozkan (1992) investigated the effect of computer-simulated experiments on students' chemistry achievement, process skills, and attitudes toward chemistry. The subjects of this study were approximately 200 students taking ninth-grade chemistry. Students assigned to the control group used a conventional class/laboratory approach, while students in the experimental group used class/computer-simulated experiment approach. After nine weeks of classes and laboratory assignments, the researchers tested all students, measuring achievement, scientific process skills, and attitudes toward chemistry. The results of all three instruments indicated that the experimental treatment was favored with high significance. The researchers concluded that because the data provided by the simulation were reliable and instantaneous, students were able to conduct and repeat the experiments until they were able to understand the concept being taught. The researchers also pointed out that students using computer-simulated experiments took only 40 minutes to complete the laboratory, while students in the control group took approximately 140 minutes. More positive attitudes toward chemistry demonstrated by students in the experimental group, suggested the researchers, might be due to the reduction in time spent gathering data in the laboratory.

Gokhale (1996) studied the effectiveness of computer-simulated experiments in enhancing higher-order thinking. Subjects of this study were 32 students enrolled in two class sections, 16 in each section, of an electronics class at a state university in the Midwest. Students were given a pretest on problem solving involving small-signal amplifiers. Both the control and experimental groups met twice a week, for six weeks. The students in the control group performed traditional electronics laboratory activities, while students in the experimental group performed computer-simulated experiments. At the end of the six-week period, both groups were given a posttest on problem solving concerning small-signal amplifiers as well as a number of questions on basic electronics knowledge. The students in the experimental group performed significantly better than the students in the control group in terms of problem solving, but no better on recalling basic electronics knowledge. Gokhale concluded that because the computer-simulated experiments allowed the student to focus on mental activity such as problem solving and because of immediate feed back which allowed students to evaluate their understanding, the computer-simulated lab was more effective in promoting higher-order thinking skills that the traditional lab. In terms of low-level recall of facts, however, either treatment was sufficient.

Grosso (1994) compared two computer-simulated experiments in chemistry with traditional "wet" chemistry laboratories. The subjects for this study were students taking freshman chemistry at a large public university. The students were divided into two groups, G1 and G2, and all students were given a pretest on chemistry principles. The G1 group performed a computer-simulated experiment on kinetics, and G2 performed a traditional laboratory activity. For the second experiment, G1 performed a traditional laboratory activity on quantitative analysis, and G2 did a similar experiment using computer-simulation. After both laboratories, all students were given a written posttest and a survey as to their opinions concerning computer-simulated experiments. The results of the attitudinal survey were mixed, with no clear preference of one method over another. The results of the written posttest showed that students used the computer-simulated experiments scored higher on the both achievement tests, but not significantly higher on either. Grosso concluded that since no significant differences were found, schools could readily substitute computer-simulated experiments for traditional laboratories in undergraduate chemistry courses.

Hall (2000) compared the effectiveness of a computer-simulated experiment to a hands-on electronics laboratory among students enrolled in an undergraduate engineering technology program. Subjects consisted of one section of students in a freshman-level introductory electronics laboratory course and one section of a junior level advanced electronics course. Each student performed four laboratory exercises using conventional hands-on techniques and was tested on the concepts learned in those lessons. Each student then completed four laboratory exercises using computer-simulated electronics laboratories. Again, all students were tested on the concepts presented in those lessons. Analysis of the scores of these students revealed no significant difference between the two treatments. Hall concluded that computer-simulated experiments effectively duplicated traditional electronics laboratories, and suggested that students could use computer-simulated experiments on their own personal computers on their own time to practice more expensive and time-consuming traditional laboratories.

Hopkins (2001) compared traditional frog dissection with a computer-simulated experiment among high school biology students. Hopkins compared these two methods for low-level achievement, attitude toward the subject, and retention. The control group consisted of 34 students, who performed a traditional frog dissection. The experimental group consisted of 23 students who used a computer-simulated dissection. After pretests on naming parts of a frog from a diagram, processes used in dissection and attitude toward dissection, both groups performed their activities. Results of the posttest indicated that there was no significant difference between the scores of students in the control group and students in the experimental group. Hopkins concluded that computer-simulated dissections could be used in place of conventional frog dissections, especially if students had difficulty with the idea of using animals for experimental purposes, and a practical alternative was desired.

Hughes (2000) compared computer-simulated experiments to "wet" practical laboratories among students in a pharmacology class at Leeds University. The control group in this investigation consisted of 42 students who performed traditional laboratories; the experimental group consisted of 46 students who performed computer-simulated experiments. After treatment, a test of pharmacological achievement was administered. The students in the experimental group scored significantly higher on the test of theoretical principals than did the students in the control group. When asked about details of the methodology and laboratory procedures, however, students in the control group were able to recall more detail. Hughes concluded that computer-simulated experiments could provide a learning aid that is just as effective as "wet" practical laboratories for learning and knowledge, but not for methodology.

Huppert, Yaakobi, and Lazarovvitz (1998) compared the effectiveness of computer-simulated experiments with a traditional microbiology laboratory in a tenth-grade biology course. Subjects were divided into control and experimental groups and given a pretest of achievement. The control group performed a traditional laboratory investigation as to how environmental conditions affected the growth curve of bacteria by counting bacterial colonies on several growth plates being grown under varying conditions. Students in the experimental group conducted the same experiment using computer-simulation. After performing the laboratories for three periods per week for four weeks, both groups were given a posttest. The students in the experimental group scored significantly higher than did the students in the control group on a posttest. In addition to this comparison, the authors also compared the achievement of students who were female and students who were male. No significant differences were found between these two groups. The researchers concluded that because students using the computer-simulated experiment were able to control up to three different variables at once, they had developed more complex and integrative cognitive processes.

Jackman, Moellenberg, and Brabson (1987) investigated the effectiveness of computer-simulated experiments as compared to traditional chemistry laboratory. Subjects were 278 students taking college chemistry at a large public university. Students were given a pretest, participated in either a three-hour laboratory or computer-simulated experiment on spectrophotometry, and then given a posttest. The mean score on the posttest for students who participated in the computer-simulated experiment was significantly higher than the mean score of the students who participated in the traditional laboratory. The researchers concluded that when properly designed, a computer-simulated experiment could be an effective educational tool enhancing students' scientific processes of thinking.

Jackman, Moellenberg, and Brabson (1990) performed an investigation, which was very similar to their 1987 study, on the effectiveness of computer-simulated experiments as compared to a traditional laboratory activity on spectrophtometry. In this study, 190 students taking chemistry at a large public university were pretested, received either a three-hour laboratory or computer-simulated experiment, and then given an achievement posttest over principles of spectrophotometery. Again, students using the computer-simulated experiment scored significantly higher than students performing a traditional laboratory. The researchers again concluded that computer-simulated experiments could be effective educational tools.

Kinzie, Strauss, & Foss, (1993) compared the use of an interactive videodisc dissection to a conventional frog dissection among 61 students enrolled in a high school biology class. Subjects were divided into groups and assigned to either the control or experimental groups. Students in the control group performed a traditional frog dissection, while students in the experimental group used an interactive videodisc dissection. After treatment, both groups were given a test of frog anatomy and dissection as well as a survey on students' attitudes toward dissection. Results of these instruments indicated that the achievement scores of the students in the experimental group were significantly higher than the scores of the students in the control group. Results of the survey on attitudes toward dissection, however, showed no significant differences between the two groups on that measure. These researchers concluded that the use of interactive videodisc technology was as effective in teaching frog anatomy as conventional dissection, and that students or educators who desire unconventional approaches to learning about vertebrate anatomy should consider interactive videodisc as an effective alternative.

Leonard (1989) investigated whether the use of interactive videodisc technology would have an effect on student's attitudes toward biology. Subjects in this study were taking an introductory biology class at a large Midwestern university. Students were randomly assigned to either a control group, which participated in conventional laboratory activities on respiration and the effect of climate on life processes, or an experimental group, which used interactive videodisc technology to simulate the laboratory experience. After four hour-long treatments, the 72 students in the conventional laboratory group and the 70 students in the interactive videodisc group answered two attitude surveys pertaining to their experiences in either conventional or simulated laboratory experiences. The researcher found that the students in the experimental group demonstrated significantly higher attitudes toward biology than did the students in the control group. While not advocating the substitution of simulations for "wet" laboratories in all situations, Leonard recommended the use of interactive videodisc simulation over conventional laboratories when those laboratories were too complex, time consuming, expensive, or impractical.

In a follow-up study, Leonard (1992) compared the effectiveness of interactive videodisc as compared to conventional laboratory activities to teach biology concepts and process skills. The subjects were randomly assigned to a control group, which used traditional laboratory activities to learn about respiration and biogeography, or an experimental group, which used interactive videodisc technology to explore the same topics. After one week, the 72 students assigned to the control group and the 70 students assigned to the experimental group were given a series of four achievement tests on biology concepts and process skills. Although the effect size indicated that there was no significant difference between the experimental and control groups in achievement, the researcher noted that the students in the experimental group spent approximately half the time in the laboratory than did the students in the control group. The researcher concluded that the interactive videodisc method of instruction was equivalent to traditional laboratory in its effectiveness on student achievement, but more efficient in the use of instructional time.

Lewis, Stern, and Linn (1993) compared the effectiveness of computer-simulated experiments with a computer-based laboratory curriculum on improving students' understanding of thermodynamics principles. Subjects in this investigation were 272 students enrolled in a semester-long physical science class in an ethnically diverse middle school. A pretest of thermodynamics understanding was administered at the beginning of the semester to all students. Students were randomly divided into a computer-based laboratory group, the control group, and a group using computer-simulated experiments, the experimental group. At the end of 13 weeks, a posttest was administered to both groups. The students in the experimental group scored significantly higher on the posttest than did students in the control group. The researchers concluded that the used of repeated simulation enhanced that students' depth and breadth of understanding.

Lyness (1985) investigated the use of an interactive videodisc system of instruction to teach CPR as compared to live CPR demonstration. Subjects in this study were 100 university students, who were divided randomly and equally into a control group and an experimental group. Students in the control group received CPR instruction using a traditional classroom and demonstration method. Students in the experimental group learned the same concepts and skills through a computer-simulated activity. After instruction, students were given a skills examination as well as a written test of conceptual knowledge. Results of the skills test as well as the written test of conceptual knowledge showed no significant difference between students in the control group and experimental group.

Marszalek and Lockard (1999) conducted an investigation to determine the effectiveness of a computer-simulated frog dissection with a conventional frog dissection in terms of initial and long-term retention of frog anatomy. The subjects, students enrolled in a seventh-grade life science class, were divided into groups. The students in the control group performed a conventional frog dissection, while the experimental group used a computer-simulated dissection. After pretesting, all students performed the laboratory to which they were assigned. The students in the control group scored significantly higher on the immediate posttest than did the students in the experimental group. The researchers indicated that there were no significant differences between the two groups in terms of retention after 3 months, but failed to provide sufficient information to calculate an effect size. The researchers concluded that conventional dissection generated more learning than the computer-simulated experiment, because students find it more difficult to transfer learning from a simulation that an actual dissection.

Mills, Amend, and Sebert (1985) investigated the effectiveness of computer-simulation as compared to the use of a textbook, to teach water resource management principles to a group of public school science teachers. The subjects consisted of 151 environmental science teachers, who were divided into either a control or experimental group. Subjects in the control group received instruction through the use of textual information, while subjects in the experimental group performed a series of computer-simulated experiments. After five 90-minute training sessions, teachers who received the computer-simulated experiments and those who did not were given a test of their knowledge of water resource management issues. The results of the measure of achievement indicated that the subjects in the experimental group scored significantly higher than did the subjects in the control group. In addition to achievement outcomes, the researchers also asked both groups to complete a survey on their attitudes concerning water resource management on an instrument measuring concern over environmental issues impacting water resources. The researchers were not surprised to find the concern of the experimental group to be lower than that of the control, as prior research had suggested that greater knowledge of resource management tended to moderate attitude extremes concerning environmental issues. The researchers concluded that the simulation could teach important concepts.

Moslehpour (1993) compared the achievement of students learning electronics concepts by computer simulation vs. traditional electronics laboratory. Subjects were 76 students enrolled in an electronics technology class at a large Midwestern university. Students were randomly divided into two groups. The students assigned to the control group conducted traditional electronics bench laboratory investigations, while students in the experimental group used a computer-simulated electronics bench. Analysis included comparing the midterm and final examination scores of the students in each group. Results indicated that students in the control group scored significantly higher than did students in the experimental group.

Pena and Alessi (1999) compared the effectiveness of microcomputer-based laboratory with computer-simulated experiments to overcome misconceptions about the motion of an object in freefall. Subjects were 330 military recruits in their 11th day of basic training at Lackland Air Force Base, Texas. The subjects were randomly divided into groups and given a pretest to determine the presence of a misconception about the motion of an object in freefall. After the pretest, students in the control group were instructed in freefall motion through the use of computer-assisted instruction. Students in the experimental group were instructed in freefall through the use of a computer-simulated experiment. The results of a posttest indicated that there was a significant difference between the students in the computer-simulated experiment group and the computer-text based group. The authors preferred the use of computer-simulated experiments over traditional laboratory activities because simulations allow students to slow down, speed up, or even halt the time frame of events, allowing them to see events more clearly. Computer-simulated experiments also allow students to observe otherwise unobservable features in a problem situation. The most important benefit of computer-simulated experiments, according to the authors, is that computer-simulated experiments encourage a "what if" inquiry approach to science.

Rieber and Parmley (1992) investigated the effectiveness of computer-simulated experiments as compared to computer-based instruction on inductive learning in adults. Subjects were 154 university-level computer science students, who were placed in either a control group, which used a computer tutorial, or an experimental group, which used a computer simulation. The content of the simulation was an instructional simulation game in which the students attempted to maneuver a space shuttle using rocket blasts. This simulation was designed to teach students about Newton's laws of motion. After four sessions of 90 minutes each using either the control or experimental treatment, all students were given a test over the application of Newton's laws. The students using the simulation scored significantly higher on the test than did the students in the control group. The researchers concluded that adults could induce and apply relevant physical science rules given experiences with real-time computer-simulations.

Rieber and Kini (1995) performed an experiment similar to the study conducted by Rieber and Parmely in 1992. In the case of the 1995 study, however, the subjects were 341 students enrolled in a fifth –grade elementary school. The content of the simulation was again an instructional simulation game in which the students attempted to maneuver a space shuttle using rocket blasts. As before, subjects were placed in either a control group, which used a computer tutorial, or an experimental group, which used the simulation. Students taking the tutorial scored significantly higher than students using the computer-simulation. The researchers concluded that children were not able to learn physical science content purely through an inductive learning strategy. Learning only occurred when lesson content was carefully selected and sequenced according to established design guidelines.

Rueter and Perrin (1999) investigated the effectiveness of computer-simulated experiments as compared to traditional lecture methods in a large non-biology major's ecology class at a large university. Subjects in the experimental group consisted of 77 students who used a food web simulation in which the numbers of producers and both first and second level consumers could be manipulated. Subjects in the control group consisted of 104 students who did not use the simulation, but attended traditional classes and laboratories. At the end of the semester, both groups were administered a posttest, in which the students in the experimental group achieved a significantly higher average than did the students in the control group. The researchers concluded that computer-simulated experiments are valuable in biology because it allows students to build dynamic models and tools for visualization of the outcomes of these models.

Samsel, Schmidt, Hall, Wood, Shroff, & Schumacker, (1994) conducted a study to determine if students studying the physiology of the heart in medical school had an attitudinal preference for computer-simulated experiments or live animal demonstrations. In this study, a computer-simulated experiment on the physiology of the heart was compared to a demonstration using an anesthetized dog. Students were encouraged to attend both laboratories, and then given a survey rating the usefulness of the laboratory in terms of helping them understand the lesson. Students rated the usefulness of the computer-simulation significantly higher than the live animal demonstration. The researchers concluded that while both lecture-demonstration and computer-simulated laboratories were both highly effective, many students were bothered by the use of living animals in experimentations and consider computer simulation to be more humane. Due to the preference for computer-simulated experiments and reduced cost, the researchers suggested increased use simulations in physiology instruction. The authors warned, however, that simulations should not be used to replace live-animal demonstrations because simulations could only present a predetermined range of responses, while live-animal demonstrations more correctly demonstrated the variety of physiological responses in vertebrates.

Spraggins and Rowsey (1986) investigated the effectiveness of a computer-simulated experiment to teach factual knowledge to students compared to worksheets. Four sections of high school biology classes consisting of a total of 81 students were assigned to the control group, whose members completed worksheets and the experimental group, whose members performed a simulation. Three topics were used in this study: A unit on the geological time line, a unit on the cell, and a unit on the circulatory system. A measure of achievement was administered immediately after the treatment as well as two weeks after the treatment. Results indicated that there was no significant difference on scores between the two groups on the immediate posttest, the students in the experimental group, however, scored higher on the delayed posttest than did the students in the control group. The researchers concluded that computer simulations were as equally effective at teaching low-level factual knowledge as worksheets

Strauss and Kinzie (1994) compared the effectiveness of an interactive videodisc simulated dissection with conventional dissection. Subjects were students enrolled in two class sections of a biology class at a small high school. The control group consisted of 8 students, who conducted a conventional frog dissection. The experimental group consisted of 9 students, who performed an interactive videodisc dissection. Both groups were given a pretest on achievement and attitude toward the subject. After conducting the dissections, all students were given an immediate posttest, and a delayed posttest was administered two weeks later. The results of the immediate posttest, delayed posttest, and attitude toward science measure showed no significant differences between the scores of students in either group. The researchers concluded that the simulated frog dissection could be as effective as traditional dissection in terms of learning the steps of dissection and the major organs within the frog's body cavity.

Tylenski (1994) compared the effectiveness of a computer-simulated dissection as an alternative to a traditional dissection with regards to student achievement. The subjects of this study were 97 students in a ninth-grade biology class, 46 of whom were assigned to the control group and 51 to the experimental group. All students were given a pretest on biology achievement, and students in the control group performed a traditional dissection, while students in the experimental group performed a computer-simulated dissection. After treatment, students in the experimental group scored significantly higher on the posttest than did the students of the control group. Tylenski concluded that computer-simulated dissections were valuable substitutions for conventional dissections especially in the light of recent legislation defending the rights of students to refuse to dissect prepared vertebrate specimens.

Vockell and Rivers (1984) used computer-simulated experiments in an attempt to enhance the problem solving skills of high school biology students. The research was conducted at three different high schools. Students were divided into control and experimental groups at each campus. After a pretest of problem solving ability was administered, the experimental group participated in simulations on plant growth, osmosis and a monohybrid genetic cross. Students in the control group received traditional instruction on the same three topics. After treatment, a series of posttests measuring interpretation, deduction, recognition of assumptions, and inferences, was administered to both groups. Results indicated that students in the experimental group at school number three attained significantly higher scores than did students in the control group. There were no significant differences at school one and two. The researchers concluded that computer-simulated experiments could help high school students increase their problem solving abilities. To be most effective, however, simulations should be integrated with curriculum objectives, and guidance should be provided.

Webb (1993) investigated the effectiveness of a computer-simulated experiment as compared to lectures on the ability of students to predict genetic outcomes when presented the genotypes and phenotypes of parent organisms. The control group consisted of 55 students taking college biology who received a series of lectures on predicting genetic outcomes, given the genetic makeup of parent fruit flies. The experimental group conducted a series of genetic simulations for a period of 6 days. At the end of the treatment, both groups were administered an achievement test. The experimental group demonstrated a significantly higher mean score on the posttest than did the control group.

Woodward, Carnine, and Gersten (1988) investigated the effectiveness of a computer-simulated experiment as compared to a conventional lesson on the achievement of 30 students studying a unit on health. Students were randomly assigned to a traditional style lesson, the control group, or a computer simulation, the experimental group. Students received their educational treatment for 40 minutes a day for a period of 12 days. Students were assessed on their knowledge of health concepts and application immediately after the unit as well as two weeks later. Results indicated that the simulation was significantly more effective in teaching health concepts than conventional lessons. The researchers concluded that the use of simulation could contribute to a student's learning of both factual and conceptual information as well as problem solving ability.

Summary of literature review

Based on the review of literature, several conclusions may be drawn. Firstly, the periods of 1972 to 1982, 1983 to 1993 and 1994 to 2001 represent significantly different technological eras in computer technology and in the software used in science classrooms. Secondly, the use of simulations in science classrooms is associated with the theories of constructivism and of inquiry based methodology. Computer simulation has been demonstrated to be effective in causing cognitive change, a key concept in constructivist theory and an important goal in the inquiry method. Thirdly, computer-simulated experiments have many practical and pedagogical advantages compared to laboratory based experiments and traditional classroom techniques, with only a few, but important disadvantages. Fourthly, previous syntheses on the effectiveness of instructional computer simulations have used achievement, retention, attitudes toward the subject being studied, and attitude toward the instructional method as the most common outcome measures. Finally, a meta-analysis investigating the effectiveness of computer-simulated experiments compared to traditional instructional methods and of the features of simulations related to their effectiveness has not been previously performed.

Chapter 3

METHODOLOGY

The focus of chapter three is the description of the methodology implemented in this study. The techniques used to identify, collect, evaluate, and code the studies included in this investigation are described, as well as the method for calculating the effect sizes of individual studies. The method for grouping the features of individual studies and analyzing their outcomes will also be discussed.

An introduction to meta-analysis

Since the introduction of microcomputers in the classroom in the 1970s, nearly 1,300 individual studies have been conducted to determine the effectiveness of computer simulation in education. Early studies, based on the comparatively primitive computers and software authoring programs of the 1970s and early 1980s, reported generally unfavorable results on the effects of computer simulation on student attitudes and achievement. Results from studies conducted the 1980s and 1990s, while being generally favorable, have often reported contradictory results regarding the appropriate use of simulations and the effectiveness of various design features of the simulations. The purpose of this study was to produce conclusive findings, through the implementation of meta-analysis, on the effects of computer-simulated laboratories on science students' achievement and attitudes.

Meta-analysis is a data collection and analysis technique introduced by Gene V. Glass in 1976. According to Glass (1976), meta-analysis is the application of statistical methods to results from a large collection of studies for the purpose of integrating the findings. The meta-analytical technique has been characterized

(Glass, McGaw, & Smith, 1981) as a statistical analysis of the individual analyses. Single research studies seldom provide definitive answers to researchers' questions, usually addressing only single populations or individual aspects of a broader research question. The accumulation of findings from related studies, according to Hunter & Schmidt (1990), is necessary to determine whether any overall conclusion can be derived.

Hunter and Schmidt (1990) pointed out that as large numbers of studies on a particular topic begin to accumulate, the typical effect is to increase the number of conflicting results, rather than resolve the issue. At this point the need is not for conducting further studies, but for making sense of the accumulated findings. Hunter and Schmidt (1990) also stated that the meta-analytical technique is both effective in revealing cumulative knowledge and in providing researchers with a clearer indication of remaining research needs, and enabling researchers to identify trends among related studies and to develop new theories.

The primary statistic used in meta-analysis is the effect size, which is calculated by dividing the mean difference between experimental and control groups by the pooled within-group standard deviation (Glass, 1976). The calculation of an effect size for each study in a meta-analysis allows individual studies to be compared on a common scale to other studies included in the meta-analysis. Effect sizes of individual studies may be combined and analyzed to produce an overall, mean effect size. The effect size indicates the number of standard deviations above or below the mean a particular outcome represents. Effect sizes generally range from approximately -3.0 to +3.0. An effect size of 0.4, for example, would indicate that the subjects scored approximately 0.4 standard deviations above the mean for a given outcome. An effect size greater than +0.20 or less than –0.20 is considered to be significant (Lauer & Asher, 1988).

Meta-analysis, however, is more than just computing effect size. Wachter and Straf (1990) claimed that meta-analysis is not primarily a statistical method, but rather an orientation toward research synthesis that uses many techniques of measurement and data analysis. The results of similarly coded studies may be grouped together for analysis for the purpose of possibly clarifying seemingly conflicting results. The mean effect size for a particular outcome may be zero, for example, but one subgroup of outcomes might be highly positive and another subgroup highly negative. Meta-analytic coding strategies are designed to detect such conditions and allow the researcher to accurately report the details of the situation. The purpose of the meta-analysis, according to Rosenthal (1984), is to derive useful conclusions from the findings of previous studies as well as synthesize those data in order to make new discoveries and relationships. The capacity of the meta-analytical technique to investigate relationships among significant features of many studies and their outcomes is among the strengths of this approach. The validity of a meta-analytical study, however, is dependent upon the degree in which the body of located studies is representative of the total research (Glass, 1976). An exhaustive search of related literature must be conducted in order to identify and include pertinent research data for the purpose of achieving the highest level of validity possible (Rosenthal, 1984). Search techniques used in this study, as suggested by Rosenthal (1984), included on-line computer searches of appropriate databases, and review of the bibliographies and reference listings of books, retrieved journal articles, unpublished research studies maintained on the ERIC database, and published and unpublished theses and dissertations.

Specific procedures of the meta-analysis technique used in the study included the following:

5. identifying and collecting the studies;
6. classifying and coding the studies;
7. quantifying outcomes on a common scale; and
8. analysis of the data.

Identifying and collecting the studies

Related literature and previously conducted studies were primarily identified using an on-line search of computer databases. Databases used in this study to identify relevant studies included the ERIC database, UMI ProQuest Digital Dissertations, and Wilson Select Plus. Descriptive search phrases including "computer simulated experiments", "computer simulation and science education", "computer simulation and biology", "computer simulation and physics", "computer simulation and chemistry", and "computer simulation and earth science" were used to identify related documents.

A preliminary screening of document abstracts was conducted, and only those studies that apparently met pre-determined inclusion criteria were considered for further screening. Studies whose abstracts indicated that they employed true or quasi-experimental designs, were reported between January, 1983, and December, 2001, and employed pre-programmed interactive videodisc simulation or computer-simulated experiments for instructional purposes in science classes were obtained from appropriate sources and then subjected to further screening.

These three preliminary inclusion criteria were established to assess the usefulness of interactive videodisc and computer-simulated experiments in science learning environments. The first criterion, that the study employed a true or quasi-experimental design, was used because "no knowledge can be gained without comparison" (Lauer & Asher, 1988, p.7). Studies not employing true or quasi-experimental designs were therefore excluded, as no basis for comparison existed.

The second inclusion criterion, that the study be reported between January, 1983, and December, 2001, was used, because the rapid rate of improvement in microcomputer processors, operating systems, memory and storage capacity, and software-authoring systems after 1983 provided the opportunity for simulations produced after that date to differ greatly from earlier simulations. Because the development of more sophisticated software-authoring systems allow more interactive, user-friendly, differential feedback, earlier more primitive studies have been excluded from this study.

The third selection criterion required that the interactive videodisc or computer-simulated experiments be preprogrammed for instructional purposes. Studies involving student-designed simulations were excluded because the quality of the simulation was based on the programming ability of the student. Simulations without definitely defined instructional purposes, such as simulation games, were excluded from the study because the outcomes were not directed to the instructional nature of the simulation.

Articles from periodicals and unpublished documents maintained in the ERIC database and stored on microfiche were obtained from the university library. Documents and journal articles maintained on-line were downloaded from the appropriate internet sites. Articles not available from the library were obtained through inter-library loan.

Unpublished doctoral dissertations were purchased directly from UMI Dissertation Express. The bibliographies and reference listings of selected documents were examined to identify related documents. Once identified, those previously unscreened documents were subjected to the same criteria for inclusion in the study.

As the documents were obtained, further examination of the results sections of those documents were conducted in order to ascertain if sufficient data were reported to allow an effect size to be calculated. Studies not reporting such statistical data as the mean, standard deviation, degrees of freedom, t-score, or F-score, were not included in the final body of studies included in the meta-analysis.

Classifying, and coding the studies

Previous meta-analyses and the review of the literature led to the identification of several important variables. Effect magnitudes for five student outcomes related to student achievement and attitude were coded. These constructs included the following:

1. low-level thinking skills,
2. high-level thinking skills,
3. retention after two weeks,
4. attitudes towards the subject being studied, and
5. attitudes toward the simulation.

Additional data were categorized on the basis of the specific characteristics relating to the study. Variables used in the study included the following:

1. the year of report of the publication, (1983 to 1993, vs. 1994 to 2001);
2. the type of simulation used (CSE vs. IVD);
3. the mode of the simulation (exploratory vs. confirmatory);

4. the subject matter (biological science vs. physical science);
5. the school grade level of student (K through 12 vs. college and professional);
6. the gender of students (female vs. male); and
7. the length of the treatment (one week or less vs. more than one week).

Each study was coded on the basis of these variables and the data entered into a computer database program as suggested by Lipsey and Wilson (2001). The use of a database program allows for more efficient sorting and comparison of variables than the traditional paper coding sheet.

Quantifying outcomes on a common scale

This study included five quantitative outcomes: achievement requiring low-level recall of facts; achievement requiring high-level thinking (problem-solving, processing skills, or transfer of learning); retention of material at least two weeks after the treatment; student attitude toward instruction; and student attitude toward the subject matter. Studies included in this meta-analysis reported quantitative results on one or more of these outcomes utilizing a variety of statistical techniques. In some cases, detailed data including group means and standard deviations were reported. Other studies reported t-statistics or F-statistics without elaborating on the data used to calculate those results. For the purposes of meta-analysis, all of these data were converted to a common metric, the effect size, using techniques originally described by Glass (1976), and refined by Hunter and Schmidt (1990), and Lipsey and Wilson (2001). Glass (1976) proposed that effect size be calculated by dividing the mean difference between the control and experimental groups by the standard deviation of the control group because the control group standard deviation is unaffected by treatment. Hunter and Schmidt (1990) preferred to divide the mean difference between the groups by the pooled within-group standard deviation in calculating effect sizes because less sampling error was introduced into the statistical analysis. Hough and Hall (1994) compared the two methodologies, finding that the use of the pooled within-group standard deviation to calculate effect size was preferable because it more closely estimated the population parameter of both experimental and control groups. Effect sizes for studies that reported mean sizes and standard deviations for both control and experimental groups were computed using the formula shown in figure 1.

$$ES' = \frac{M_{Exp} - M_{Con}}{SD_{pooled}}$$

Figure 1. Formula for effect size.

In the formula for effect size:

ES' is the effect size measure,

M_{Exp} is the estimated mean achievement of the group using computer-simulations (the experimental group),

M_{Con} is the estimated mean achievement of the group using no simulations (the control group), and

SD_{pooled} is the estimated pooled within-group standard deviation.

In cases where both pretest and posttest data were reported, the formula shown in figure 2 was used.

$$ES' = \frac{(M_{Exp-post} - M_{Exp-pre}) - (M_{Con-post} - M_{Con-pre})}{SD_{Pooled}}$$

Figure 2. Formula for effect size using pretest and posttest data.

In the formula for effect size using pretest and posttest data:

$M_{Exp-post}$ is the mean posttest score of the experimental group,

$M_{Exp-pre}$ is the mean pretest score of the experimental group,

$M_{Con-post}$ is the mean posttest score of the control group, $M_{Con-pre}$ is the mean pretest score of the control group, and

SD_{Pooled} is the pooled within-group standard deviation.

The formula used to compute the pooled within-group standard deviation is shown in figure 3.

$$SD_{pooled} = \sqrt{\frac{(n_{Exp} - 1)SD_{Exp}^2 + (n_{Con} - 1)SD_{Con}^2}{n_{Exp} + n_{Con} + 2}}$$

Figure 3. Formula for pooled within-group standard deviation.

In the formula for the pooled within-group standard deviation:

SD_{pooled} is the pooled within-group standard deviation,

n_{Exp} is the number of students in the experimental group, n_{Con} is the number of students in the control group,

SD_{Exp} is the standard deviation of the experimental group, and

SD_{Con} is the standard deviation of the control group.

Effect sizes for studies that reported t-scores were computed using the formula shown in figure 4.

$$ES' = t\sqrt{\frac{n_{Exp} + n_{Con}}{n_{Exp} \times n_{Con}}}$$

Figure 4. Formula for effect size for studies reporting t-scores.

In the formula for effect size for studies reporting t-scores:

ES' is the effect size, t is the reported t score,

n_{Exp} is the sample size of the experimental group, and

n_{Con} is the sample size of the control group.

Effect sizes for studies that reported F-statistics were computed using formula shown in figure 5.

$$ES' = \sqrt{\frac{2F}{N}}$$

Figure 5. Formula for effect size for studies reporting F-statistic.

In the formula for the effect size for studies that reported the F-statistic:

ES' is the effect size,

F is the reported F statistic, and

N is the sample size of both the experimental and control groups.

Lipsey and Wilson (2001) suggested that measurement error in studies with small populations were statistically larger than measurement error in studies with larger populations. Without correction, therefore, studies involving small populations, especially studies with less than 20 subjects, would inflate the inherent measurement error. Lipsey and Wilson (2001), therefore, recommended that the effect size be corrected by multiplying the calculated effect size by a correction term which took into account the sample size. The formula shown in figure 6 was used for measurement error correction.

$$ES = (ES')\left(1 - \frac{3}{4N - 9}\right)$$

Figure 6. Formula for effect size error correction.

In the formula for effect size error correction:

ES is the corrected effect size

ES' is the effect size uncorrected for sampling error due to sample size differences, and

N is the total number of students included in the study.

In addition to affecting the measurement error inherent in each study, the number of subjects in each primary study also impacts the relative influence of the study on the overall mean effect size. The overall mean effect size must be computed as a weighted average, with studies with larger populations having a greater influence on the mean effect size than studies with fewer subjects. Because the precision of the overall effect size is dependent on the population size for each study, a weight factor was computed. The formula used to compute the weight factor is shown in figure 7.

$$w = \frac{1}{(1/\tilde{n}) + [ES^2 / 2(n_{Exp} + n_{Con})]}$$

Figure 7. Formula for weight factor.

In the formula for the weight factor:

w is the weight factor,

ES is the corrected effect size of the primary study,

$\tilde{n}$ is the weighted average of the subjects in each group,

n_{Exp} is the number of subjects in the experimental group, and

n_{Con} is the number of subjects in the control group.

The formula used to calculate the weighted average of the subjects in each group is shown in figure 8.

$$\tilde{n} = \frac{n_{Exp} \times n_{Con}}{n_{Exp} + n_{Con}}$$

Figure 8. Formula for the weighted average of subjects.

In the formula for the weighted average of subjects:

$\tilde{n}$ is the weighted average of the subjects,

n_{Exp} is the number of subjects in the experimental group, and

n_{Con} is the number of subjects in the control group.

The overall mean effect size for a group of studies is calculated by dividing the sum of the products of the individual effect sizes and their weights by the sum of their weights. The formula used to compute the overall mean effect size is shown in figure 9.

$$\overline{ES} = \frac{\sum(ES \times w)}{\sum w}$$

Figure 9. Formula for overall mean effect size.

In the formula for overall mean effect size:

$\overline{ES}$ is the overall mean effect size,

ES is the effect size for each primary study, and

w is the weight factor.

All effects of the use of interactive videodisc and computer-simulated experiments were calculated using the methods previously mentioned and effect sizes were recorded along with other variables on coding sheets. An example of the coding sheet is represented in Appendix A.

The use of a coding sheet allows the researcher to separate studies into the appropriate groups for calculating overall mean effect sizes. Additionally, the coding information may be used to separate major groups into subgroups according to individual study characteristics.

Treatment of the data

An overall mean effect size was calculated to determine whether the treatment had an overall positive, negative or no effect for each of the following constructs:

1. achievement requiring low level recall of facts,
2. achievement requiring high-level thinking skills such as problem solving, processing skills, or transfer of learning ,
3. retention of material at least two weeks after the treatment,
4. attitude toward the instructional method, and

5. attitude toward the subject matter.

Once calculated for each of the five constructs, the effect sizes were subjected to a test of homogeneity to identify outliers as suggested by Hedges (1986). Hedges recommended setting aside a small portion of the data (less that 15 – 20%) because it allows the data to be modeled in a single straightforward way. Effects sizes reported from primary studies that exceeded the 95% confidence interval for the data set for that construct were considered to be outliers and were not included in the calculation of the overall mean effect size.

The synthesis of many individual primary effect sizes into one overall mean effect size offers the advantage of "weighting" over the reporting of individual effect sizes. Weighting refers to the assigning of a "weight", or relative importance of one study compared to another in terms of the population of each study. A study containing 500 subjects, for example, would be weighted more heavily than a study containing 50 subjects. The results of the study containing 500 subjects, therefore, would contribute more to the overall effect size than a study containing 50 subjects.

Effect sizes indicate the number of standard deviations above or below the mean a particular outcome represents. Effect sizes, therefore, generally range between approximately -3.0 to +3.0. An effect size of +0.4, for example, would indicate that the subjects scored 0.4 standard deviations above the mean for a given outcome.

Cohen (1988) defined effect sizes as "small", d = 0.20, "medium", d = 0.50, and large", d = 0.80. Cohen chose an effect size of 0.20 to represent the smallest designation because an effect size of 0.20 represents the critical value for a two-tailed t-test at a significance level of $p < 0.05$, if the population sampled is equal to or greater than 100 subjects. Effect sizes of 0.05 and 0.08 represent higher levels of statistical significance.

Effect sizes are also useful in indicating the average percentile standing of the treated (experimental) participants relative to the untreated (control) participants, as well as the percentage of non-overlap between the two groups (Cohen, 1988). This relationship is demonstrated in Appendix B.

An effect size of 0.0 indicates that the mean of the treated group is at the 50^{th} percentile of the untreated group, and there is complete overlap of the distribution of data points for the two groups. An effect size of 0.80, however, indicates that the average score of the experimental group is at the 79^{th} percentile of the untreated group, and that nearly half of the distribution of the data points associated with the treated group does not overlap the untreated group.

Meta-analysis is more than a method for computing mean effect sizes, but is rather an orientation towards research synthesis (Wachter & Straf, 1990).

In the case of a hypothetical meta-analysis attempting to resolve conflicting results from a large number of studies measuring the effectiveness of a particular treatment on academic achievement, for example, a researcher might find an insignificant overall effect size. If a similar numbers of studies reported positive and negative effect sizes, the overall effect size might be insignificant, but with proper analysis, the underlying cause for such conflicting findings might become apparent. If the researcher grouped the results of similarly coded studies into separate categories for analysis, for example, it might be revealed through tests of homogeneity that studies introducing the treatment at the beginning of the lesson cycle reported significantly higher achievement outcomes than did studies that introduced the treatment at the end of the lesson cycle. Further analysis using multiple tests of homogeneity, in the case of this hypothetical study, allowed the researcher to clarify and explain the true nature of the relationship.

In addition to calculating the overall mean effect sizes for the achievement and attitudinal outcomes addressed by the primary research questions, additional features of the related studies were coded and subjected to meta-analysis. Studies containing similar coding were grouped for the purpose of determining if studies with similar codes contained similar results.

Gurevitch and Hedges (in Scheiner & Gurevitch, 1993) suggested that multiple tests of between-group homogeneity, which would be equivalent to an ANOVA for raw statistical data, be performed on the derived data included in each subgroup to determine if the subgroups being tested were significantly different. Significant differences ($p < 0.01$) between the subgroups indicated that the characteristic used to differentiate the groups reflected effect size outcomes which varied significantly between the groups. These differences might have possibly contributed to a mean effect size that did not accurately describe the complete nature of the reported effect outcomes.

The studies were broken into groups and analyzed as follows:

1. Effect sizes of all studies with similar grade levels of students (K – 12, college and professional) were grouped together, and the measure of between-group homogeneity for each student grade level was calculated to determine if one student grade level was more affected by simulation than another.
2. Effect sizes of all studies with similar subject matter (life science, physical science) were grouped together, and the measure of between-group homogeneity

for each subject was calculated to determine if one subject was more affected by simulation than another.

3. Effect sizes of all studies with similar modes (exploratory, confirmatory) were grouped together, and the measure of between-group homogeneity for each instructional mode was calculated to determine if one instructional mode was more effective than another in producing positive outcomes.
4. Effect sizes of all studies with similar lengths of treatment (one week or less, more than one week) were grouped together, and the measure of between-group homogeneity for each length of treatment was calculated to determine if one length of treatment was more effective than another in producing positive outcomes.
5. Effect sizes of all studies with similar types of simulation (interactive videodisc or computer-simulated experiments) were grouped together, and the measure of between-group homogeneity for each type of simulation was calculated to determine if one type of simulation was more effective than another in producing positive outcomes.
6. Effect sizes of all studies with similar periods of publication (1983 – 1993, 1994 - 2001) were be grouped together, and the measure of between-group homogeneity for each period of publication was calculated to determine if the simulations of one period was more effective than another in producing positive outcomes.
7. Effect sizes of all studies students with similar genders (female, male) were grouped together, and measure of between-group homogeneity for each gender

was calculated to determine if one student gender was more affected by simulation than another.

The formula used to calculate the between-group homogeneity was is shown in figure 10.

$$Q_{between} = \sum\left[\sum w_{ij}\left(d_i - \bar{d}\right)^2\right]$$

Figure 10. Formula for between-group homogeneity.

In the formula for between-group homogeneity:

$Q_{between}$ is the between-group homogeneity,

w_{ij} is the sum of the weights for all studies,

d_i is the effect size for each study in the subset, and

$\bar{d}$ is the overall mean effect size for all studies.

Once calculated, the magnitude of the between-group homogeneity was compared to a table of chi-squared values. If the calculated value equaled or exceeded the chi-squared value for n-1 degrees of freedom at $p < 0.01$ level, the result indicated that considerable differences in homogeneity existed between the two groups. If the calculated value was less than the appropriate chi-squared value, no homogeneity between the groups was indicated.

Summary

Meta-analysis was used in this study to calculate the overall effect sizes relating to achievement and attitudinal outcomes of students using computer-simulated experiments and interactive videodisc simulations in science education. The methods used to identify, obtain, code, and classify those studies were described. Methods and relevant mathematical formulas used to calculate the overall effect size and to determine the homogeneity of studies based on characteristics of the simulations were also discussed. The overall mean effect sizes for each of the primary research questions as well as the results of the multiple tests of homogeneity performed on the studies divided into subgroups based on specific characteristics were reported in the following chapter.

Chapter 4

PRESENTATION AND ANALYSIS OF DATA

Since the introduction of practical microcomputer and interactive videodisc technology into the classroom in the 1980s, dozens of research studies have been conducted to determine the effectiveness of computer-simulated experiments as compared to traditional learning activities. These research studies produced varied and sometimes contradictory findings, leaving researchers and educators divided as to the effectiveness of simulations in the science classroom. This study, employing meta-analytic methodology, synthesized the findings of research literature related to the effectiveness of computer-simulated experiments as compared to traditional learning activities, in order to gain useful conclusions from the findings of previous studies.

This chapter will present the data obtained from 40 studies that assessed the results of the use of interactive videodisc and computer-simulated experiments in science education. Additionally, results of studies with similar characteristics, such as subject matter or grade level, were grouped together and the measure of between-group homogeneity was computed to determine if any significant differences existed between the subgroups.

As stated previously, positive effect sizes indicate that groups using computer-simulated experiments and interactive videodisc technology benefited from their use, while negative effect sizes indicate that the groups using the computer-simulated experiments and interactive videodisc treatment suffered. Effect sizes greater or less than

± 0.20 were considered to be significant ($p<0.05$) if the total number of subjects was equal to or greater than 100.

Identification of studies

The search strategies listed in Chapter III led to the identification of approximately 225 possible documents of interest. After initial screening, over 70% of the documents were rejected for use in the meta-analysis as they were not research studies, but reports on the current uses or opinions on the uses computer-simulated experiments or interactive videodisc simulations. Of the remaining research studies many did not meet all of the original search criteria. These remaining studies were rejected for a variety of reasons including:

1. the studies did not use PC, Macintosh®, or interactive videodisc technology;
2. the studies were qualitative in nature;
3. the study did not use a comparison group;
4. the study did not employ an experimental or quasi-experimental research design; and
5. insufficient data were presented to calculate an effect size.

A total of 46 studies were identified for meta-analysis after the selection process was completed. Of these 46, six studies had effect sizes that fell outside of the 95 percent confidence interval calculated for all studies, and were therefore identified as outliers. These outliers were not included in the final analysis, as suggested by Hedges (1986). A panel of three judges coded each of the remaining 40 studies separately, resulting in the identification of 54 individual effect sizes. Discrepancies concerning the classification of the studies as measuring low-level or high-level achievement were the most common, but were adjudicated until all judges were in agreement. The data was recorded on a coding sheet as represented in Appendix A, as well as entered into a computer database program.

Research questions

Research question 1

The first research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to low-level thinking skills? Twenty studies compared computer-simulated experiments with traditional learning activities relating to low-level recall of facts. Effect sizes for each of those studies were calculated and an overall mean effect size was computed for those studies. The mean overall mean effect size and individual effect sizes for those studies are presented in Table 1.

Table 1

Effect sizes for low-level achievement

Author	ES	weight	N	Mean ES
Barker	0.62	7.15	30	
Branch	0.11	21.72	87	
Buttles	0.82	24.23	110	
Choi	0.01	29.95	117	
Dewhurst	0.26	3.40	14	
Fawver	0.29	21.02	85	
Geban	0.74	30.26	130	
Gokhale	0.42	7.83	32	
Hopkins	-0.31	13.64	57	
Jackman 1	0.38	85.99	190	
Jackman 2	0.45	46.31	350	
Kinzie	0.42	7.34	30	
Lewis	0.29	67.29	272	
Lyness	0.33	24.40	99	
Marszalek	-0.44	43.47	194	
Mills	1.01	31.50	151	
Pena	0.68	20.09	85	
Spraggins	0.10	20.65	83	
Strauss	0.08	4.23	17	
Tylenski	0.47	23.54	97	
				0.34*

* $p < 0.05$

Twenty primary effect sizes of studies measuring low-level achievement were weighted according to the number of subjects participating in each study. The total number of subjects for these studies was 2230. Individual effect sizes from the primary studies ranged from - 0.44, a medium-sized negative effect size to + 1.01, a large positive result. An overall mean effect size of + 0.34 was calculated from these primary studies. This value exceeded the critical value of 0.20, which indicated that computer-simulated experiments contributed a significant positive effect on the low-level achievement of science students as compared to traditional learning activities.

Research question 2

The second research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to high-level thinking skills? Twenty-two studies compared computer-simulated experiments with traditional learning activities relating to higher-order thinking skills. Effect sizes for each of those studies were calculated and an overall mean effect size was computed for those studies. The overall mean effect size and individual effect sizes for those studies are presented in Table 2.

Table 2

Effect sizes for high-level achievement

Author	ES	weight	N	Mean ES
Barnea	0.95	16.01	79	
Berlin	0.20	44.03	177	
Brant	0.55	22.11	101	
Carlsen	0.61	16.64	70	
Chou	0.43	13.68	56	
Faryniarz	0.48	13.68	58	
Friedler	0.84	22.66	74	
Geban	0.86	29.61	130	
Gokhale	1.08	6.97	32	
Grosso	0.26	157.13	1132	
Hall	-0.22	6.69	27	
Hughes	0.54	21.19	88	
Huppert	0.24	44.52	181	
Leonard92	0.10	35.45	142	
Moslehpour	-0.39	18.65	76	
Rieber92	0.43	37.63	154	
Rueter	0.39	68.94	181	
Vockell 1	0.18	26.14	105	
Vockell 2	0.05	13.67	65	
Vockell 3	0.35	62.39	266	
Webb	1.19	17.99	89	
Woodward	0.81	6.94	30	
				0.38*

* $p < 0.05$

Twenty-two primary effect sizes of studies measuring high-level achievement were weighted according to the number of subjects participating in each study. The total number of subjects for these studies was 3866. Individual effect sizes from the primary studies ranged from - 0.39, a small negative effect size, to + 1.19, a large positive result. An overall mean effect size of + 0.38 was calculated from these primary studies. This value exceeded the critical value of 0.20, which indicated that computer-simulated experiments contributed a significant positive effect on the high-level achievement of science students as compared to traditional learning activities.

Research question 3

The third research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to retention of material for at least two weeks after treatment? Six studies compared computer-simulated experiments with traditional learning activities relating to retention at least two weeks after treatment. Effect sizes for each of those studies were calculated and an overall mean effect size was computed for those studies. The overall mean effect size and individual effect sizes for those studies are presented in Table 3.

Table 3

Effect sizes for retention

Author	ES	weight	N	Mean ES
Barker	0.23	7.45	30	
Choi	0.01	27.69	111	
Hopkins	0.11	13.70	49	
Spraggins	0.21	20.56	83	
Strauss	0.39	4.15	17	
Woodward	0.83	6.90	30	
				0.19

Six primary effect sizes of studies measuring retention of material for at least two weeks after treatment were weighted according to the number of subjects participating in each study. The total number of subjects for these studies was 320. Individual effect sizes from the primary studies ranged from - 0.01, an insignificant result, to + 0.83, a large positive effect size. An overall mean effect size of + 0.19 was calculated from these primary studies. This value was only slightly less than the critical value, indicating that computer-simulated experiments contributed no more or less to students' retention of data for more than two weeks than did traditional learning activities.

Research question 4

The fourth research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student attitude outcomes relating to attitudes toward the subject matter? Five studies compared computer-simulated experiments with traditional learning activities on student achievement outcomes relating to attitudes toward the subject. Effect sizes for each of those studies were calculated and an overall mean effect size was computed for those studies. The mean effect size and individual effect sizes for those studies are presented in Table 4.

Table 4

Effect sizes for attitudes toward the subject

Author	ES	weight	N	Mean ES
Hopkins	0.07	13.71	57	
Kinzie	-0.12	7.49	30	
Leonard89	0.23	35.26	142	
Mills	-0.23	34.87	150	
Strauss	-0.82	3.91	17	
				-0.03

Five primary effect sizes of studies measuring attitudes toward the subject were weighted according to the number of subjects participating in each study. The total number of subjects for these studies was 396. Individual effect sizes from the primary studies ranged from - 0.82, large negative result, to + 0.23, a small positive effect size.

An overall mean effect size of - 0.03 was calculated from these primary studies. This value was less than the critical value, indicating that computer-simulated experiments contributed any more or less to student attitudes toward the subject being studied as compared to traditional learning activities.

Research question 5

The fifth research question was: What are the differences between the use of computer-simulated experiments and traditional learning activities on student attitude outcomes relating to attitudes toward the method of instruction? Only one study compared computer-simulated experiments with traditional learning activities on student achievement outcomes relating to attitudes toward the method used to teach the subject. The unique effect size for that study is presented in Table 5.

Table 5

Effect sizes for attitude toward the method

Author	ES	weight	N
Samsel	1.04*	19.32	88

The single study measuring attitudes toward computer-simulated experiments as the instructional method reported an effect size of 1.04, indicating that for this group of 88 subjects, computer-simulated experiments were effective in promoting positive attitudes toward the computer-simulated methodology. This single study alone was insufficient to compute an overall mean effect size for this research question.

Additional features

In addition to calculating mean effect sizes for achievement and attitudinal outcomes, several features associated with the studies also were coded. The subgroups were subjected to tests of between-group homogeneity to determine if a particular subgroup was more influential on the overall mean effect size than another group. A resulting between-group homogeneity value less than the established critical value ($p < 0.01$), indicated that no significant differences existed between the impacts of the subgroups on the overall mean effect size. A between-group homogeneity value exceeding the critical value indicated that the subgroups had differing effects on the overall mean effect size, suggesting that differences within that group of studies existed due to the characteristic used to divide the studies into groups. The studies were broken into groups and analyzed as follows:

8. Effect sizes of all studies with similar grade levels of students (K-12, college/professional) were grouped together, and the measure of between-group homogeneity for each student grade level was calculated to determine if one student grade level was more affected by simulation than another;
9. effect sizes of all studies with similar subject matter (biological sciences, physical sciences) were grouped together, and the measure of between-group homogeneity for each subject was calculated to determine if one subject was more affected by simulation than another;
10. effect sizes of all studies with similar instructional modes (exploratory, confirmatory) were grouped together, and the measure of between-group homogeneity for each instructional purpose was calculated to determine if one

instructional purpose was more affected than another in producing positive outcomes;

11. effect sizes of all studies with similar lengths of treatment (one week or less, more than one week) were grouped together, and the measure of between-group homogeneity for each length of treatment was calculated to determine if one length of treatment was more affected than another in producing positive outcomes;
12. effect sizes of all studies with similar types of simulation (interactive videodisc or computer-simulated experiments) were grouped together, and the measure of between-group homogeneity for each type of simulation was calculated to determine if one type of simulation was more affected than another in producing positive outcomes;
13. effect sizes of all studies with similar periods of publication (1983 – 1993, 1994, - 2001) were grouped together, and the measure of between-group homogeneity for each period of publication was calculated to determine if the simulations of one period was more affected than another in producing positive outcomes;
14. effect sizes of all studies students with similar genders (female, male) were grouped together, and the measure of between-group homogeneity for each gender was calculated to determine if one student gender was more affected by simulation than another.

Differences associated with grade level

Data from 11 studies reported low-level achievement outcomes for college or professional students, while 9 studies reported those outcomes for K-12 students. The mean effect sizes for those groups are reported in Table 6.

Table 6

Achievement-low/college-professional vs. K-12

Sub-group	Mean ES	Studies	$Q_{between}$
College, professional	0.49	11	
K-12	0.14	9	33.38*

* exceeds χ^2 value for 2 *df*, $p < 0.01$

The overall mean effect size calculated for low-level achievement in the subgroup consisting of students enrolled in college or professional school was 0.49, a moderately significant effect size, while the effect size for students enrolled in Kindergarten through the twelfth grade was 0.14, which was not significant. The between-group homogeneity value calculated for these groups was 33.38, which exceeded the critical value of 6.63. This indicated that the subsets lacked homogeneity at a significant level ($p < 0.01$), and that the subset of studies consisting of subjects enrolled in college and professional schools had effect sizes that were significantly different from the effect sizes of studies consisting of subjects enrolled in Kindergarten through twelfth grade.

Data from 13 studies reported high-level achievement outcomes for college or professional students, while 9 studies reported those outcomes for K-12 students. The mean effect sizes for those groups are reported in Table 7.

Table 7

Achievement-high/college-professional vs. K-12

Sub-group	Mean ES	Studies	$Q_{between}$
College, professional	0.35	13	
K-12	0.42	9	1.76

The overall mean effect size calculated for low-level achievement in the subgroup consisting of students enrolled in college or professional school was 0.35, and the effect size for students enrolled in Kindergarten through the twelfth grade was 0.42. The between-group homogeneity value calculated for these groups was 1.76, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Data from only 1 study reported retention outcomes for college or professional students, while 5 studies reported those outcomes for K-12 students. Due to insufficient data, between-group homogeneity could not be calculated for these groups.

Data from 3 studies reported attitude toward the subject outcomes for college or professional students, while 2 studies reported those outcomes for K-12 students. The mean effect sizes and between-group homogeneity for those groups are reported in Table 8.

Table 8

Attitude-subject/college-professional vs. K-12

Sub-group	Mean ES	Studies	$Q_{between}$
College, professional	0.001	3	
K-12	-0.13	2	1.04

The overall mean effect size calculated for low-level achievement in the subgroup consisting of students enrolled in college or professional school was 0.01, and the effect size for students enrolled in Kindergarten through the twelfth grade was -0.13. The between-group homogeneity value calculated for these groups was 1.04, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Differences associated with subject area

Data from 13 studies reported low-level achievement outcomes for biological sciences, while 7 studies reported those outcomes for physical sciences. The mean effect sizes for those groups are reported in Table 9.

Table 9

Achievement-low/biological vs. physical sciences

Sub-group	Mean ES	Studies	$Q_{between}$
Biological sciences	0.27	13	
Physical sciences	0.39	7	3.95

The overall mean effect size calculated for low-level achievement in the subgroup consisting of students enrolled in biological science classes was 0.27, and the effect size for students enrolled in physical science classes was 0.39. The between-group homogeneity value calculated for these groups was 3.95, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Data from 13 studies reported high-level achievement outcomes for students enrolled in biological science classes, while 9 studies reported those outcomes for students in physical science classes. The mean effect sizes for those groups are reported in Table 10.

Table 10

Achievement-high/biological vs. physical sciences

Sub-group	Mean ES	Studies	$Q_{between}$
Biological sciences	0.41	13	
Physical sciences	0.35	9	1.27

The overall mean effect size calculated for high-level achievement in the subgroup consisting of students enrolled in biological science classes was 0.41, and the effect size for students enrolled in physical science classes was 0.35. The between-group homogeneity value calculated for these groups was 1.27, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Data from only 1 study reported retention outcomes for physical sciences, while 5 studies reported those outcomes for biological sciences. Due to insufficient data, between-group homogeneity could not be calculated for these groups. No effect sizes were reported for student outcomes for attitude toward the subject for physical sciences, therefore no comparison could be made.

Differences associated with instructional modes

Data from 6 studies reported low-level achievement outcomes for the confirmatory mode, while 14 studies reported those outcomes for the exploratory mode. The mean effect sizes for those groups are reported in Table 11.

Table 11

Achievement-low/confirmatory vs. exploratory

Sub-group	Mean ES	Studies	$Q_{between}$
Confirmatory	0.44	6	
Exploratory	0.27	14	7.96*

* exceeds χ^2 value for 2 *df*, $p < 0.01$

The overall mean effect size calculated for low-level achievement in the subgroup consisting of students taught using simulations in the confirmatory mode was 0.44, and the effect size for students taught using simulation in the exploratory mode was 0.27. The between-group homogeneity value calculated for these groups was 7.96, which exceeded the critical value of 6.63, indicating that the subsets lack homogeneity at a significant level ($p < 0.01$). These results indicated that the effect sizes of studies consisting of students receiving simulation in the confirmatory mode were significantly different from the effect sizes of studies consisting of students receiving instruction in the exploratory mode.

Data from 10 studies reported high-level achievement outcomes for the confirmatory mode, while 13 studies reported those outcomes for the exploratory mode. The mean effect sizes for those groups are reported in Table 12.

Table 12

Achievement-high/confirmatory vs. exploratory

Sub-group	Mean ES	Studies	$Q_{between}$
Confirmatory	0.35	10	
Exploratory	0.41	13	1.27

The overall mean effect size calculated for high-level achievement in the subgroup consisting of students taught using simulations in the confirmatory mode was 0.35, and the effect size for students taught using simulations in the exploratory mode was 0.41. The between-group homogeneity value calculated for these groups was 1.27, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

There were no studies reporting outcomes in the confirmatory mode for the constructs of retention or attitudes toward the subject. No comparisons, therefore, could be made for these groups.

Differences associated with length of treatment

Data from 17 studies reported low-level achievement outcomes for the studies lasting one week or less, while 3 studies reported those outcomes studies lasting more than one week. The mean effect sizes for those groups are reported in Table 13.

Table 13

Achievement-low/1 week or less vs. more than 1 week

Sub-group	Mean ES	Studies	$Q_{between}$
Less that 1 week	0.28	17	
More than 1 week	0.73	3	83.14*

* exceeds χ^2 value for 2 *df*, $p < 0.01$

The overall mean effect size calculated for low-level achievement in the subgroup consisting of studies lasting less than one week was 0.28, and the effect size for studies lasting more than one week was 0.73. The between-group homogeneity value calculated for these groups was 83.14, which exceeded the critical value of 6.63, indicating that the subsets lack homogeneity at a significant level ($p < 0.01$). These results indicated that the effect sizes of studies lasting more than one week were significantly different from the effect sizes of studies lasting less than one week.

Data from 10 studies reported high-level achievement outcomes for the less than 1 week, while 12 studies reported those outcomes for the more than 1 week. The mean effect sizes for those groups are reported in Table 14.

Table 14

Achievement-high/1 week or less vs. more than 1 week

Sub-group	Mean ES	Studies	$Q_{between}$
Less that 1 week	0.33	10	
More than 1 week	0.46	12	6.26

The overall mean effect size calculated for high-level achievement in the subgroup consisting of studies lasting less than one week was 0.33, and the effect size for studies lasting more than one week was 0.46. The between-group homogeneity value calculated for these groups was 6.26, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Data from 5 studies reported retention outcomes for the less than 1 week, while only 1 study reported those outcomes for the more than 1 week. Due to insufficient data, between-group homogeneity could not be calculated for these groups. There were no studies reporting outcomes for studies lasting more than 1 week for the constructs of attitudes toward the subject.

Differences associated with the type of simulation

Data from 14 studies reported low-level achievement outcomes for the computer-simulated experiments, while 6 studies reported those outcomes for the interactive videodisc simulations. The mean effect sizes and between-group homogeneity for those groups are reported in Table 15.

Table 15

Achievement-low/CSE vs. IVD

Sub-group	Mean ES	Studies	$Q_{between}$
Computer-simulated	0.35	14	
Interactive videodisc	0.28	6	1.98

The overall mean effect size calculated for low-level achievement in the subgroup consisting of studies utilizing computer-simulated experiments was 0.35, and the effect size for studies utilizing interactive videodisc simulation was 0.28. The between-group homogeneity value calculated for these groups was 1.98, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Data from 21 studies reported high-level achievement outcomes for the computer-simulated experiments, while only 1 study reported those outcomes for the interactive videodisc. Due to insufficient data, mean effect sizes and between-group homogeneity could not be calculated for these groups.

Data from 4 studies reported retention outcomes for computer-simulated experiments, while 2 studies reported those outcomes for interactive videodisc. The mean effect sizes and between-group homogeneity for those groups are reported in Table 16.

Table 16

Retention/CSE vs. IVD

Sub-group	Mean ES	Studies	$Q_{between}$
Computer-simulated	0.17	4	
Interactive videodisc	0.29	2	0.84

The overall mean effect size calculated for retention of material after two weeks or longer using computer-simulated experiments was 0.17, an insignificant effect size, while the effect size for utilizing interactive videodisc simulation was 0.29, which was significant. The between-group homogeneity value calculated for these groups was 0.84, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous

Data from 3 studies reported attitude toward the subject outcomes for computer-simulated experiments, while 3 studies reported those outcomes for interactive videodisc. The mean effect sizes for those groups are reported in Table 17.

Table 17

Attitude-subject/CSE vs. IVD

Sub-group	Mean ES	Studies	$Q_{between}$
Computer simulated	-0.15	3	
Interactive videodisc	0.09	3	2.7

The overall mean effect size calculated for attitudes toward the subject in the subgroup consisting of studies utilizing computer-simulated experiments was -0.15, an insignificant effect size, while the effect size for utilizing interactive videodisc simulation was 0.09, which is also insignificant. The between-group homogeneity value calculated for these groups was 2.70, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Differences associated with period of publication

Data from 13 studies reported low-level achievement outcomes for the studies conducted during the period 1983-1993, while 7 studies reported those outcomes for the studies conducted during the period 1994 - 2001. The mean effect sizes and between-group homogeneity for those groups are reported in Table 18.

Table 18

Achievement-low/1983-1993 vs. 1994-2001

Sub-group	Mean ES	Studies	$Q_{between}$
1983-1993	0.41	13	
1994-2001	0.05	7	46.83*

* exceeds χ^2 value for 2 *df*, p < 0.01

The overall mean effect size calculated for low-level achievement in the subgroup consisting of studies published during the period of 1983 – 1993 was 0.41, a moderately significant effect size, while the effect size for studies published during the period of 1994 - 2001 was 0.05, which is not significant. The between-group homogeneity value calculated for these groups was 46.83, which exceeded the critical value of 6.63, indicating that the subsets lack homogeneity at a significant level (p < 0.001). These results indicated that the subset of studies published during the period of 1983 - 1993 were significantly different from the studies published during the period of 1994 - 2001.

Data from 13 studies reported high-level achievement outcomes for the studies published during the period 1983-1993, while 7 studies reported those outcomes for the studies conducted during the period 1994 - 2001. The mean effect sizes and between-group homogeneity for those groups are reported in Table 19.

Table 19

Achievement-high/1983-1993 vs. 1994-2001

Sub-group	Mean ES	Studies	$Q_{between}$
1983 – 1993	0.45	13	
1993 – 2001	0.31	7	55.19*

* exceeds χ^2 value for 2 *df*, $p < 0.01$

The overall mean effect size calculated for high-level achievement in the subgroup consisting of studies published during the period of 1983 – 1993 was 0.45, and the effect size for studies published during the period 1994 – 2001 was 0.31. The between-group homogeneity value calculated for these groups was 55.19, which exceeded the critical value of 6.63, indicating that the subsets lack homogeneity at a significant level. These results indicated that the effect sizes of studies published during the period of 1983 - 1993 were significantly different from the effect sizes of studies conducted during the period of 1994 - 2001.

Data from 4 studies reported retention outcomes for the studies conducted during the period 1983 - 1993, while 2 studies reported those outcomes for the studies conducted during the period 1994 - 2001. The mean effect sizes and between-group homogeneity for those groups are reported in Table 20.

Table 20

Retention/1983-1993 vs. 1994-2001

Sub-group	Mean ES	Studies	$Q_{between}$
1983 – 1993	0.19	4	
1993 – 2001	0.18	2	0.001

The overall mean effect size calculated for retention of material for two weeks or more for the subgroup consisting of studies published during the period 1983 – 1993 was 0.19, and the effect size for studies published during the period 1994 – 2001 was 0.18. The between-group homogeneity value calculated for these groups was 0.001, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Data from 3 studies reported attitude toward the subject outcomes for the studies conducted between the years of 1983-1993, while 2 studies reported those outcomes for the studies conducted between the years of 1994-2001. The mean effect sizes and between-group homogeneity for those groups are reported in Table 21.

Table 21

Attitude-subject/1983-1993 vs. 1994-2001

Sub-group	Mean ES	Studies	$Q_{between}$
1983 – 1993	-0.01	3	
1994 – 2001	-0.13	2	0.99

The overall mean effect size calculated for attitude toward the subject for the subgroup consisting of studies published during the period 1983 – 1993 was -0.01, and the effect size for studies published during the period 1994 – 2001 was -0.13. The between-group homogeneity value calculated for these groups was 0.99, which did not exceed the critical value of 6.63, indicating that the subsets could be considered to be homogeneous.

Differences associated with gender

Only 1 study compared differences in low-level achievement, based on gender, 1 study compared differences in retention based on gender, and only 2 studies compared differences in high-level achievement based on gender. Due to the insufficient number of studies, no measure of between-group homogeneity could be computed for these studies.

Summary

Effect sizes from 40 primary studies, relating to low-level student achievement, high-level student achievement, students' retention, students attitudes toward the subject matter, and students' attitudes toward the method of instruction were synthesized using meta-analytical techniques. An overall mean effect size was calculated for each of those sub-groups. Mean effect sizes exceeding the critical value of $\pm$ 0.20 were considered to be significant ($p < 0.05$) outcomes. Additionally, studies were grouped together into subgroups according to characteristics of those studies for the purpose of determining the homogeneity of the effect sizes within those subgroups. Subgroups of studies exhibiting significant homogeneity ($p < 0.01$) were considered to have contributed unequally to the mean effect size, and suggested that differences in the studies effect sizes were related to different characteristics of the simulations.

Chapter 5

SUMMARY, FINDINGS, CONCLUSIONS, IMPLICATIONS FOR PRACTICE, AND RECOMMENDATIONS FOR FURTHER STUDY

The final chapter consists of a summary of the study and the findings of the meta-analysis. Conclusions based on those findings will be discussed, as will implications for practice. Finally, the chapter will conclude with recommendations for areas for further study.

Summary

The purpose of this study was a synthesis, using meta-analysis, of the findings of research literature related to the effectiveness of computer-simulated experiments in science education. The study employed meta-analysis to examine the effectiveness of simulation features and implementation strategies of computer-simulated experiments and interactive videodisc simulation on student outcomes relating to low-level achievement, high-level achievement, retention, attitudes toward the subject, and attitudes toward the method of instruction.

In addition to separating primary studies into groups corresponding to these major questions, the study grouped the primary studies within those major categories to determine whether differences existed between subgroups relating to different simulation features or student characteristics.

Findings

The 40 primary studies generated a total of 54 individual effect sizes. These effect sizes were partitioned into subsets that related to the effect of computer-simulated experiments and interactive videodisc simulation on student outcomes relating to three areas of achievement, and two areas of attitude. After calculating a 95% confidence interval and eliminating data points considered being outliers, an overall mean effect size was calculated for each subset.

Research question 1

The first research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to low-level thinking skills? Twenty primary research articles, involving a total of 2230 subjects, reported sufficient data for an effect size and weighting factor to be calculated for the construct of low-level achievement. Individual effect sizes for these studies ranged from -0.44 to +1.01 for this type of achievement. An overall mean effect size of +0.34 indicated that computer-simulated experiments and interactive videodisc simulation had a significant positive effect on students' low-level achievement such as recall of facts, application, and comprehension. An effect size of this magnitude places the mean of the experimental group at the 64th percentile level.

Research question 2

The second research question was: What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to high-level thinking skills? Twenty-two primary research articles, involving a total of 3866 subjects, reported sufficient data for an effect size and weighting factor to be calculated for the construct of high-level achievement. Individual effect sizes from these studies ranged from -0.39 to +1.19 for this type of achievement. An overall mean effect size of +0.38 indicated that the use of computer-simulated experiments and interactive videodisc simulation had a significant positive effect on students' high-level achievement such as problem solving, processing skills, or transfer of learning. An effect size of this magnitude places the mean of the experimental group at approximately the 65th percentile level.

Research question 3

The third research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student achievement outcomes relating to retention of material for at least two weeks after treatment? Six primary research articles, involving a total of 320 subjects, reported sufficient data for an effect size and weighting factor to be calculated for the construct of retention of facts for more than two weeks. Individual effect sizes from these studies ranged from -0.01 to +0.83 for retention of material for two weeks or longer. An overall mean effect size of +0.19 indicated students using computer-simulated experiments and interactive videodisc simulation achieved as well as students engaged in traditional learning activities on measures of retention of material after two weeks. An effect size of this magnitude places the mean of the experimental group at approximately the 58th percentile level.

Research question 4

The fourth research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student attitude outcomes relating to attitudes toward the subject matter? Five primary research articles, involving a total of 396 subjects, reported sufficient data for an effect size and weighting factor to be calculated for the construct of attitude toward the subject being studied. Individual effect sizes from these studies ranged from -0.82 to +0.23 for this measure of student attitude. An overall mean effect size of -0.03 indicated that students using computer-simulated experiments and interactive videodisc simulation performed equally as well as students engaged in traditional learning activities on measures of students' attitudes toward the subject. An effect size of this magnitude places the mean of the experimental group at approximately the 50th percentile level.

Research question 5

The fifth research question was as follows: What are the differences between the use of computer-simulated experiments and traditional learning activities on student attitude outcomes relating to attitudes toward the method of instruction? A single study containing 88 subjects was identified that compared attitudes of students using computer-simulated experiments and interactive videodisc simulation with students engaging in traditional learning activities, therefore no analysis was performed, as the both the number of subjects and number of studies was insufficient.

Additional features

In addition to grouping the 54 individual primary effect sizes into categories corresponding to the five research questions, the primary effect sizes were also divided into subgroups according to characteristics such as grade level, instructional mode, and length of treatment, within the major groupings. The subgroups were subjected to tests of between-group homogeneity to determine if a particular subgroup was more influential on the overall mean effect size than another group. Between-group homogeneity values exceeding the critical value indicated that differences within that group of studies existed due to the characteristic used to divide the studies into groups. One subgroup might include, for example, only elementary students, while the other includes only secondary students. The elementary subgroup might demonstrate a large positive effect size, while the secondary sub-group might demonstrate a large negative effect size. While the overall mean effect size might be insignificant, a test of between-group homogeneity will identify the disparity, and present a clearer picture of reality.

A significant lack of homogeneity ($p < 0.01$) was found between the following subgroups:

1. The sub-group of students enrolled in college or professional subgroup was found to be significantly different from the sub-group of students in Kindergarten through twelfth grade, belonging to the set of studies representing low-level achievement;
2. the sub-group of students experiencing simulation in the confirmatory mode was found to be significantly different from the sub-group of students experiencing simulation in the exploratory mode, belonging to the set of studies measuring outcomes of low-level achievement;
3. the subgroup of students using simulations lasting more than one week was found to be significantly different from the sub-group of students using simulations lasting less than one week, belonging to the set of studies measuring outcomes of low-level achievement; and
4. the sub-group of studies published during the period of 1983 to 1993 was found to be significantly different from the sub-group of studies published during the period of 1994 to 2001, belonging to the set of studies measuring outcomes in both low-level and high-level achievement.

Conclusions

The following conclusions are based on the findings of this study:

1. The use of computer-simulated experiments and interactive videodisc simulation in science classrooms improves students' low-level achievement, such as the ability to learn scientific facts, comprehend scientific processes, and apply that knowledge to everyday phenomena as compared to traditional science laboratory activities;
2. the use of computer-simulated experiments and interactive videodisc simulation in science classrooms improves students' problem solving ability and other high-level thinking skills as compared traditional science laboratory activities;
3. the use of computer-simulated experiments and interactive videodisc simulation in science classrooms is as equally effective as traditional science laboratory activities in promoting retention of material for a period of two weeks or more;
4. the use of computer-simulated experiments and interactive videodisc simulation in science classrooms is as equally effective as traditional science laboratory activities in promoting positive student attitudes towards the subject matter; and
5. research on the effects of simulation on students' attitudes is much less prevalent than research on student achievement.

Support for these conclusions were also found in Armstrong (1991), who performed a meta-analysis on the effect of computer simulations across a broad area of subject matter. Armstrong found an effect size of +0.31 for low-level recall of facts, which is consistent with the mean effect size of +0.34 found in this study. Further support for the advantage of computer-simulated experiments over traditional laboratory activities on low-level achievement outcomes was found in qualitative investigations conducted by Khoo and Koh (1998) and Eylon, Ronen, and Ganiel (1996).

A meta-analysis conducted by Armstrong (1991) found a mean effect size of +0.28 for high-level achievement, which is consistent with the mean effect size of +0.38 found in this study. Further evidence supporting the effectiveness of computer-simulated experiments as compared to traditional laboratory activities in promoting high-level thinking skills was found in qualitative studies conducted by Kinnear (1986), Okey and Oliver (1987), and Mintz (1993).

Previous meta-analyses conducted by Armstrong (1991) and Lee (1997) on the effectiveness of computer simulation to increase retention of subject matter for periods of two weeks or longer indicated similar non-significant results. Armstrong (1991), however, reported an effect size of -0.32 for the construct of attitudes toward the subject matter, which is contrary to the findings of this study.

In addition, computer-simulated experiments and interactive videodisc simulation are more effective in teaching low-level thinking skills:

1. If used for periods longer than one week than if used for periods of one week or less,
2. if used by college level students and students in professional school than if used by students in elementary and secondary schools, and
3. if used in the confirmatory mode rather than used in the exploratory mode.

The use of computer-simulated experiments and interactive videodisc simulation may also be more effective in teaching both low-level and high-level skills if simulations produced during the 1983-1994 time period are used.

Discussion

The conclusions of this study on the effect of simulations in science education are consistent with the conclusions of previous meta-analyses performed on studies of simulations in all fields of education with respect to student achievement. The findings of this study are contradictory, however, to a meta-analysis performed by Armstrong in 1991 with regard to student attitudes toward the subject matter. The meta-analysis performed by Armstrong (1991) synthesized the results of studies on a wide variety of subjects, while this study used studies exclusively utilizing simulation in science subject areas. While some subjects might not be ideally suited for incorporating computer-simulation into the lesson, according to Lee (1997) science is a very fit subject for simulation type learning.

Armstrong's (1991) meta-analysis on the effect of computer simulation found a positive effect size of 0.40 for student attitudes toward the method of instruction. Unfortunately, only one study relating to that construct was found that measured student attitudes toward computer-simulated experiments in science education. The effect size for that one study, however, was +1.04, a very large positive effect. While this single study consisting of 88 subjects was not a sufficient number of studies on which to perform meta-analytic synthesis, the results of this study are consistent with previous findings. The presence of only a single study on the effects of computer-simulated experiments on student attitudes toward the method of instruction indicates a relative lack of interest on the part of researchers on the role of students' attitudes toward science. While improving students' grades and achievement may be the goal of an individual science course, the ultimate goal of science educators is to improve students' science literacy and to encourage students to continue the study of science.

Simpson and Oliver (1985, 1990) concluded that students with positive attitudes toward science are more likely to take science courses in school, while students with poor attitudes will likely avoid science, and lack scientific knowledge. Additionally, attitudes toward science have been shown to positively correlate to students' grades in science classes and with science achievement as measured by standardized tests (Germann, 1988). More emphasis, therefore, should be placed on research pertaining to student attitudes toward the method of their science instruction.

The significant differences in achievement between the students in college and professional schools and students in elementary and secondary schools might be related to the differences in the purposes of the laboratory at those grade levels. Laboratories at elementary and secondary levels are often designed to stimulate interest, to be thought provoking, to teach laboratory skills, or to teach the steps of the scientific method. Laboratories at more advanced levels, however, are designed to broaden or deepen a students understanding of concepts, and to allow students to apply previously learned concepts.

The significant differences in achievement between studies using computer-simulated experiments in the confirmatory mode over the exploratory mode might be due to the fact that nearly all of the traditional laboratory exercises have been designed to verify and confirm information previously taught in the classroom. Traditional laboratory activities are not typically designed to introduce concepts, or to allow students to explore relationships. The computer-simulated experiments designed to replicate traditional laboratory activities, therefore, are also more suited to the confirmatory mode rather than the exploratory mode.

Computer-simulated experiments lasting more than one week allow students to become familiar with the computer interface and to learn how to fully utilize the abilities of the computer to perform meaningful laboratory simulations. Simulations lasting less than one week would barely allow students enough time to familiarize themselves with all of the controls and features of a complex simulation, preventing the students from receiving the benefits of the simulated environment. As discussed previously, many computer-simulated experiments have been based upon traditional laboratory activities, which have been designed to be completed in one class period, because of the difficulties in leaving the apparatus set up for long periods of time. Computer-simulated experiments do not share this limitation, and may be designed for long-term investigations.

Surprisingly, simulations produced between 1983 and 1993 proved to be more effective at promoting student achievement than more recent simulations, especially in achievement outcomes relating to achievement in low-level thinking skills. Perhaps the earlier simulations were less complicated and easier for the students to master. Additionally, earlier simulations were often more guided, while recent simulations demonstrate more realistic representations of a traditional laboratory. The lack of guidance in more recent simulations might serve to confuse and intimidate students. A simple, guided, unsophisticated approach might be a more effective strategy for teaching basic low-level concepts.

Implications for practice

Because the use of computer-simulated experiments and interactive videodisc simulations have demonstrated only positive achievement effects and no significant adverse effects in retention or attitude toward the subject, the use of these technologies in science classrooms should be encouraged. This appears to be especially true for students in colleges and professional schools; when used to summarize and confirm concepts learned in the classroom, rather than introduce them; for laboratory exercises lasting more than 1 week; and for simulations produced between 1983 and 1993.

Because computer-simulated experiments have been shown to be effective replacements for traditional laboratory activities, they should be used:

1. Whenever traditional laboratories are impractical, such as simulations of large ecosystems, dangerous, such as a simulation of a nuclear reactor, or would normally use expensive equipment, such as simulations of tracking sub-atomic particles or determining molecular structure;
2. as an alternative to traditional animal dissection, especially if students object to the use of animals for confirmatory laboratory use; and
3. to supplement the use of traditional laboratory activities, especially when used to assist students in overcoming misconceptions, or the comprehension of complex relationships.

Support for these recommendations are also found in studies conducted by Hakerem, Dobrynina, and Shore (1993), Monaghan and Clement (1999), Windschitl and Andre (1998), Zietsman and Hewson (1986), and Weller (1995), on the use of computer simulation to overcome students' misconceptions.

Recommendations for further study

Due to the small numbers of studies relating differences between computer-simulated experiments and traditional laboratory activities relating to students' attitudes toward the subject area and students' attitudes toward computer-simulated experiments as the method of instruction, further studies investigating the effects of computer-simulated experiments on student attitudes are needed.

Constructivist theory and the inquiry method of teaching science promote simulated experiences to construct knowledge and to challenge preconceptions. Unfortunately, unless simulated laboratory experiences are purposely designed for the exploratory mode of instruction, the full benefit of computer-simulated experiments might not be realized. The development of computer-simulated experiments as well as the investigation of specific characteristics relating to positive achievement outcomes of computer-simulated experiments utilizing the exploratory mode is also called for. The identification of these features could lead to the development of effective simulations utilizing the exploratory mode, and therefore encouraging scientific inquiry.

Finally, an investigation of features relating to specific characteristics contained in simulations produced between the years of 1983 and 1993 and leading to effective achievement outcomes is warranted. The determination of specific characteristics of early simulations might lead to the development of more effective simulations that employ modern technology.

Computer-simulated experiments currently in use have demonstrated their effectiveness in promoting both low-level and high-level achievement. By examining the particular characteristics of simulations and implementation strategies employed in colleges and

professional schools, and in simulations produced during the period 1983 – 1993, perhaps the effectiveness of computer-simulated experiments might be further enhanced.

REFERENCES

Armstrong, P. S. (1991). Computer-based simulations in learning environments: A meta-analysis of outcomes. *Dissertation Abstracts International,* 53 (01), 100A. (UMI No. 215517)

Bangert-Drowns, R.L., Kulik, J.A., & Kulik, C.C. (1985). Effectiveness of computer-based education in secondary schools. *Journal of Computer–Based Instruction,* 12, 59–68.

Barker, S. P. (1988). Comparison of effectiveness of interactive videodisc vs. lecture-demonstration instruction. *Physical Therapy*, 68(5), 699-703.

Barnea, N., & Dori, Y.J. (1999). High school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. *Journal of Science Education and Technology,* 8, 257–271.

Becker, H. J. (1986). The effects of computer use on children's learning: Limitations of past research and a working model for new research. *Peabody Journal of Education*, 64, 81-110.

Berlin, D.F., & White, A.L. (1985). Computer simulations and the transition from concrete manipulation of objects to abstract thinking. French Lick Springs, IN: National Association for Research in Science Teaching. (ERIC Document Reproduction Service No. ED254410)

Branch, C. E., Ledford, B. R., Robertson, B. T., & Robison, L. (1987). The validation of an interactive videodisc as an alternative to traditional teaching techniques: Auscultation of the heart. *Educational Technology*, 27(3), 16-22.

Brant, G., Hooper, E., & Sugrue, B. (1991). Which comes first the simulation or the lecture? *Journal of Educational Computing Research,* 7, 469–481.

Bredemeier, M.E., & Greenblat, C.S. (1881). The educational effectiveness of simulation games. *Simulation and Games*, 12, 307-332.

Brna, P. (1987). Confronting dynamics misconceptions. *Instructional Science*, 16, 351–379.

Brna, P. (1991). Promoting creative confrontations. *Journal of Computer Assisted Learning*, 7, 14–22.

Buttles, S. (1992). A model for incorporating and evaluating use of a computer laboratory simulation in the nonmajors biology course. *The American Biology Teacher*, 54, 491–494.

Carlsen, D.D., & Andre, T. (1992). Use of a microcomputer simulation and conceptual change text to overcome student preconceptions about electric circuits. *Journal of Computer Based Instruction*, 19, 105–109.

Choi, B., & Gennaro, E. (1987). The effectiveness of using computer simulated experiments on junior high students' understanding of the volume displacement concept. *Journal of Research in Science Teaching*, 24, 539-552.

Chou, C. (1998). The effectiveness of using multimedia computer simulations coupled with social constructivist pedagogy in a college introductory physics classroom. *Dissertation Abstracts International*, 59 (07), 2429A. (UMI No. 9839055)

Clariana, R.B. (1988). Computer simulations of laboratory experiences. *Journal of Computers in Mathematics and Science Teaching*, Winter, 14-19.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Deckers, J., & Donatti, S. (1981). The integration of research studies on the use of simulation as an instructional strategy. *Journal of Educational Research*, 74, 424–427.

Dewhurst, D.J., Hardcastle, J., Harcastle, P.T., & Stuart, E. (1994). Comparison of a computer simulation program and a traditional laboratory practical class for teaching the principles of intestinal absorption. *Advances in Physiological Education*, 12, S95 - S46.

Dewey, J. (1910). *How we think*. Lexington, Mass: D.C. Heath.

Eylon, B., Ronen, M., & Ganiel, U. (1996). Computer simulations as tools for teaching and learning: Using a simulation environment in optics. *Journal of Science Education and Technology*, 5, 93–110.

Faryniarz, J.V., & Lockwood, L.G. (1992). Effectiveness of microcomputer simulations in stimulating environmental problem solving by community college students. *Journal of Research in Science Teaching*, 5, 453–470.

Fawver, A.L., Branch C.E., Trentham, L., Robertson, B.T., & Beckett, S.D. (1990). A comparison of interactive videodisc instruction with live animal laboratories. *Advances in Physiology Education*, 4, S11-S14.

Feurzeig, W. (1992). Visualization tools for model-based inquiry. Los Angeles, CA: Conference on Technology Assessment. (ERIC Document Reproduction Service No. ED208901)

Friedler, Y., Merin, O., & Tamir, P. (1992). Problem solving inquiry-oriented biology tasks integrating practical laboratory and computer. *Journal of Computers in Mathematics and Science Teaching*, 11, 347-357.

Geban, O. Askar, P., & Ozkan, I. (1992). Effects of computer simulations and problem solving approaches on high school students. *Journal of Educational Research*, 86, 5–10.

Gerhold, G. (1985). Computers and the high school chemistry teacher: Some precepts for their use. *Journal of Chemical Education*, 62, 236-37.

Germann, P. (1988). Development of the attitude toward science in school assessment and its use to investigate the relationship between science achievement and attitude toward science in school. *Journal of Research in Science Teaching*, 25, 689-703

Glass, G.V. (1976). Primary, secondary, and meta-analysis of research. *Educational Researcher*, 5, 3–8.

Glass, G. V., McGaw, B., & Smith, M. L. (1981). *Meta-analysis in social research.* Beverly Hills, CA: Sage Publication.

Gockhale, A.A. (1989). *To investigate the effectiveness of computer simulation vs. laboratory experience and the sequencing of instruction in teaching logic circuits.* An unpublished doctoral dissertation. Iowa State University.

Gockhale, A.A. (1996). Effectiveness of computer simulation for enhancing higher order thinking. *Journal of Industrial Teacher Education*, 33(4), 36–46.

Gorsky, P., & Fiengold, M. (1992). Using computer simulations to restructure students conception of force. *Journal of Computers in Mathematics and Science Teaching*, 11, 163–178.

Grosso, M.R. (1994). *The comparison of computer simulation and traditional laboratory exercises in a college freshman chemistry course.* Unpublished doctoral dissertation. State University of New York at Buffalo.

Hakerem, G., Dobrynia, G., & Shore, L. (1993). The effect of interactive, three dimensional, high-speed simulations on high school science students' conception of the molecular structure of water. Atlanta, GA: National Association for Research in Science Teaching. (ERIC Document Reproduction Service No. 362930)

Hall, T.M. (2000). A quantitative analysis of the effectiveness of simulated electronics laboratory experiments. *Journal of Engineering Technology*, 17(2), 60–66.

Hedges, L. V. (1986). Issues in meta-analysis. In E.Z. Rothkopp (Ed.), *Review of research in education.* (Vol. 13). Washington, DC: American Educational Research Association.

Hewson, M., & Hewson, P. (1983). Effect of instruction using student prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching,* 20(8), 731-743.

Hopkins, K.S. (2001). *The effects of computer simulation vs. hands-on dissection and the placement of computer simulations within the learning cycle on student achievement and attitude. Dissertation Abstracts International,* 62 (01), 119A. (UMI No. 3002439)

Hough, S.L., & Hall, B.W. (1994). Comparison of the Glass and Hunter-Schmidt Meta-Analytic Techniques. *Journal of Educational Research,* 87(5),292–296.

Hughes, I.E. (2000). Alternatives to laboratory practicals: Do they meet the needs? *Innovations in Education and Teaching International*, 38, 3–7.

Hunter, J.E., & Schmidt, F.L. (1990). *Methods of Meta-analysis.* Newbury Park, CA: Sage Publications.

Huppert, J., Yaakobi, J., & Lazorovvitz, R. (1998). Learning microbiology with computer simulations: Students' academic achievement by method and gender. *Research in Science and Technological Education.* 16. 231–245.

Ignatz, M, & Ignatz, M. (1987). Computer Lab Modules as Problem Solving Tools. (ERIC Document Reproduction Service No. ED300203)

Jackman, L.E., Moellenberg, W.P., & Brabson, G.D. (1987). Evaluation of three methods for teaching general chemistry. *Journal of Chemical Education*, 9, 794–796.

Jackman, L. E., Moellenberg, W. P., & Brabson, G.D. (1990). Effects of conceptual systems and instructional methods on general chemistry laboratory achievement. *Journal of Research in Science Teaching*, 27, 699-709.

Jones, G. L., & Keith, K. D. (1983). Computer clinical simulations in health sciences. *Journal of Computer-based Instruction*, 9, 108-114.

Kelly, P.R. (1998). Transfer of learning from a computer simulation as compared to a laboratory activity. *Journal of Educational Technology Systems*, 26, 345-351.

Khoo, G., & Koh, T. (1998). Using visualization and simulation tools in tertiary science education. *Journal of Computers in Mathematics and Science Education*, 17, 5-20.

Kinnear, J. F. (1986). Computer simulation and problem solving in genetics. San Francisco, CA: American Educational Research Association. (ERIC Document Reproduction Service No. ED 272370)

Kinnear, J. F. (1986). Using computer simulation to enhance problem solving skills and concept development in biology students. St Lucia, Queensland: Conference on Computer-Aided Learning in Tertiary Education. (ERIC Document Reproduction Service No. ED 272370)

Kinzie, M.B., Strauss, R., & Foss, J. (1993). The effects of an interactive dissection simulation on the performance and achievement of high school biology students. New Orleans, LA: Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED 362173)

Kosinski, R.J. (1984). Producing Computer Assisted Instruction for biology Laboratories. *American Biology Teacher*, 46, 162-167.

Korfiatis, K., Papatheodorou, E., Stamou, G.P., & Paraskevopoulous, S. (1999). An investigation of the effectiveness of computer simulation programs as tutorial tools for teaching population ecology at university. *International Journal of Science Education*, 21, 1269–1280.

Kuhn, T. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Kulik, C.C., & Kulik, J.A. (1986). Effectiveness of computer-based education in colleges. *AEDS Journal*, 19, 81–108.

Kulik, C.C., & Kulik, J.A. (1989). *Effectiveness of computer-based instruction: An updated analysis*. Ann Arbor, MI: University of Michigan, Center for Research on Learning and Teaching.

Kulik, J.A., Kulik, C.C., & Bangert-Drowns, R.L. (1985). Effectiveness of computer-based education in elementary schools. *Computers in Human Behavior*, 1, 59–74.

Lauer, J.M., & Asher, J.W. (1988). *Composition research: Empirical designs*. New York: Oxford University Press.

Lee, J. (1999). Effectiveness of computer-based instructional simulation: a meta-analysis. *International Journal of Instructional Media*, 26, 71–85.

Leonard, W. H. (1989). A comparison of student reactions to biology instruction by interactive videodisc or conventional laboratory. *Journal of Research in Science Teaching*, 26(2), 95-104.

Leonard, W.H. (1992). A comparison of student performance following instruction in interactive videodisk vs. conventional laboratory. *Journal of Research in Science Teaching*, 29, 93–102.

Lewis, E.L., Stern, J.L., & Linn, M.C. (1993) The effect of computer simulations on introductory thermodynamics understanding, *Educational Technology*, January, 45-58.

Lunetta, V.N., & Hofstein, A. (1981). Simulations in Science Education. *Science Education*, 65, 243-252.

Lipsey, M.W., & Wilson, D.B. (2001). *Practical Meta-analysis*. Thousand Oaks, CA: Sage Publications.

Lyness, A. L. (1985). Effectiveness of interactive video to teach CPR theory and skills. Anaheim, CA.: Research and Theory Division of the Association for Educational Communications and Technology, (ERIC Document Reproduction Service No. ED256298)

MacKenzie, I.S. (1988). Issues and methods in micro-computer based labs. *Journal of Computers in Mathematics and Science Teaching*, 7(3), 12–18.

McKenzie, D.L., & Padilla, M.J. (1984). Effects of Laboratory activities and Written Simulations on the Acquisition of Graphing Skills by Eighth Grade Students. (ERIC Document Reproduction Service No. ED244780)

Marszalek, C.S., & Lockard, J. (1999). Which way to jump: Conventional frog dissection, CD-tutorial, or microworld?. Houston, TX: Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED436157)

Mills, T.J., Amend, J., & Sebert, D. (1985). An assessment of water resource education for teachers using interactive compiter simulation. *The Journal of Environmental Education*, 16 (4), 25–29.

Min, R. (1995). *Simulation Technology and Parallelism in Learning Environments*. De Lier, Netherlands: Academic Book Center.

Mintz, R. (1993). Computerized simulation as an inquiry tool. *School Science and Mathematics*, 93(2), 76–80.

Monaghan, J.M., & Clement, J. (1999). Use of a computer simulation to develop mental simulations for understanding relative motion. *International Journal of Science Education*, 21, 921–944.

Moore, J. L., & Thomas, F. H. (1983). Computer simulation of experiments: A valuable alternative to traditional laboratory work for secondary school science teaching. *School Science Review*, v64, 641-655

Moslehpour, S. (1993). *A comparison of achievement resulting from learning electronics by computer simulation vs. traditional laboratory instruction.* Unpublished doctoral dissertation. Iowa State University, Ames Iowa.

Muffoletto, R., & Knupfer, N. N. (1993). Computers in Education: Social, Political, and Historical Perspectives. (ERIC Document Reproduction Service No. ED366317)

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning.* Washington DC: National Academy Press.

Offner, S. (1993). The Importance of Dissection in Biology Teaching. *American Biology Teacher*, 55, 147-149.

Okey, J.R., & Oliver, R.G. (1987). Learning from computer simulations. Washington D.C.: National Association of Research in Science Teaching. (ERIC Document Reproduction Service No. ED282753)

Orlans, F.B. (1988). Debating Dissection. *The Science Teacher*, 55, 36–40.

Pena, C.M., Alessi, S.M. (1999). Promoting a qualitative understanding of physics. *The Journal of Computers in Mathematics and Science Teaching*, 18, 439-457.

Physics Education Research Group (2001). *A constructivist view of science education.* Retrieved February 12, 2002, from the University of Massachusetts at Amherst, Physics Education Group Web site: http://umperg.physics.umass.edu/perspective/constructivism

Piaget, J., & Inhelder, B. (1969). *The Psychology of the Child.* New York: Basic Books.

Pierfy, D. (1977). Comparative simulation game research: stumbling blocks or stepping-stones? *Simulation and Games*, 8, 255–268.

Richards, J., Barowy, W., & Levin, D. (1992). Computer simulations in the science classroom. *Journal of Science Education and Technology*, 1, 67–69.

Rieber, L.P., & Parmley, M.W. (1992). Effects of animated computer simulations on inductive learning with adults: A preliminary report. Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED348019)

Rieber, L.P, & Kini, A. (1995). Using inductive simulations in inductive learning strategies with children in science. *International Journal of Instructional Media*, 22 (2), 135-144.

Rivers, R. H., & Vockell, E. (1987). Computer simulations to stimulate scientific problem solving. *Journal of Research in Science Teaching*, 24(5), 403-415.

Roblyer, M.D., & Edwards, J. (2000). *Integrating educational technology into teaching.* Upper Saddle River, NJ: Prentice-Hall.

Ronen, M., Langly, D., & Ganiel, U. (1992). Integrating computer simulations into high school physics teaching. *Journal of Computers in Mathematics and Science Teaching*, 11, 319–329.

Rosenthal, R. (1984). *Meta-analytical procedures for social research.* Newbury Park, CA: Sage Publications

Rueter, J.G., & Perrin, N.A. (1999). Using a simulation to teach food-web dynamics. *The American Biology Teacher*, 61, 116–123.

Samsel, R.W., Schmidt, J.B., Hall, J.B., Wood, L.D.H., Shroff, S.G., & Schumacker, P.T. (1994). Cardiovascular physiology teaching: computer simulation vs. animal demonstrations. *Advances in Physiology Education*, 11, s36–s46.

Scheiner, S.M., & Gurevitch, J. (Eds.). (1993). *Design and analysis of ecological experiments*. London: Chapman and Hall.

Schrock, J.R. (1984). Computers in Science Education: Can They Go Far Enough? Have We Gone Too Far? *American Biology Teacher*, 46, 252-256.

Schwab, J. (1960). What Do Scientists Do? *Behavioral Science*, 5(1).

Schwab, J. (1966). *The Teaching of Science*. Cambridge, MA: Harvard University Press.

Simmons, P.E., & Lunetta, V.N. (1993). Problem solving behaviors during a genetics computer simulation: Beyond the expert novice dichotomy. *Journal of Research in Science Teaching*, 30, 153-173.

Simpson, R., & Oliver, J. (1985). Attitude toward science and achievement motivation profiles of male and female science students in grades six through ten. *Science Education*, 69, 511-526.

Simpson, R., & Oliver, J. (1990). A summary of major influences on attitude toward and achievement in science among adolescent students. *Science Education*, 74, 1-10.

Slack, S., & Stewart, J. (1990). High school students' problem-solving performance on realistic genetics problems. *Research in Science Teaching*, 27, 55–67.

Spraggins, C. C., & Rowsey, R.E. (1986). The effect of simulation games and worksheets on learning of varying ability groups in a high school biology classroom. *Journal of Research in Science Teaching*, 23(3), 219-229.

Stewart, J., Hafner, R., Johnson, S., & Finkel, E. (1992). Science as model-building: computers and high school genetics. *Educational Psychologist*, 27, 317–336.

Stratford, S.J. (1997). A review of computer-based model research in precollege science classrooms. *The Journal of Computers in Mathematics and Science Teaching*, 16 (1), 3-23.

Strauss, R.T., & Kinzie, M.B. (1994). Student achievement and attitudes in a pilot study comparing an interactive videodisc simulation to conventional dissection. *The American Biology Teacher*, 56, 398–402.

Tylinski, D.J. (1994). The effect of a computer simulation on junior high students' understanding of the physiological systems of an earthworm. *Dissertation Abstracts International*, 55 (04), 923A. (UMI No. 9423384)

Veit, S. (1993). Stan Veit's history of the personal computer. Asheville, NC: WorldComm.

Vockell, E. L., & Rivers, R. H. (1984). Computerized science simulations stimulus to generalized problem solving capabilities. New Orleans, LA: American Educational Research Association. (ERIC Document Reproduction Service No. ED253397)

Wachter, K.W., & Straff, M.L. (Eds.). (1990). *The future of meta-analysis.* New York: Russell Sage Foundation

Waugh, M.L. (1985). Proposed directions for research in computer-based education. (ERIC Document Reproduction Service No. ED257627)

Waugh, R.A., Mayer, J.W., Ewy, G.A., Felner, J.M., Issenberg, B.S., Gessner, I.H., et al. (1995), Multimedia computer-assisted instruction in cardiology. *Archives of Internal Medicine*, 155, 197-203

Webb, D.J. (1993). Problem solving in genetics using simulation software. *Dissertation Abstracts International*, 54(03), 802A. (UMI No. 9320327)

Weller, H.G. (1995). Diagnosing and Altering Three Aristotelian Alternative Conceptions in Dynamics: Microcomputer Simulations of Scientific Models. *Journal of Research in Science Teaching*, 32(3), 271–290.

Weller, H.G. (1996). Assessing the Impact of Computer-based Learning in Science. *Journal of Research on Computing in Education*, 28(4), 461-484.

White, B.Y. (1993). ThinkerTools: Causal models, conceptual change, and science education. *Cognition and Instruction*, 10, 1–100.

Windchitl, M. A., & Andre, T. (1998). Using computer simulations to enhance conceptual change: the roles of constructionist instruction and student epistemological beliefs, *Journal of Research in Science Teaching*, 35, 145–160.

Woodward, J., Carnine, D., & Gersten, R. (1988). Teaching problem solving through computer simulations. *American Educational Research Journal*, 25(1), 72-86.

Yerrick, R. (1996). Computer aided physics inquiry as a venue for pre-service science teacher education. Retrieved December 16, 2001, from the University of North Carolina, The Carolina Colloquy's Electronic Journal of University Teaching and Learning Web site: http://cte.uncwil.edu/et/articles/yerrick/index.htm

Zietsman, A. I., & Hewson, P. W. (1986). Effect of instruction using microcomputer simulations and conceptual change strategies on science learning. *Journal of Research in Science Teaching*, 23(1), 27-39.

Appendixes

Appendix A

Data coding sheet

Author(s): Geban, O. Askar, P. & Ozkan, I

Data:

M_{Exp} 24.23 M_{Con} 20.41

SD_{Exp} 5.37 SD_{Con} 4.95

n_{Exp} 60 n_{Con} 70

t ______ F ______

Year of Publication: (1992).

Construct: Ach-high✓ Achiev-low Ret Att-sub Att-method

Level: K-12✓ college/pro

Subject: biological physical✓

Length : 1 week or less more than 1 week✓

Mode : exploratory confirmatory✓

Technology: CSE✓ IVD

Gender: female male

Raw Effect Size (**ES'**): .742

Corrected Effect Size (**S**): .737

Weight Factor (**w**): 30.26

ES × w: 22.39

Appendix B

Relationship between effect size, percentile, and percent overlap

	Effect Size	Percentile	% Nonoverlap
	2.0	97.7	81.1%
	1.9	97.1	79.4%
	1.8	69.4	77.4%
	1.7	95.5	75.4%
	1.6	94.5	73.1%
	1.5	93.3	70.7%
	1.4	91.9	68.1%
	1.3	90	65.3%
	1.2	88	62.2%
	1.1	86	58.9%
	1.0	84	55.4%
	0.9	82	51.6%
Large	0.8	79	47.4%
	0.7	76	43.0%
	0.6	73	38.2%
Medium	0.5	69	33.0%
	0.4	66	27.4%
	0.3	62	21.3%
Small	0.2	58	14.7%
	0.1	54	7.7%
	0.0	50	0%

Appendix C

Studies used in the meta-analysis

Barker, S. P. (1988). Comparison of effectiveness of interactive videodisc vs. lecture-demonstration instruction. *Physical Therapy*, 68(5), 699-703.

Barnea, N., & Dori, Y.J. (1999). High school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. *Journal of Science Education and Technology*, 8, 257–271.

Berlin, D.F., & White, A.L. (1985). Computer simulations and the transition from concrete manipulation of objects to abstract thinking. French Lick Springs, IN: National Association for Research in Science Teaching. (ERIC Document Reproduction Service No. ED254410)

Branch, C. E., Ledford, B. R., Robertson, B. T., & Robison, L. (1987). The validation of an interactive videodisc as an alternative to traditional teaching techniques: Auscultation of the heart. *Educational Technology*, 27(3), 16-22.

Brant, G., Hooper, E., & Sugrue, B. (1991). Which comes first the simulation or the lecture? *Journal of Educational Computing Research*, 7, 469–481.

Buttles, S. (1992). A model for incorporating and evaluating use of a computer laboratory simulation in the nonmajors biology course. *The American Biology Teacher*, 54, 491–494.

Carlsen, D.D., & Andre, T. (1992). Use of a microcomputer simulation and conceptual change text to overcome student preconceptions about electric circuits. *Journal of Computer Based Instruction*, 19, 105–109.

Choi, B., & Gennaro, E. (1987). The effectiveness of using computer simulated experiments on junior high students' understanding of the volume displacement concept. *Journal of Research in Science Teaching*, 24, 539-552.

Chou, C. (1998). The effectiveness of using multimedia computer simulations coupled with social constructivist pedagogy in a college introductory physics classroom. *Dissertation Abstracts International*, 59 (07), 2429A. (UMI No. 9839055)

Dewhurst, D.J., Hardcastle, J., Harcastle, P.T., & Stuart, E. (1994). Comparison of a computer simulation program and a traditional laboratory practical class for teaching the principles of intestinal absorption. *Advances in Physiological Education*, 12, S95 - S46.

Faryniarz, J.V., & Lockwood, L.G. (1992). Effectiveness of microcomputer simulations in stimulating environmental problem solving by community college students. *Journal of Research in Science Teaching*, 5, 453–470.

Fawver, A.L., Branch C.E., Trentham, L., Robertson, B.T., & Beckett, S.D. (1990). A comparison of interactive videodisc instruction with live animal laboratories. *Advances in Physiology Education*, 4, S11-S14.

Friedler, Y., Merin, O., & Tamir, P. (1992). Problem solving inquiry-oriented biology tasks integrating practical laboratory and computer. *Journal of Computers in Mathematics and Science Teaching*, 11, 347-357.

Geban, O. Askar, P., & Ozkan, I. (1992). Effects of computer simulations and problem solving approaches on high school students. *Journal of Educational Research*, 86, 5–10.

Gockhale, A.A. (1989). *To investigate the effectiveness of computer simulation vs. laboratory experience and the sequencing of instruction in teaching logic circuits.* An unpublished doctoral dissertation. Iowa State University.

Gockhale, A.A. (1996). Effectiveness of computer simulation for enhancing higher order thinking. *Journal of Industrial Teacher Education*, 33(4), 36–46.

Grosso, M.R. (1994). *The comparison of computer simulation and traditional laboratory exercises in a college freshman chemistry course.* Unpublished doctoral dissertation. State University of New York at Buffalo.

Hall, T.M. (2000). A quantitative analysis of the effectiveness of simulated electronics laboratory experiments. *Journal of Engineering Technology*, 17(2), 60–66.

Hopkins, K.S. (2001). The effects of computer simulation vs. hands-on dissection and the placement of computer simulations within the learning cycle on student achievement and attitude. *Dissertation Abstracts International*, 62 (01), 119A. (UMI No. 3002439)

Hughes, I.E. (2000). Alternatives to laboratory practicals: Do they meet the needs? *Innovations in Education and Teaching International*, 38, 3–7.

Huppert, J., Yaakobi, J., & Lazorovvitz, R. (1998). Learning microbiology with computer simulations: Students' academic achievement by method and gender. *Research in Science and Technological Education*. 16. 231–245.

Jackman, L.E., Moellenberg, W.P., & Brabson, G.D. (1987). Evaluation of three methods for teaching general chemistry. *Journal of Chemical Education*, 9, 794–796.

Jackman, L. E., Moellenberg, W. P., & Brabson, G.D. (1990). Effects of conceptual systems and instructional methods on general chemistry laboratory achievement. *Journal of Research in Science Teaching*, 27, 699-709.

Kinzie, M.B., Strauss, R., & Foss, J. (1993). The effects of an interactive dissection simulation on the performance and achievement of high school biology students. New Orleans, LA: Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED 362173)

Leonard, W. H. (1989). A comparison of student reactions to biology instruction by interactive videodisc or conventional laboratory. *Journal of Research in Science Teaching*, 26(2), 95-104.

Leonard, W.H. (1992). A comparison of student performance following instruction in interactive videodisk vs. conventional laboratory. *Journal of Research in Science Teaching*, 29, 93–102.

Lewis, E.L., Stern, J.L., & Linn, M.C. (1993) The effect of computer simulations on introductory thermodynamics understanding, *Educational Technology*, January, 45-58.

Lyness, A. L. (1985). Effectiveness of interactive video to teach CPR theory and skills. Anaheim, CA.: Research and Theory Division of the Association for Educational Communications and Technology, (ERIC Document Reproduction Service No. ED256298)

Marszalek, C.S., & Lockard, J. (1999). Which way to jump: Conventional frog dissection, CD-tutorial, or microworld?. Houston, TX: Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED436157)

Mills, T.J., Amend, J., & Sebert, D. (1985). An assessment of water resource education for teachers using interactive compiter simulation. *The Journal of Environmental Education*, 16 (4), 25–29.

Moslehpour, S. (1993). *A comparison of achievement resulting from learning electronics by computer simulation vs. traditional laboratory instruction.* Unpublished doctoral dissertation. Iowa State University, Ames Iowa.

Pena, C.M., Alessi, S.M. (1999). Promoting a qualitative understanding of physics. *The Journal of Computers in Mathematics and Science Teaching*, 18, 439-457.

Rieber, L.P., & Parmley, M.W. (1992). Effects of animated computer simulations on inductive learning with adults: A preliminary report. Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED348019)

Rueter, J.G., & Perrin, N.A. (1999). Using a simulation to teach food-web dynamics. *The American Biology Teacher*, 61, 116–123.

Samsel, R.W., Schmidt, J.B., Hall, J.B., Wood, L.D.H., Shroff, S.G., & Schumacker, P.T. (1994). Cardiovascular physiology teaching: computer simulation vs. animal demonstrations. *Advances in Physiology Education*, 11, s36–s46.

Spraggins, C. C., & Rowsey, R.E. (1986). The effect of simulation games and worksheets on learning of varying ability groups in a high school biology classroom. *Journal of Research in Science Teaching*, 23(3), 219-229.

Strauss, R.T., & Kinzie, M.B. (1994). Student achievement and attitudes in a pilot study comparing an interactive videodisc simulation to conventional dissection. *The American Biology Teacher*, 56, 398–402.

Tylinski, D.J. (1994). The effect of a computer simulation on junior high students' understanding of the physiological systems of an earthworm. *Dissertation Abstracts International,* 55 (04), 923A. (UMI No. 9423384)

Vockell, E. L., & Rivers, R. H. (1984). Computerized science simulations stimulus to generalized problem solving capabilities. New Orleans, LA: American Educational Research Association. (ERIC Document Reproduction Service No. ED253397)

Webb, D.J. (1993). Problem solving in genetics using simulation software. *Dissertation Abstracts International,* 54(03), 802A. (UMI No. 9320327)

Woodward, J., Carnine, D., & Gersten, R. (1988). Teaching problem solving through computer simulations. *American Educational Research Journal*, 25(1), 72-86.

Appendix D

Coding data for studies used in meta-analysis

Author	construct	ES'	weight	N	Pub date	level	subject	length	type	mode
Barker	Achiev-low	0.62	7.15	30	1988	coll/pro	bio	1 wk <	IVD	exp
Barker	Retention	0.23	7.45	30	1988	coll/pro	bio	1 wk <	IVD	exp
Barnea	Achiev-high	0.95	16.01	79	1999	K-12	phys	1 wk <	CSE	conf
Berlin	Achiev-high	0.20	44.03	177	1986	K-12	phys	> 1wk	CSE	exp
Branch	Achiev-low	0.11	21.72	87	1987	coll/pro	bio	1 wk <	IVD	conf
Brant	Achiev-high	0.55	22.11	101	1991	coll/pro	phys	< 1 wk	CSE	conf
Buttles	Achiev-low	0.82	24.23	110	1992	coll/pro	bio	> 1wk	CSE	conf
Carlsen	Achiev-high	0.61	16.64	70	1992	coll/pro	phys	1 wk <	CSE	exp
Choi	Achiev-low	0.01	29.95	117	1987	K-12	phys	1 wk <	CSE	exp
Choi	Retention	0.01	27.69	111	1987	K-12	phys	1 wk <	CSE	exp
Chou	Achiev-high	0.43	13.68	56	1988	coll/pro	phys	1 wk <	CSE	exp
Dewhurst	Achiev-low	0.26	3.40	14	1994	coll/pro	bio	1 wk <	CSE	exp
Faryniarz	Achiev-high	0.48	13.68	58	1992	coll/pro	bio	1 wk <	CSE	conf
Fawver	Achiev-low	0.29	21.02	85	1990	coll/pro	bio	> 1wk	IVD	conf
Friedler	Achiev-high	0.84	22.66	74	1992	K-12	bio	> 1wk	CSE	conf
Geban	Achiev-low	0.74	30.26	130	1992	K-12	phys	> 1wk	CSE	conf
Geban	Achiev-high	0.86	29.61	130	1992	K-12	phys	> 1wk	CSE	conf
Gokhale	Achiev-low	0.42	7.83	32	1989	coll/pro	phys	> 1wk	CSE	exp
Gokhale	Achiev-high	1.08	6.97	32	1996	coll/pro	phys	> 1wk	CSE	exp
Grosso	Achiev-high	0.26	157.13	1132	1994	coll/pro	phys	1 wk <	CSE	conf
Hall	Achiev-high	-0.22	6.69	27	2000	coll/pro	phys	> 1wk	CSE	exp
Hopkins	Achiev-low	-0.31	13.64	57	2001	K-12	bio	1 wk <	CSE	exp
Hopkins	Att-sub	0.07	13.71	57	2001	K-12	bio	1 wk <	CSE	exp
Hopkins	Retention	0.11	13.7	49	2001	K-12	bio	1 wk <	CSE	exp
Hughes	Achiev-high	0.54	21.19	88	2000	coll/pro	bio	1 wk <	CSE	conf
Huppert	Achiev-high	0.24	44.52	181	1998	K-12	bio	1 wk <	CSE	conf
Jackman87	Achiev-low	0.45	46.31	350	1987	coll/pro	phys	1 wk <	CSE	conf
Jackman90	Achiev-low	0.38	85.99	190	1990	coll/pro	phys	1 wk <	CSE	conf
Kinzie	Achiev-low	0.42	7.34	30	1993	K-12	bio	1 wk <	IVD	exp

Author	construct	ES'	weight	N	Pub date	level	subject	length	type	mode
Kinzie	Att-sub	-0.12	7.49	30	1993	K-12	bio	1 wk <	IVD	exp
Leonard	Att-sub	0.23	35.26	142	1990	coll/pro	bio	1 wk <	IVD	exp
Leonard92	Achiev-high	0.10	35.45	142	1992	coll/pro	bio	1 wk <	IVD	exp
Lewis	Achiev-low	0.29	67.29	272	1993	K-12	phys	> 1wk	CSE	exp
Lyness	Achiev-low	0.33	24.4	99	1985	coll/pro	bio	> 1wk	IVD	exp
Marszalek	Achiev-low	-0.44	43.47	194	1999	K-12	bio	1 wk <	CSE	exp
Mills	Achiev-low	1.01	31.5	151	1985	coll/pro	bio	1 wk <	CSE	exp
Mills	Att-sub	-0.23	34.87	150	1985	coll/pro	bio	1 wk <	CSE	exp
Moslehpour	Achiev-high	-0.39	18.65	76	1993	coll/pro	phys	> 1wk	CSE	conf
Pena	Achiev-low	0.68	20.09	85	1999	coll/pro	phys	1 wk <	CSE	exp
Rieber92	Achiev-high	0.43	37.63	154	1992	coll/pro	phys	1 wk <	CSE	exp
Rueter	Achiev-high	0.39	68.94	181	1999	coll/pro	bio	> 1wk	CSE	exp
Samsel	Att-meth	1.04	19.32	88	1994	coll/pro	bio	1 wk <	CSE	exp
Spraggins	Achiev-low	0.10	20.65	83	1986	K-12	bio	1 wk <	CSE	exp
Spraggins	Retention	0.21	20.56	83	1986	K-12	bio	1 wk <	CSE	exp
Strauss	Achiev-low	0.08	4.23	17	1994	K-12	bio	1 wk <	IVD	exp
Strauss	Retention	0.39	4.15	17	1994	K-12	bio	1 wk <	IVD	exp
Strauss	Att-sub	-0.62	3.91	17	1994	K-12	bio	1 wk <	IVD	exp
Tylenski	Achiev-low	0.47	232.54	97	1994	K-12	bio	1 wk <	CSE	exp
Vockell 1	Achiev-high	0.18	26.14	105	1984	K-12	bio	> 1wk	CSE	conf
Vockell 2	Achiev-high	0.05	13.67	65	1984	K-12	bio	> 1wk	CSE	conf
Vockell 3	Achiev-high	0.35	62.39	266	1984	K-12	bio	> 1wk	CSE	conf
Webb	Achiev-high	1.19	17.99	89	1993	coll/pro	bio	1 wk <	CSE	conf
Woodward	Achiev-high	0.81	6.94	30	1988	K-12	bio	> 1wk	CSE	conf
Woodward	Retention	0.83	6.90	30	1988	K-12	bio	> 1wk	CSE	conf

VITA

J. Van LeJeune was born in Alexandria, Louisiana, on March 28, 1956, the son of J. H. LeJeune Jr. and Lillian Angelique Smith LeJeune. After graduating from Holy Savior Menard Central High School, Alexandria, Louisiana, in 1974, he enrolled at Louisiana State University at Alexandria for two semesters and at Louisiana State University in Baton Rouge for two semesters. He received his Bachelors of Science degree in 1986 from McNeese State University with a major in Science Education, and began his teaching career in the fall of that year at Alexandria Senior High School in Alexandria, Louisiana. In 1993 he enrolled in the Graduate School of Northwestern State University of Louisiana at Natchitoches, Louisiana, where he received a Master of Education degree with an emphasis in Gifted and Talented Education in 1996. He entered the Graduate School of Texas A&M University – Commerce in 1997. He was employed as a science teacher at Greenville High School in Greenville, Texas. While continuing his employment as a full-time high school science teacher, he also began working as an adjunct instructor for Paris Junior College at the Greenville Technical Center, Greenville, Texas, in 1999, and has continued in that position to the present. He was awarded the Doctor of Education degree from Texas A&M University- Commerce with a major in Supervision, Curriculum, and Instruction with an emphasis in Higher education in August 2002. In 1978, he married Mary Ann Parr of Alexandria, Louisiana. One son, Joseph Adam LeJeune was born in October 1979.

Permanent address:

408 Mink Dr.

Greenville, Texas, 75402