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To investigate the effectiveness of computer simulation versus laboratory experience, and the sequencing of instruction, in teaching logic circuits

Gokhale, Anuradha Ashok, Ph.D.

Iowa State University, 1989

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Ann Arbor, MI 48106

To investigate the effectiveness of
computer simulation versus laboratory experience,
and the sequencing of instruction,
in teaching logic circuits

by

Anuradha Ashok Gokhale

A Dissertation Submitted to the
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1989

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DEDICATION

This dissertation is dedicated

to the memory of my father,

Achyut Janardan Pendse.

CHAPTER I. INTRODUCTION

Researchers are currently getting mixed results in many of their studies dealing with the effectiveness of computer-assisted instruction (CAI). Kulik, Bangert, and Williams (1983) synthesized the findings of 51 computer-assisted instruction studies and provided evidence for the position that computers can enhance the effectiveness of instruction, reduce the time required for learning and produce positive results toward computing. Educators have compared traditional classroom teaching versus CAI and found that both instructional modes produce equivalent test scores (Bork, 1986; Clark, 1985; and Krendl & Lieberman, 1988).

According to Hobbs (1987), CAI offers the potential for interactive individualized learning. A degree of learner control may be available, enabling students to determine, to a greater or lesser extent, their own route through interrelated material. However, a survey of research literature shows that present designs of CAI materials have evolved in a largely ad hoc manner and have failed to incorporate the principles of educational psychology. One must realize that instruction and learning are complementary systems coexisting within the sphere of education.

Lepper (1985) offers one of the most articulate discussions of the role of learning theory in the design, use and evaluation of educational software. He points out that there are two types of effective educational software: those which facilitate the acquisition of factual information (such as through drill and practice programs), and those which facilitate understanding conceptual information (such as through simulation programs). Lepper (1985) describes how drill and practice formats are actually grounded in behavioral learning theory, and how discovery-oriented software reflects the cognitive perspective on learning.

CAI is categorized into four major types of presentations (Streibel, 1985):

1. drill and practice,
2. tutorial,
3. simulation, and
4. problem-solving.

According to Streibel (1985), the drill and practice approach is shown to embody a deterministic, behavioral technology that turns learning into a systematically designed and quality-controlled form of work. However, the simulation and problem solving type of courseware extends the behavioral and technological approach even further by using interactions in order to maximize the learner's performance gains.

In assessing the educational importance of simulations in computer-based instruction, Crookall (1988) states:

> One might say simulation has come to the rescue of computer use in the classroom (p. 3).

The essence of simulation or problem solving programs is that the student is encouraged to explore a model through a process of discovery learning (Papert, 1980). Many times the process is so complex that, at least initially, understanding is more effectively achieved using a simplified representation. Simulations can be made more effective by making use of the computer's ability to engage in an interactive conversation in order to impress salient features upon the student. For these reasons, the simulation and problem-solving techniques are very important in the development of educational software.

Most instructional theorists indicate that one of the major tasks in program design is to decide how to sequence all of the content (skills and information) that has been identified (Lahey, 1979). According to Gagne (1987), the sequence of the primary components of instruction can be varied, depending on whether a deductive or inductive approach is desired. A deductive approach requires presentation of formal instruction or rules before the examples and practice. An inductive approach requires presentation of the examples or even just the practice first, followed by the rules.

The basic experimental paradigm has been to compare the learning ease, retention, and transfer of subjects who were given the material in a general-background-to-specific-facts sequence with subjects who received identical material in the opposite sequence, or who received no general-background aid at all (Mayer, 1981).

Thomas and Boysen (1984) have developed a classification system based on the instructional use of computer software. The authors classified the software as:

1. Experiencing,
2. Informing,
3. Reinforcing, and
4. Integrating.

Experiencing programs are used to set the cognitive or affective stage for future learning. Informing programs are used to transmit information to the student. A program is classified as reinforcing if the knowledge is applied in the same context in which it was learned. Integrating programs are designed to aid the student to assimilate and integrate isolated facts, concepts and principles into functional units.

Thomas and Hooper (1989) classified and analyzed several simulation studies according to the instructional function for which the simulation study was used. On the basis of this analysis, the authors concluded that:

1. simulations are most effective when used before or after formal instruction,
2. the effects of simulation are not revealed by tests of knowledge but are revealed by tests of transfer and application, and
3. extensive research is needed on simulation design and use.

Thus, method of instruction and sequencing of instruction are fundamental decisions in the instructional design. The present study has focused on the effect of these two variables in the teaching and learning of logic circuits.

Statement of the Problem

This study was designed to examine the effectiveness of computer simulation versus laboratory experience, and the sequencing of instruction, in teaching logic circuits.

Objectives of the Study

The purpose of this study was fivefold:

1. To examine the computer as an instructional tool integrated into, rather than apart from classroom activities.

2. To assist the Industrial Technology profession in identifying whether computer-based simulation or laboratory experience helps students better understand the underlying concepts of logic circuits.

3. To evaluate the effectiveness of sequencing computer simulation or laboratory activities with a reading assignment, in teaching logic circuits.

4. To assist educators in understanding the interaction between sequencing of instruction and the instructional content.

5. To provide developers of computer-based instructional materials with information which would be useful in the design of computer-based lessons.

Theoretical Framework

Medium theory, with its focus on information flow and presentation as determinants of outcomes, appears to hold some promise for the study of computers and learning (Krendl & Lieberman, 1988). Medium theory posits that it is the way in which a particular medium affects information flow and presentation that determines its effects, not the content that it delivers (Salomon, 1979). Thus, the characteristics or features of a particular medium, which determine the presentation of content, affect how users access, process and use information. It is important to discuss different theories of learning that are based on the medium of instruction.

Dewey (1938) developed a "problem solving" theory of learning based on the importance of firsthand experience to learning. The basic premise of this theory is that learning happens as a result of "doing" and "experiencing" things in the world. Learning then, he argued, must be based on meaningful learning experiences and genuine problem-solving. The author stressed that it is wrong to think of physical and mental activity as two unrelated things; the words "physical" and "mental" are distortions - the learner's physical activity is suffused with the mental, and vice versa. He has written that laboratory experience is a very effective learning medium.

The information processing model draws attention away from the importance of physical activity and focuses on the mental activity that takes place in the learner (Phillips & Soltis, 1985). According to Tennyson and Christensen (1988), the model includes the following components: (a) the receptor component by which external information is entered into the brain; (b) the perception component where the information is filtered according to individual criteria; (c) the short-term/working-memory component; (d) the long-term memory component; and (e) the cognitive process of creating knowledge within the cognitive system itself. The authors state that this model is reflected in problem-oriented simulations that present meaningful situations in which students are required to make solution proposals using knowledge stored in memory.

Papert (1984) has argued strongly in support of the use of computers for discovery learning. Krendl and Lieberman (1988) have written that additional research should examine the computer as an instructional tool integrated into, rather than apart from, classroom activities. Integration of the computer with other activities is critical to the development of the field of computer-assisted instruction.

The present study focused on two methods of instruction: computer simulation and laboratory experience. In light of the widespread and increasing use of educational software, it is necessary to evaluate its effectiveness in comparison with traditional teaching method, such as the laboratory approach. This study also explored the effect of a second variable, sequencing of instruction.

According to Gagne (1987), sequencing of instruction is important because if the sequence of a piece of instruction is bad, people will not learn as well. Ausubel (1968) stated that the sequence in which learning occurs influences the stability of cognitive structures and thereby influences long-term retention and transfer. New knowledge is made meaningful by relating it to prior knowledge and optimization of prior knowledge is done through sequencing. Ausubel (1968) has argued that the use of 'advance organizers' will result in better conceptual learning. Bruner (1966) and Wittrock (1966) have written that 'discovery strategies' prior to formal instruction will result in better retention and transfer.

Mayer (1977) offers a theoretical understanding of the cognitive principles involved in sequencing of instruction. The Assimilation Encoding Theory is a three-stage model that involves a systematic encoding process. This theory posits active integration of new information with existing knowledge, and a different type of learning outcome, varying in breadth rather than only in amount retained. Thus, in addition to receiving information and possessing the relevant knowledge in long-term memory, it also involves transferring the anchoring knowledge from long-term memory to working memory and actively integrating that knowledge with incoming information during learning.

Thomas and Hooper (1989), discuss the instructional use and sequencing of computer simulation, and its effect on the students' cognitive process. The authors state that computer simulations play two major roles in instruction: preparing students to learn new materials and testing materials that have been previously learned. When used prior to formal instruction, the program may build intuition and alert the student to the overall nature of the process and the need for a deeper understanding. When used after formal instruction, the program offers the student an opportunity to apply the learned material. The authors propose that the use of simulation for achieving high-level objectives and transfer should be greatly expanded.

Thus, the sequencing of instruction is a very important part of the instructional design. It is also necessary to compare traditional laboratory experience with recently evolved computer simulation.

Statement of the Research Questions

The research questions and hypotheses examined in this study were as follows:

Research Question I

Will there be a significant difference in achievement on a test of application of logic circuits between students using the computer simulation program and students doing the laboratory procedures?

Statistical Hypothesis I

$H_O : \mu_{computer} = \mu_{lab}$

$H_A : \mu_{computer} \neq \mu_{lab}$

The criterion variable for this hypothesis was the posttest score.

Research Question II

Will there be a significant difference in achievement on a test of application of logic circuits between students who receive the laboratory or simulation experience before a reading assignment and students who receive identical material in the reverse sequence?

Statistical Hypothesis II

$H_O : u_{before} = u_{after}$

$H_A : \mu_{before} \neq \mu_{after}$

In the above equation, 'before' refers to 'activity before reading', and 'after' refers to 'activity after reading'. The criterion variable for this hypothesis was the posttest score.

Research Question III

Will there be a significant interaction between sequencing of instruction and method of instruction in teaching of logic circuits?

Statistical Hypothesis III

$H_O : \mu_{seq} + \mu_{method} + \mu_{seq*method} - \mu_{total} = 0$

$H_A : \mu_{seq} + \mu_{method} + \mu_{seq*method} - \mu_{total} \neq 0$

In the above equation, 'seq' refers to sequencing of instruction, and 'method' refers to the method of instruction. The criterion variable for this hypothesis was the posttest score.

Assumptions of the Study

This study was based upon the following assumptions:

1. It was assumed that the number of errors and the test scores were normally distributed, random, and independent. Homogeneity of variance was also assumed. In other words, all samples were assumed to be from the same population.

2. It was assumed that no interaction (social, academic, or otherwise) occurred among students outside of the experimental setting which affected the results of the study.

3. It was assumed that the experimental set up during the entire study did not differ in any manner affecting the experiment.

4. It was assumed that the laboratory or computer simulation experience for the different groups did not differ in any manner affecting the experiment.

Delimitations of the Study

The limitations of this study were as follows:

1. The sample was limited to students at Iowa State University.

2. The number of subjects in this study were limited to 96 students.

3. Random assignment of subjects to different treatment groups did not guarantee group equality. Matching on variables related to the dependent variables was not possible. Group differences which existed due to extraneous variables may have had an effect on the experimental results.

4. Neither the laboratory activity nor the computer simulation activity had recording mechanism to determine the level of student accomplishment in these activities.

5. The pretest may have alerted the students to the instruction that was to follow.

Definition of Terms

The following terms and definitions were used for the purposes this study:

Advance organizer

The introductory material that activated existing cognitive structures in order to facilitate the assimilation of new information. Advance organizers lay the foundation for concept learning by providing a framework for the student to use when integrating new information with old.

Computer-assisted instruction (CAI)

Use of the computer as an aid in a classroom setting to enhance student learning.

Concept

A specific set of objects, symbols, or events which share common characteristics and can be referenced by a particular word or symbol.

Discovery learning

Trying to understand something when minimal amount of learning guidance is provided. Discovery learning presents examples to the student. The student uses intuition, trial and error, or guided instruction to assimilate and accommodate the information. The information is used to form the definition or concept to be learned.

Meaningful learning

A process in which the learner connects new material with knowledge that already exists in memory. This definition is based on cognitive psychology.

Problem-oriented simulations

Simulations that focus on the development and improvement of higher-order thinking strategies that employ the cognitive processes of differentiation and integration.

Schema

The components of long term memory activated during learning.

Transfer of learning

Student is able to apply what is learned during instruction to a new situation, usually the intended real performance.

CHAPTER II. REVIEW OF LITERATURE

This chapter focuses upon the review of research related to independent variables of method of instruction and instructional sequencing. However, the review will be incomplete without the discussion of appropriate theories of learning. The review of literature has been classified into four major sections. The first section discusses the theories of learning relevant to this study. The second section deals with computer simulation techniques and laboratory procedures used to enhance instruction. Its subsection describes different computer simulation programs in logic circuits. The third section discusses instructional sequencing. The fourth section examines the relationship between learning styles and instruction. The summary presents a systematic evaluation of different concepts discussed within each section.

Theories of Learning

First, there seem to be different domains of learning, some simple and some more complex, some involving the acquisition of knowledge and others involving the mastery of skills. There is a possibility that different theories of learning have resulted from various investigators approaching the phenomenon of learning from different directions. Psychologists and philosophers have contributed to the development of several types of learning theories. However, this section focuses on only those theories that are relevant to this study.

Experiential approach

The philosopher and educationist Dewey (1938), writing about American schools earlier this century has stated that:

> Those under instruction are too customarily looked upon as acquiring knowledge as theoretical spectators, minds which appropriate [gain] knowledge by direct energy of intellect. The very word pupil has almost come to mean one who is engaged not in having fruitful experiences but in absorbing knowledge directly (p. 164).

Dewey (1938) noted that the mind, the "organ" for acquiring knowledge, traditionally was conceived as being quite unrelated to "the physical organs of activity", and activity of the body was regarded as having nothing to do with learning. Indeed, activity was thought "to be an irrelevant and intruding physical factor". In contrast, Dewey stressed the link between learning and doing. He was a pioneer of "activity methods" in the classroom. He sought to bring general education in touch with the realities of contemporary life.

According to Dewey (1938), the best way to gain knowledge was through experience. In determining the place of thinking in experience he noted that experience involves a connection of doing or trying with something which is undergone in consequence. Thinking is the accurate and deliberate instituting of connections between what is done and its consequences. The stimulus to thinking is found when one wishes to determine the significance of some act, performed or to be performed. Thinking includes all of these steps:

- the sense of a problem,
- the observation of conditions,
- the formation and rational elaboration of a suggested conclusion, and
- the active experimental testing.

Dewey's theory had some application in the present study. Laboratory or computer simulation were the experiential activities that were part of the instruction. Through these activities, students were expected to gain meaningful learning experiences that facilitated better understanding of the logic circuits. These activities were designed to stimulate the thinking process within the student. Students were given an opportunity for active participation and were expected to "learn by doing".

Behavioral approach

According to Kazdin (1980), learning is one of the fundamental processes underlying behavior. Most of the behavior is learned behavior. Learning is the process by which a relatively enduring change in behavior occurs as a result of practice. The words 'relatively enduring' signify that the change in behavior is more permanent. The term practice is intended to cover both formal training and uncontrolled experiences. The learning process cannot be directly observed. It must be inferred from changes in behavior. The changes in behavior that characterize learning may be adaptive and promote effectiveness, or they may be nonadaptive and ineffective.

Three types of learning are important in developing and altering behavior (Skinner, 1966). These are classical conditioning, operant conditioning, and observational learning. The name most closely associated with operant conditioning is that of Skinner, the world-famous behaviorist. This form of conditioning is concerned with learning that occurs as a consequence of behavior. In classical conditioning, the sequence of events is independent of the subject's behavior. Behaviors that can be controlled by altering the consequences (reinforcers and punishments) that follow them, are referred to as operants. An operant is strengthened (increased) or weakened (decreased) as a function of the events that follow it.

Phillips and Soltis (1985) have stated that the behaviorist takes learning to be the result of actions of the environment on the learner. The learners learn to act in acceptable ways by being praised when they do the right things and by praise being withheld when they do not. Working with laboratory rats and pigeons, Skinner (1966) discovered that an action or response does not have to be rewarded or reinforced every time it occurs. The rats learned very effectively if they were rewarded fairly frequently but randomly. The animals that were rewarded for their actions stopped performing those actions if the rewards were held back.

According to Skinner (1966), operants are distinguished by virtue of being controlled by their consequences. The sequence is described as the A-B-C operant mode. 'A' designates the antecedent or stimulus that precedes the behavior 'B'. The consequence 'C' results from the behavior. Skinner believes that such consequences will be acted out in the future. This notion lends itself particularly well to the study of various learning principles such as reinforcement and knowledge of results. This theory had some application in this study. The students may have learned as a result of positive reinforcement during computer simulation or laboratory activity.

The computer simulation program awarded points to the student for every correct response. The student realized that getting the right answer to a question was very rewarding. If a correct answer was given, the student received score points, which could be regarded as immediate positive feedback. The student then moved on to the next item. Thus the student had probably learned that he had a correct understanding of that content. If the answer was wrong, no points were awarded, or in other words, reinforcement was held back. The student may have now learned that he had an incorrect understanding of that content. At the end of each option, the program indicated the total number of points the student had earned out of the highest possible score in that option. This served as an additional reinforcer.

In the laboratory activity, the student was able to utilize all possible input combinations for each logic gate. Whenever the correct combination of inputs occurred, the output light bulb was turned on. The experimental set up reinforced the student for every correct behavior, using immediate feedback (light bulb turned on). This was a form of positive reinforcement which may have helped the student to understand the working of that particular logic gate.

Cognitive approach

Bloom's Taxonomy of Educational Objectives (1956), is an influential work in the domain of learning. The classification is into three domains: the cognitive domain, concerned with intellectual knowledge and skills; the affective domain, concerned with feelings, attitudes and values; and the psychomotor domain, concerning physical skills.

Bloom and Krathwohl's taxonomies in the cognitive domain are essentially hierarchical descriptions of 'levels of competence' or 'levels of mastery'. For example, it is suggested that cognitive development follows a sequence from knowledge (of specific facts or procedures), through comprehension of the knowledge, through its application in a particular situation, to the higher order mental skills of analysis, synthesis and evaluation, all of which are involved in the problem-solving process (Barnes & Windham, 1985).

Piaget is a psychologist whose theories of cognitive development have had great influence on education. According to Piaget (1969), concept formation follows an invariant pattern through a series of clearly definable stages which must be experienced and passed through in a set order. The maturational and hierarchical development of conceptual skills has important implications for all curriculum design.

Bruner (1966) has written that the ultimate goal of instruction is to insure that the student becomes an efficient self-learner. This can be achieved using optimum amount of learning guidance. When minimal amount of learning guidance is provided, instruction is said to emphasize 'discovery' on the part of the learner. Conversely, discovery is de-emphasized when the amount of learning guidance provided is large. According to Wittrock (1966), studies of 'discovery learning' suggest that small amounts of learning guidance have advantages for retention and transfer. The techniques of bringing about learning by discovery incorporate the use of questioning, or experiential exploration. These activities lead the learners to discover the component concepts by themselves.

Ausubel (1968) believed that the principle factor influencing meaningful learning was the learner's existing cognitive structure. In order to facilitate new learning, Ausubel proposed that instructional strategies draw out the components of the existing structures that are particularly relevant in learning the new material and use these components as "subsumers" for the new learning. Based upon this "subsumption" theory, Ausubel has designed an instructional strategy that uses "advance organizers" to facilitate meaningful learning.

Mayer (1977) has suggested three general theoretical frameworks for meaningful versus rote instruction. Reception Theory is a one-stage model that posits that test performance is a function of the amount of information that is received by the learner. This theory predicts, for example, that if the test measures content from the instructional material, then presenting an organizer before, after, or not at all should have no effect on test performance. Addition Theory is a two-stage model that posits more is learned if the learner possesses the proper prerequisite anchoring concepts. This theory predicts that presenting an organizer before learning should result in more learning than presenting the organizer after learning (or not at all), since only in the former case can the organizer provide the needed anchors.

According to Mayer (1977), the Assimilation Encoding Theory is a three-stage model that involves a different encoding process. This theory posits active integration of new information with existing knowledge, and a different type of learning outcome, varying in breadth rather than only in amount retained. Thus, in addition to receiving information and possessing the relevant knowledge in long-term memory, it also involves transferring the anchoring knowledge from long-term memory to working memory and actively integrating that knowledge with incoming information during learning.

The sequencing of instruction that was investigated in this study was based on the cognitive learning theories discussed above. The purpose was to determine whether computer simulation or laboratory activity should precede or follow the reading assignment, when teaching logic circuits. The objective of this exercise was to find out which sequence will result in effective learning.

Psychologists, philosophers and educationists are still trying to understand how the mind works and how people learn (Phillips & Soltis, 1985). It is important to realize that the underlying purpose of all learning theories is to explain the process of learning. Each theory is based on different assumptions and has useful applications in a different context. It is necessary to test these theories in order to address many important educational questions.

Existing theories can serve as a basis for future research; theory development should be a primary goal of experimental research (Krendl & Lieberman, 1988). This study was based on the following themes discussed by different instructional theorists:

- importance of "hands-on" experience,
- learning through positive reinforcement,

- the role of cognitive structures in learning, and
- learner readiness in terms of prior knowledge.

Computer Simulation and Problem-Solving Techniques

Computers have become an integral part of everyday life in both work and leisure. Hence, it is essential that computers become a part of higher education curriculum, as have other tools and resources. This device offers an individualized, self-pace form of instruction. Thus, it is important to evaluate the conditions under which the use of computers is most effective.

This section has been classified into four subsections:

1. Use of computers in education,
2. Computer simulation and higher-order thinking skills,
3. Computer simulation versus other media, and
4. Simulation programs in logic circuits.

Use of computers in education

Kelly (1985) has reported that during the late '70s and early '80s the price of the microcomputer decreased and CAI software increased in availability. The trend now in education is to teach with the computer and that can be divided into two classifications:

1. to teach with the computer as a tool, for example word processing, spreadsheet, databases; and
2. to teach with the computer as an aide, for example drill and practice, tutorials, and simulations.

In CAI one deals with the computer as an aid to enhance instruction and learning.

Nachmias and Linn (1986) have listed a number of computer talents which may best match the expectations of teachers. These are: speed of operation, flexibility of response, facility to use graphics, timing control, randomization, ability to use animation, external device control and use of input-output devices.

Dixon (1984), has written that the power of the microcomputer as an instructional tool, comes from five basic features. These include the ability to:

1. analyze and prescribe (systematize),
2. provide active involvement in learning,
3. allow the student to pace the instruction,
4. provide exploration of time and space, and
5. provide instruction at a cost effective level.

Burns and Bozeman (1981) have presented a meta-analysis of research studies of computer-assisted mathematics instructional effectiveness. The report concludes that: mathematical instructional programs supplemented with CAI material are more effective in fostering student achievement. Compared to traditional classroom instruction, computer-assisted instruction in mathematics instruction accelerated students' development of mathematics skills (Vickers, 1984). Researchers have found increases not only in academic achievement, but also in students' perceptions of the amount of learning they achieve in relation to their effort. That is, students thought that they learned more for less investment of effort when they used a computer.

According to Waugh (1985), though the use of computer-based instruction needs to be enhanced, it must be remembered that computers cannot replace teachers as caring human beings whose professional knowledge and experience enables them to match students' learning experiences to their needs, abilities and interests. Also, the computer cannot make decisions for itself without being given precise instructions on what to do. The computer is there to enhance and stimulate, not to replace conventional practices.

In the technocratic educational framework, teachers and students should analyze the human purposes of technological innovation. The use of the computer as a dispenser of factual data has very limited value in creative thinking (Tennyson & Christensen, 1988). Hence, the examination of the possibilities for computer-induced expansion of student cognitive processes is essential.

Computer simulation and higher-order thinking skills

The simulation and problem-solving type of software seems to have considerable appeal for many educators involved in educational computing (Kearsley, 1985). There seems to be a two-part reasoning for this. Self-directed, exploratory learning is the only method which exploits the unique potential of computers. Also, these approaches will yield greater gains in the long run for students than will using computers for traditional learning methods (Kearsley, 1984).

Papert's book 'Mindstorms' (1980), is associated with the application of exploratory learning to educational computing. Papert (1980) has criticized much of what is done with computers in education; because it has encouraged the student to be programmed by the computer instead of the computer to be programmed by the student. Papert (1980) has said that the most versatile, stimulating and useful programs are those which can be used as a tool to explore a variety of situations or problems.

According to Reigeluth and Schwartz (1989), educational simulations should comprise of all the three phases in the learning process:

- acquisition,

- application, and
- assessment.

The first function, acquisition, is to present the content. The learner must first acquire a basic knowledge of the content or behavior. Then he or she must learn to apply this knowledge to the full range of relevant cases or situations. The final stage is an assessment, in some cases a self-assessment, of what has been learned. The assessment function of the simulation determines if the learner has achieved mastery. Mastery is a specified criterion for the number of correct responses on a set of divergent and difficult, previously unencountered, practice situations.

Based on instructional theory and an examination of many simulations, Reigeluth (1987) identified five simulation features that act as vehicles for achieving acquisition, application, and assessment. These include:

1. generality,
2. example,
3. practice,
4. feedback, and
5. help.

The generality is a statement of the relationship among changes that characterize a procedure or principle. An example is a specific instance or case that shows the relationship among changes described in one or more generalities. Practice provides the learner with the opportunity to apply one or more generalities to diverse situations. Feedback provides the learner with confirmatory or corrective information regarding his or her responses. Help provides the learner with direction and assistance during the presentation of the generality, examples, practice, and feedback. It appears that both the difficulty of the content and the instructional approach (expository or discovery) should determine what type and how much help is needed.

Dalbey, Tournaire and Linn (1986) hypothesized that the interactive nature of the computer learning environment would facilitate the development of higher-order skills involved in planning and problem-solving. By receiving immediate feedback on the accuracy of their work, the students were expected to learn new techniques for solving problems. Although they learned some skills, students had difficulty transferring them; they could not solve problems when the problem specifications deviated from those previously encountered in instruction.

Rivers and Vockell (1987) investigated the use of support materials with simulations to stimulate scientific problem solving. A series of science simulations were used in three different studies. Each study consisted of three groups; traditional instruction, simulation with study guide and support materials and simulations that contained in their introduction a set of strategies to use in solving the simulations. No significant differences were found on unit posttests covering the content of the course. Differences were found, on improvement of general problem solving skills, in which guided discovery was superior and discovery was better than the traditional instruction.

Computer simulation versus other media

When computer simulations are compared to other media such as print, film, video, or lectures, a primary advantage claimed for them is increased transfer of learning (Alessi & Trollip, 1985; Reigeluth, 1987). Transfer of learning refers to a student being able to apply what is learned during instruction to a new situation, usually the intended real performance. Although simulations are assumed to enhance transfer better than books or other media, "hands-on" instruction with real equipment is often presumed to have still better transfer (Alessi, 1988). But simulations may still be preferred for other reasons, notably cost and safety (Hopkins, 1975).

Choi and Gennaro (1987) made a comparison between computer simulations and physical laboratories in science courses. The authors compared three groups of eighth-grade students. One group used computer simulations while another group used laboratory apparatus to study Archimedes' principle. Following the treatment, the groups jointly participated in a ten minute discussion of the principle. A third group, the control group, received no treatment. Both treatment groups performed better than the control group, but no significant differences were found between the treatment groups.

Another study conducted by Hollen, Bunderson and Dunham (1971) investigated the differences between computer simulation and laboratory experience. The authors extended the tutorial lesson format to simulation of qualitative analysis in beginning chemistry. In this lesson, students could respond to questions indicating what actions they wanted to perform next. If the expected response was not given, the program provided feedback and guidance. Students using the lesson had scores which were equivalent to the scores of a group that performed the experiments in the chemistry lab. However, the computer group required significantly less learning time.

Carrier et al. (1985) worked with six fourth-grade classrooms to examine the differential effects of mathematics instruction delivered by computer versus worksheets. Another study involved eighty-four second, third, and fourth graders and compared mathematics learning from a computer versus flashcards (Fuson & Brinko, 1985). These investigations took special care to control the instructional features and content of each treatment, making the worksheets and flashcards as similar as possible to the material presented in the computer conditions. Both studies reported no significant differences in students' mathematics learning as a result of instructional medium used. Therefore, the authors propose that earlier research reporting superior mathematics learning from computer-assisted instruction compared to other instructional delivery methods often failed to provide equivalent instructional treatments. They concluded that when the specific features and the content of the instruction are similar, no learning differences emerge.

In applying medium theory to computer-based information seeking, Krendl and Fredin (1985-86) identified features of the medium that seemed likely to affect information presentation and, therefore, were likely to affect information-seeking patterns and subsequent learning outcomes. Prior to conducting the study, the authors predicted that student's information-seeking strategies would be natural extensions of the characteristics of the medium relevant to the completion of a particular task, in this case conducting research for writing a science term paper. Because cross-reference searches could be obtained on the computer-delivered system by simply entering the new key word, the authors proposed that students using the computer-delivered encyclopedia were more likely to conduct cross-reference searches. They predicted that students using the print encyclopedia, on the other hand, were more likely to limit the number of cross-reference searches they conducted and to rely more heavily on careful readings of the most directly relevant entries. As predicted, students who used the electronic encyclopedia scored higher on measures of knowledge. According to the students, use of the computer eased the process of information gathering, as well as the process of writing the paper.

Simulation programs in logic circuits

There are a limited number of computer simulation programs available for teaching logic circuits. The more widely used programs are: Rocky's Boots and High Wire Logic. Rocky's Boots is developed by The Learning Company. This program introduces students to logic circuit components such as wires, AND-gates, OR-gates, and NOT-gates, one at a time. The program then shows the student how to build simple electronic machines. After students master the logic gates they go on to build more complex machines using CLOCKS, FLIPFLOPS, and DELAYS. The students also have an opportunity to design their own games using Rocky's game editor.

The High Wire Logic Program is developed by Sunburst Corporation. This computer-based instructional program was utilized in this study. It shows students two sets of shapes such as hexagon, rectangle, circle, square or triangle. These shapes appear in different colors such as green, blue, orange, or purple. The shapes also appear in two sizes: large or small. In addition, the shapes are either filled or empty. The students are challenged to write as many rules as they can, that fit the shapes on the wire, but do not fit the shapes in the net. The rules they write must be based on one of these logic types: AND, OR, AND-OR, AND-AND, OR-OR, and XOR.

The High Wire Logic program was more appropriate for this study because it dealt with the general concepts involved in logic gates and their applications, and not actual circuits involving logic gate symbols. Additional details of this computer simulation program are discussed in Chapter 3.

Sequencing of Instruction

A majority of discovery strategies have employed inductive sequencing procedures. Primary elements of these inductive sequencing strategies have included questioning, experiential exploration, reflection, and evaluation. A main goal of these discovery strategies has been the development of problem-solving skills. The teacher's role has not been one of information dispenser (the more traditional role), but rather one of facilitator or catalyst. The student, then, is required to put the bits of information he "discovers" together for himself (Wittrock, 1966).

Proponents of inductive sequencing strategies have believed that such strategies instill greater degrees of autonomy and intuition in the learner (Gagne, 1987). These strategies, the proponents state, have been designed to increase the student's ability to integrate information. By providing opportunities for students to apply this integrated information to new problem-solving situations, inductive strategies have claimed better results.

Lim-Quek (1985) studied the effects of two instructional sequences: principle-procedure and procedure-principle, on the application and transfer of learning. Students in the two groups were given the same instruction, differing only in the order in which the modules were presented. A posttest measured near-transfer and far-transfer learning, and a post-questionnaire gathered personal data and responses on attitudes and preferences regarding the sequencing of instruction. Results showed no significant difference in learning outcomes but there was a general preference for the principle-procedure sequence.

Lahey (1979) has compared the effects of several presentation sequences on lesson performance. Thirty-six students were randomly assigned to one of four groups differing by the instructional presentation sequence used. The first group saw lessons in a rule-examples-practice sequence; the second, in an examples-rule-practice sequence; the third, in a practice-examples-rule sequence; and the fourth, in a random sequence. There were no consistent differences in performance among the four groups.

Brant, Hooper and Sugrue (1989) conducted a study to determine the appropriate sequential placement of a simulation program in genetics. The authors compared three groups of students. One group used the simulation prior to lecture on genetics, one after the lecture and the control group did not use the simulation until after the test. The group using the simulation prior to the lecture scored significantly higher than the control group. Those using the simulation after the lecture scored only slightly better than the control group. In a follow-up experiment involving only two groups, the before group scored significantly better than the after group. The test questions involved moderate transfer of the material covered in the lecture. An analysis of questions involving recall and direct application which were contained in a unit test over the material showed no group differences.

Taylor (1987) studied the effects of sequencing of instruction. In his study one group used the simulation early in the semester, while the other group used it later. Three tests were given which revealed no differences. However, students who used the simulation early in the course had a more favorable attitude toward the simulation and its value. According to Thomas and Hooper (1989), for these students, the simulation may have had an experiencing effect. The students realized its value, but the tests may not have required sufficient transfer to pick up existing differences.

Learning Style and Instruction

Over the past two decades, a great deal of progress has been made toward recognizing the varying needs and characteristics of the learner. As a result of the wide range of individual differences, "individualized instruction" has become one of the cornerstones of modern educational practice. As Jeter and Chauvin (1982) note:

> Educators are keenly aware that each student possesses unique needs, interests, and abilities, and that each child should have an opportunity to pursue an effective instructional program that is challenging and interesting (p. 2).

Thus, effective instruction must take into account the learning style of the student as well as the rate of learning.

According to Smith and Renzulli (1984), literature on learning styles reveals a wide range of definitions that have been adopted to describe this construct. These definitions range from concerns about preferred sensory modalities (e.g., visual, auditory, and tactile) to descriptions of personality characteristics that have implications for behavior patterns in learning situations (e.g., the need for structure versus flexibility). Others have focused attention on cognitive information processing patterns, such as Kolb's (1984) work on concrete versus abstract thinking abilities.

A study conducted by Smith (1976) examined the relationship of learning style matching to student achievement, motivation, and interest in subject matter.

Overall, the results of this study confirmed the fact that learning style matching significantly enhances educational outcomes. Students who were taught by their preferred method achieved better, were more interested in the subject matter, liked the way the subject was taught, and wanted to learn other school subjects in the same way. Motivation was not significantly different for matched versus unmatched students.

The learning-style inventory that was used in the present study was developed by Kolb (1985). According to Stice (1987), this inventory, based on the theories of Dewey, Lewin, and Piaget, provides a framework for examining one's learning strengths and weaknesses. Kolb's model conceives learning as a four-stage cycle. Kolb (1985) found that learners generally report themselves as being one of four types: divergers, assimilators, convergers, or accommodators. These four types of learners are explained in detail in the following paragraphs. Additional information about Kolb's Learning Style Inventory is provided in Chapter 3.

Divergers

Divergers are those who fall in the upper right-hand quadrant of the Learning-Style Type Grid. They prefer to learn by concrete experience (CE) and reflective observation

(RO). They are creative, good at generating alternatives, recognize problems, and understand people.

Assimilators

Assimilators are in the lower right-hand quadrant of the Learning-Style Type Grid. They learn primarily by reflective observation (RO) and abstract conceptualization (AC). They are best at understanding a wide range of information and putting it into logical form. They generally are more interested in the logical soundness of an idea than its practical value. They are probably less interested in people than in abstract ideas.

Convergers

These types of learners fall in the lower left-hand quadrant of the grid. They are strong on abstract conceptualization (AC) and active experimentation (AE). They like the practical application of ideas and theories, do well on conventional tests, use deductive reasoning, and are good at defining and solving problems and making decisions.

Accommodators

Accommodators are located in the upper left-hand quadrant of the grid. Their learning preferences are active experimentation (AE) and concrete experience (CE). They adapt well to immediate circumstances, learn primarily from "hands on" experience, get things done, take risks, and tend to act on feelings rather than on logical analysis.

Summary

This chapter focused on both method of instruction and instructional sequencing, in teaching logic circuits. The first section discussed the learning theories that formed the basis for this investigation. Dewey's (1938) problem-solving theory outlines the importance of experiential learning. The laboratory and computer simulation activities were designed to provide meaningful learning experiences to the students. Laboratory procedure represents the traditional type of instruction. Computer-based simulation is an effective way of applying technology to learning. Learning through positive reinforcement that occurred during both activities is related to the behavioral learning theory. The use of the 'experiential exploration' approach was based on cognitive learning theory. This formed the basis for investigating the sequencing of instruction in teaching logic circuits.

The second section reviewed different characteristics of computer simulations that are used to enhance learning.

The attempt was to describe the importance of computer simulations in improving higher-order thinking skills. The section also discussed various studies that compared computer simulation with other media such as laboratory procedures. The third section described studies that dealt with sequencing of instruction. Many of these studies used computer simulation programs as part of the treatment. The fourth section evaluated the role of student learning style in effective instruction.

CHAPTER III. METHODS AND PROCEDURES

This chapter includes an overview of the experimental treatments, the research design and the population used in this study. The characteristics of the population as well as the sample are presented in the first section. The second section provides a description of the computer-based simulation program that was used as one of the experimental treatments. Section three contains a discussion of the laboratory procedures which was administered as the second treatment. The fourth section describes the content of the reading assignment in relation with the computer simulation program and the laboratory procedures. Section five discusses the instruments used in this study. Research methods used to collect and analyze the data are presented in section six, along with the statistical tests of significance.

Description of the Subjects

Human subjects were involved in this study. As a result, the human subjects committee at Iowa State University was consulted prior to conducting the study. A copy of the human subjects form approved by the committee can be found in Appendix A.

The population for this study consisted of undergraduate students enrolled at Iowa State University, Ames, Iowa. The sample, however, was confined to students enrolled in the Summer semester of 1989. About 90% of the students were taking at least one class in the College of Education. A total of ninety-six subjects participated in this study.

An eleven-item questionnaire was developed to collect descriptive data concerning each participant's demographic information, educational background, and previous digital electronics experience. Demographic and related information requested from the students included age, sex, year in college, major field of study, college grade point average, and number of hours employed (including voluntary work). The students were also asked to indicate if they had any formal education in logic circuits or boolean algebra or digital electronics either in high school or in college. In addition, the students were also requested to describe the kind of experience they may have had with logic gates in either course-related or job-related activities. A copy of the questionnaire is included as the first page of the pretest provided in Appendix B.

Results of the questionnaire revealed that the average age of the participants was twenty-five years with a range of eighteen to fifty-four years. Sixty-three of the ninety-six participants were females and the remaining thirty-three were males. Six students were currently classified as freshman, forty were sophomores, thirty-four were juniors, and sixteen were seniors. The mean grade point average was 2.99 on a four-point scale, with a range of 1.92 to 3.96. The participants were employed for an average of eighteen hours per week and the work hours ranged from zero to forty-eight hours. Ninety-two of the ninety-six participants reported that they had no formal education in digital electronics either in high school or in college. Four participants stated that they had taken a course in digital electronics in high school but not in college. Only two participants indicated that they had taken formal education involving logic circuits in high school as well as in college. Thus, ninety-six percent of the participants had no background in digital electronics. Kolb's Learning Style Inventory was used to classify the participants into four types of learners. Seventeen students were Type I learners, twenty-five were Type II, forty-three were Type III, and eleven were Type IV. A summary of these statistics is given in the last section of this chapter.

Description of the Computer-based Simulation Program

The computer program that was used in this study is called HIGH WIRE LOGIC distributed by the Sunburst Corporation. This program is designed for 48K Apple II with Applesoft, Apple II plus, Apple IIe, Apple IIc, IBM PC and PCjr. A color monitor or television is required. The program is based on Boolean logic that challenges students to:

- work with higher order rules,
- identify multiple solutions,
- scan for clues and hints,
- make organized lists, and
- examine assumptions.

The skills and strategies listed above are part of the Problem Solving Skill Matrix devised by Stanger and a group of teachers from Rochester, Minnesota (program manual). The Problem Solving Skill Matrix is depicted in Figure 1. The matrix was based largely on the work of Gagne, also reflects the influence of Piaget, Guilford, Meeker, Bruner, Bloom, and Torrance (program manual). The title screen of the HIGH WIRE LOGIC program appears in Figure 2. This program offers both "practice" and "play" options. The characteristics of both options are described below.

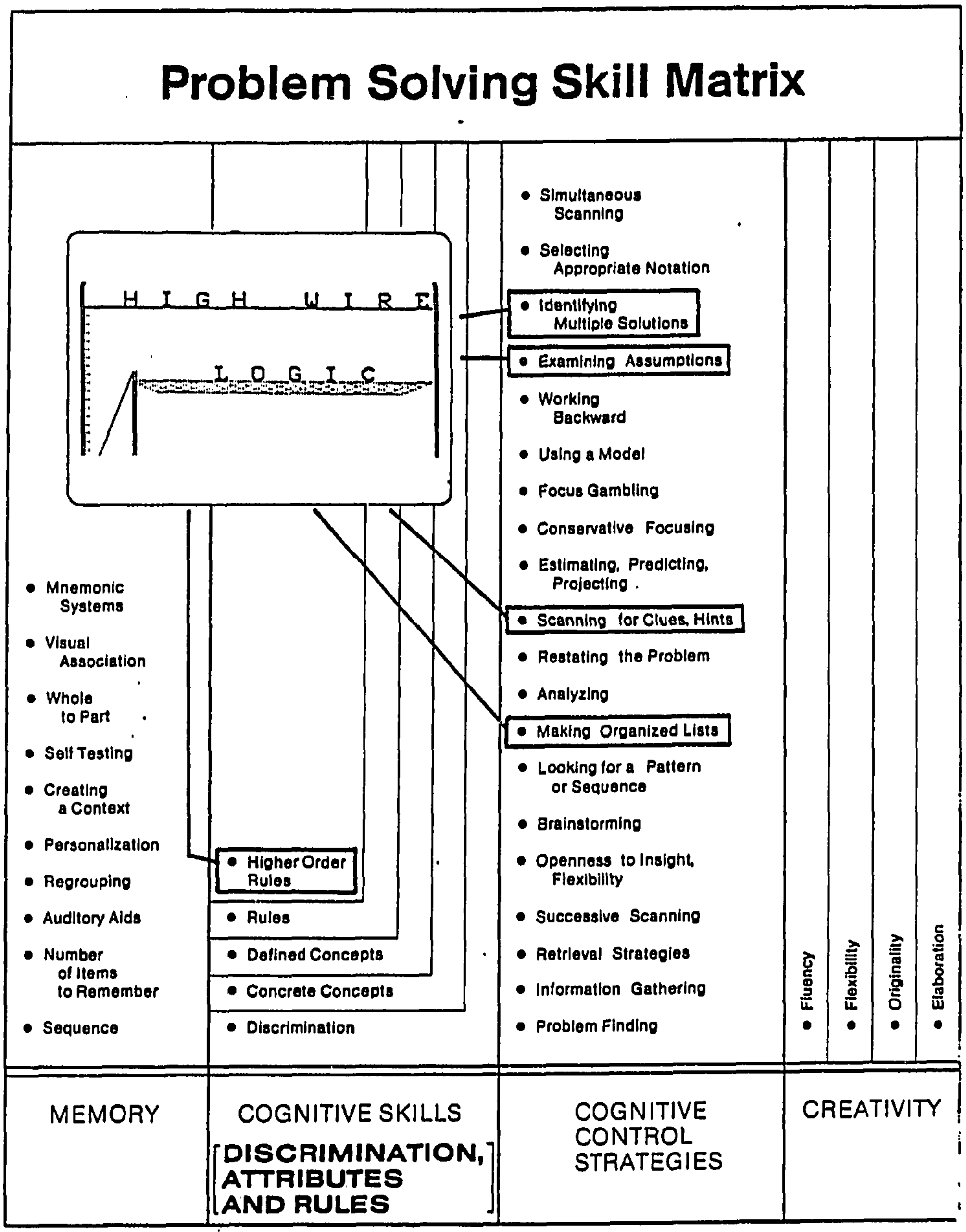

FIGURE 1. Problem Solving Skill Matrix

<u>Practice</u>

This option introduces and allows students to practice six logic types as shown in Figure 3:

1. AND,
2. OR,
3. AND-OR,
4. AND-AND,
5. OR-OR, and
6. EXCLUSIVE OR (XOR).

HIGH WIRE LOGIC provides students with practice in the formation of higher order rules using Boolean logic. In order for students to form these rules, they must become familiar with the six logic types mentioned above. In addition, students must also understand how to use those logic types to form the rules. In the Practice option, an example and an explanation for the logic type selected is given, and students are told how to enter a rule. Students may then practice using the logic type as many times as desired. The Practice option for the AND gate is shown in Figure 4 and Figure 5. The program did not award the same number of points to each logic rule. However, no empirical evidence exists to suggest that this has an effect on student learning.

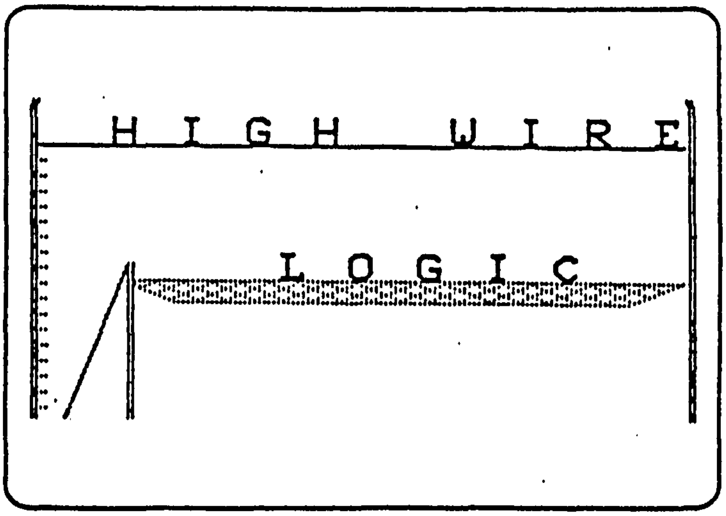

FIGURE 2. Title Screen of High Wire Logic

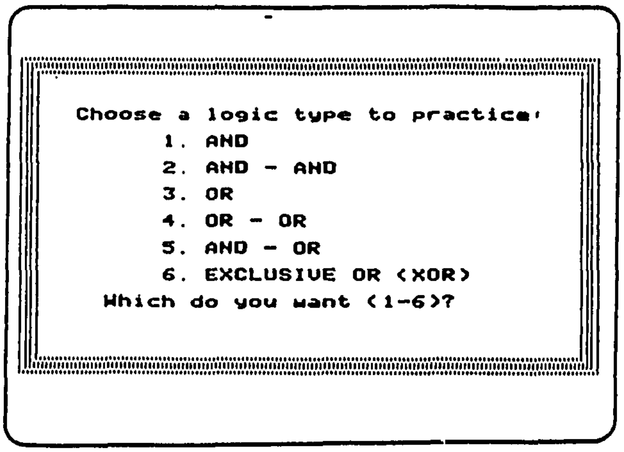

FIGURE 3. Practice Menu

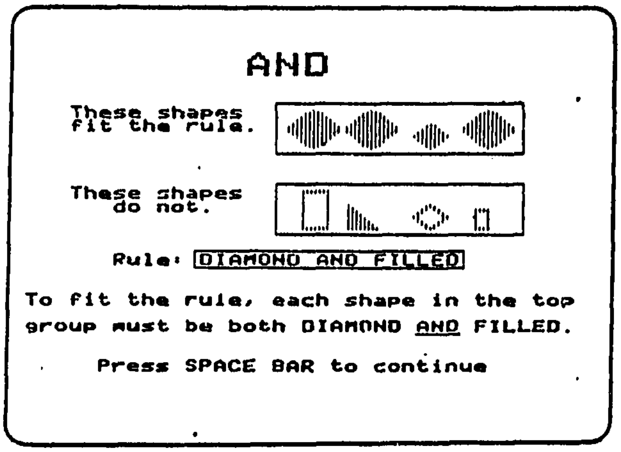

FIGURE 4. Practice option for an AND gate

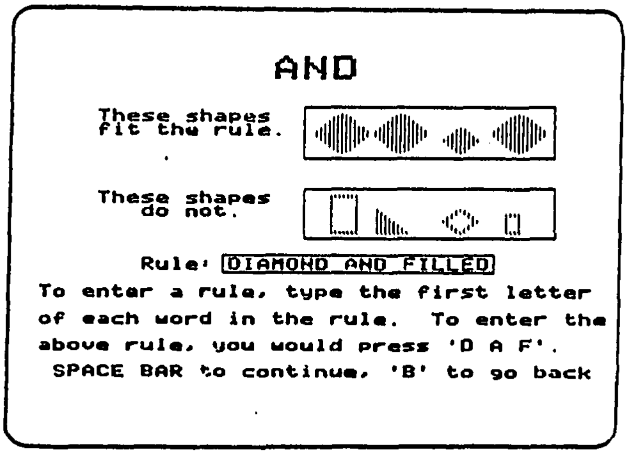

FIGURE 5. Practice option for an AND gate

Play

In this option, students work with two sets of shapes; one set on a high wire and another set that falls into a net. There are four basic shapes:

1. triangle,
2. hexagon,
3. rectangle, and
4. diamond.

These shapes appear in two different sizes:

1. large, and
2. small.

In addition, they may either be:

1. empty, or
2. filled.

They have one of the following four colors:

1. green,
2. blue,
3. orange, or
4. purple.

The object of the game is for the student to write as many rules as possible that fit the shapes on the high wire but not the shapes in the net. Students may continue to write rules until their third wrong answer, or until they are unable to think of any other rules. The computer then displays an example of another correct rule. Students score points for each correct rule written. The more difficult the logic type used, the higher the point value awarded. The point value for each logic type is shown in Figure 6. Should the student forget the possible logic types, shapes, or attributes, a list is available by pressing "?" as depicted in Figure 7.

HIGH WIRE LOGIC provides students with three levels of difficulty. Level one problem is shown in Figure 8 and Figure 9. Level one utilizes the first four logic types in each game. Upon completion of the game, students are shown their best score and the number of answers used to achieve that score. Level two and level three problems are depicted in Figure 10 and Figure 11 respectively. Level two uses the first five logic types. When play at a level is ended, in addition to their best score and the number of answers used to get it, students are shown the highest possible score for that same game and the number of possible answers. This is shown in Figure 12 and Figure 13.

The computer will accept any logic type at any level, but the "highest possible score" shown is based on correct answers using the logic types specified. Because of this, at level two it is possible to score higher than the "highest possible score" shown by the computer. This will only happen if the student uses EXCLUSIVE OR (XOR) in addition to the logic types identified as level two (AND, OR, AND-AND, OR-OR, AND-OR).

Level three makes use of all six logic types. The student's score and number of answers, as well as the highest possible score and the total number of correct answers, appear on the screen as the game is played. Both scores are shown after the game is completed. At this level, the score earned by the student cannot be greater than the "highest possible score" shown by the computer.

Cognitive implications

This computer-based software involved cognition of figural objects and their symbolic and semantic attributes. The operation of cognition involves discovery, awareness, recognition of information in various forms and comprehension or understanding. The student's ability to foresee consequences involved in figural problems was evaluated by the computer program.

The program combined simulation and problem-solving techniques and involved interactive computing and graphics. Students used the computer as an aid in solving problems, reviewing concepts, and evaluating their own progress. The student was provided with a facility to manipulate and test ideas and hypotheses whilst aided by the computer, which was very much under the student's control.

Logic type	Point value
AND	1
AND - AND	2
OR	3
OR - OR	4
AND - OR	5
XOR	6

You may continue writing rules for a problem until you get three wrong.

SPACE BAR to continue, 'B' to go back

FIGURE 6. Logic Type and its Point Value

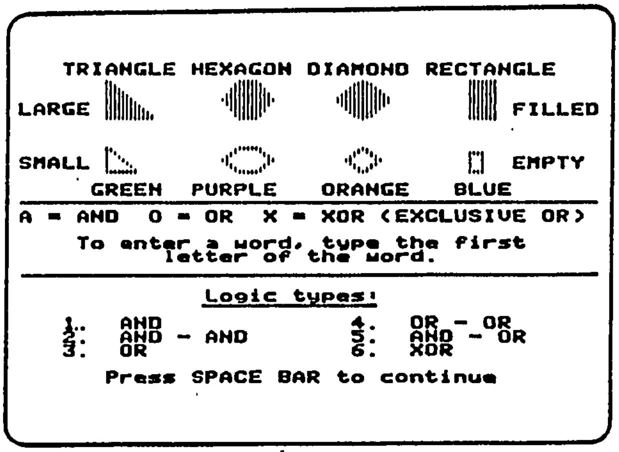

FIGURE 7. Help Menu for the Play option

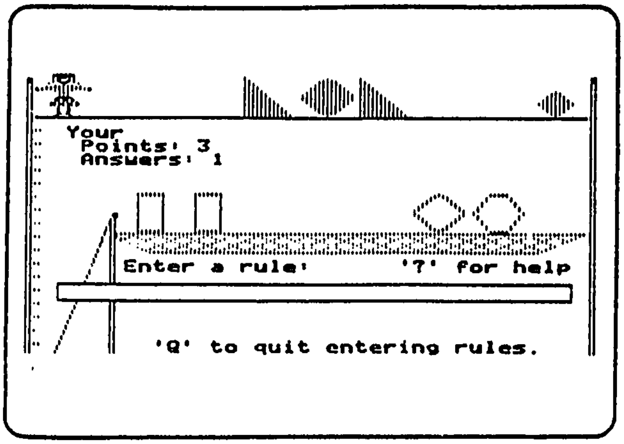

FIGURE 8. Level One Problem

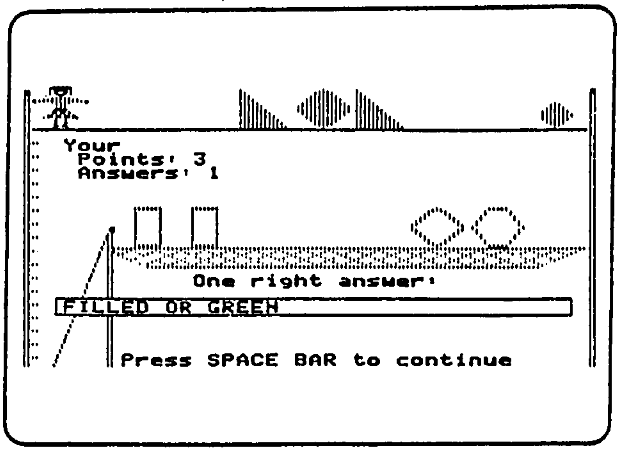

FIGURE 9. Level One Problem

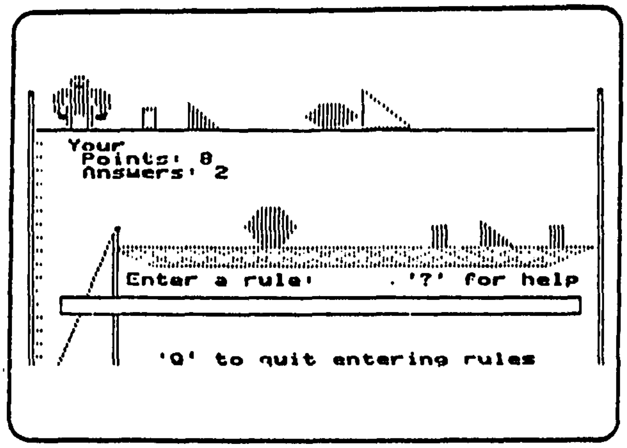

FIGURE 10. Level Two Problem

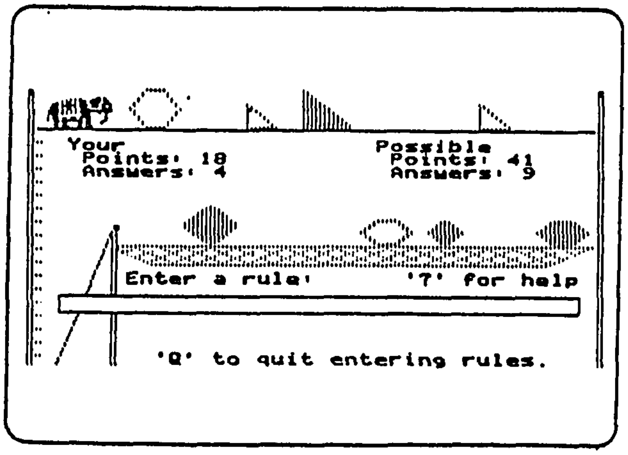

FIGURE 11. Level Three Problem

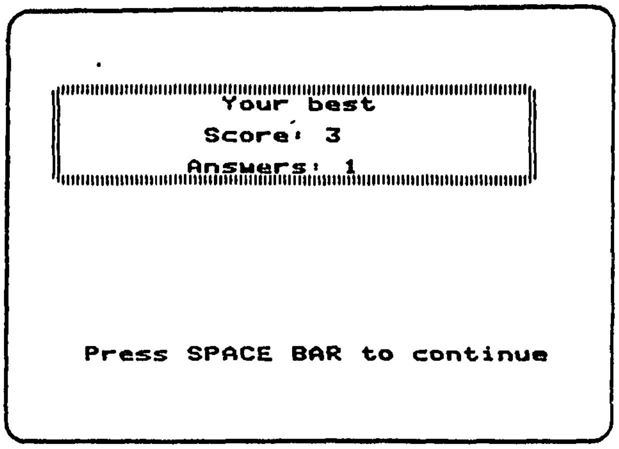

FIGURE 12. Student's Best Score

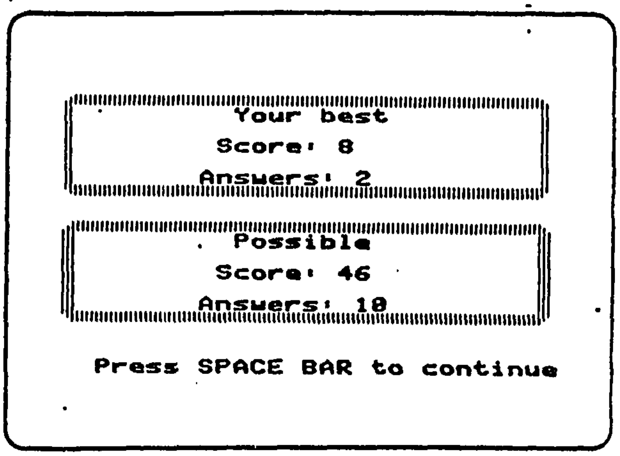

FIGURE 13. Highest Possible Score

Description of the Laboratory Procedure

The laboratory activity comprised of four experiment stations. Each experiment station consisted of a logic circuit board called LOGI-TRAN TWO made by Fabri-Tek Education Systems Inc. The inputs and output for each of the four logic gates: AND, OR, NOT, and Exclusive-OR, were already wired. The clock provided on the logic board was connected to the inputs of the logic gate via switches. The switches could be turned on and off to result in different input combinations. The output of the logic gate was connected to a light bulb which was also provided on the logic board.

The students were required to spend ten minutes at each of the four stations. A step-wise instruction sheet was provided at each experiment station. The students were not informed about the type of logic gate that was set up at each station. The objective of the activity as mentioned on each of the instruction sheet was: to explore the operation of that particular logic gate. The students were instructed to manipulate the input configuration to the logic gate and observe the resulting output. The last step on the instruction sheet urged the students to think about what they had observed. The students had the option of repeating the entire procedure to gain better understanding. Copies of the four instruction sheets are provided in Appendix C.

Description of the Reading Assignment

The reading assignment booklet consisted of nineteen pages. The students were instructed to read the booklet for forty minutes. The booklet covered the following concepts:

- Digital levels,
- AND gate,
- OR gate,
- NOT gate,
- Exclusive-OR gate,
- NAND gate,
- NOR gate, and
- Combination logic.

The first section reviewed the two digital levels: logic 0 and logic 1. The correspondence between:
logic 0, low voltage, and false state, and
logic 1, high voltage, and true state;
was pointed out. The second section explained the technical meaning of a logic gate. The following sections described the six logic gates: AND, OR, NOT, Exclusive-OR, NAND, and NOR. Each type of gate was introduced by noting the following characteristics:

1. conversational example,
2. schematic symbol,
3. truth table, and
4. boolean operator.

The last section introduced the student to combination logic. The process of constructing a boolean equation from a logic diagram was described by using an example. A truth table listed the inputs, the intermediate values, and the outputs. Finally, three-input logic gates were introduced along with their truth tables. A summary highlighted the key points in the booklet. The content validity of this booklet was confirmed by four professors at Iowa State University. A copy of the reading assignment can be found in Appendix D.

Description of the Instruments

Two of the three instruments used in this study were developed by the author. The pretest and posttest were designed to measure student understanding of logic circuits and hence belonged to the cognitive domain. Bloom's Taxonomy (1956) which classifies the cognitive domain into six categories was used as a guide to develop blueprints for the pretest and the posttest. In this study, measurement data were collected using the following three instruments:

1. Posttest,
2. Pretest, and
3. Kolb's Learning Style Inventory.

Posttest

The posttest was a paper-and pencil test and consisted of twenty-seven items. The test was administered to seventy-two undergraduate students at Iowa State University in the Spring of 1989, when the pilot study was conducted. The students majored in Industrial Education and Technology. These students did not have any prior knowledge of logic circuits and therefore represented the population described in this study. The sample was thus appropriate for the pilot study.

The Reliability analysis of the test was based on these data. The RELIABILITY procedure in the SPSSx statistical program was used to determine the Reliability Coefficient. Procedure RELIABILITY performs an item analysis on the components of additive scales by computing commonly used coefficients of reliability. This procedure also prints basic summary statistics including item means, standard deviations, inter-item covariance and correlation matrices, scale means, and item-to-item correlations. Five different models are available in this procedure.

The ALPHA model which computes Cronbach's alpha was used to determine the reliability of the instruments. Since the data were in dichotomous form, Cronbach's alpha is equivalent to reliability coefficient KR-20 (Kuder-

Richardson Formula 20). The Cronbach Reliability Coefficient was found to be 0.94. The corrected correlation coefficients between each item and the total test score were positive and all items were judged to be good items by the program. The content validity of the test was confirmed by four professors at Iowa State University, who are knowledgeable in this area. A copy of the posttest is provided in Appendix E.

Using Bloom's Taxonomy (1956), the first ten of the twenty-seven items were classified into knowledge, comprehension, or application categories in the cognitive domain. These items were classified as "knowledge" type of items. The remaining seventeen items belonged to the analysis, synthesis, or evaluation categories of the cognitive domain. These items were classified as "transfer" type of items.

Pretest

The pretest was a paper-and-pencil test which initially consisted of twenty-two items. The test was administered to sixty-five undergraduate students at Iowa State University during the Spring of 1989. Reliability analysis of the test was based on these data. It was found that the Cronbach Reliability Coefficient was 0.82. However, items eleven and twelve did not enter the analysis since they had zero mean and thus zero variance. In other words, no student had passed either item eleven or item twelve. Both the items were based on XOR logic. Hence, the final form of the pretest did not contain these two items. Item two was found to be negatively correlated with the total test score. This reduced the reliability of the test. Hence Reliability analysis was repeated after excluding item two. The Cronbach Reliability Coefficient now increased to 0.83. It was thus clear that item two was a poor item. In summary, item eleven, item twelve, and item two were excluded from the final form of the pretest.

The pretest that was used in this study was a paper-and-pencil test and consisted of nineteen items. The first nine items were figural problems in which the student had to identify the figures that satisfied the corresponding logic rule. These nine items were based on five different types of logic rules: AND, OR, AND-AND, OR-OR, and AND-OR. The figures had different shapes: circle, triangle, rectangle, and square. The figures were either solid, or shaded or left empty. Each item consisted of one logic rule and approximately nine figures. The student was asked to circle those figures that satisfied the corresponding rule. Using Bloom's Taxonomy (1956), these items belonged to the application category in the cognitive domain.

The next ten items were based on the concepts involved in logic gates. In six of those items, students were asked to match the logic symbols with the corresponding logic gates. The other items were multiple choice and tested the students on their understanding of truth tables and Boolean operators for different logic gates. These items were classified into either knowledge or comprehension categories of the cognitive domain. A copy of the pretest is provided in Appendix B.

Kolb's Learning Style Inventory

The learning style inventory that was used in this study was developed by Kolb (1985). Kolb's model conceives learning as a four-stage cycle, shown in Figure 14. The different learning stages in this cycle are described as follows:

Concrete Experience (CE)

This stage emphasizes personal involvement. One tends to rely on feelings rather than on a systematic approach to problems and situations, and on one's ability to be open-minded and adaptable to change. Learning in this stage is characterized by learning from specific experiences, relating to people, and being sensitive to feelings and people.

Reflective Observation (RO)

In this stage, people examine ideas from different points of view. They rely on patience, objectivity, and careful judgement, but do not necessarily take any action. They rely on their own thoughts and feelings to form opinions. Learning by watching and listening is characterized by careful observation before making a judgement, viewing from different perspectives, and looking for the meaning of things.

Abstract Conceptualization (AC)

Learning in this stage involves using logic and ideas, rather than feelings, to understand problems and situations. Reliance is on systematic planning and developing theories and ideas to solve problems. "Thinkers" learn by logical analysis of ideas, systematic planning, and acting on intellectual understanding of a situation.

Active Experimentation (AE)

In this stage learners actively experiment with influencing situations. They have a practical approach and a concern for what really works. They value getting things done and seeing the results. This kind of learner has an ability to get things done, a willingness to take risks, and can influence people and events through action.

The Kolb Learning-Style Inventory consists of a 12-item paper and pencil instrument which can be completed and self-scored in ten to fifteen minutes. The subject obtains scores for each of the four learning stages: CE, RO, AC, and AE. The AE-RO difference is computed and the result plotted on the x-axis of a rectangular graph. The AC-CE difference is also determined and is plotted on the y-axis. The resulting single point (y=CE-AC, x=RO-AE) identifies the subject as a diverger (Type I), an assimilator (Type II), a converger (Type III), or an accommodator (Type IV). Figure 15 shows the four types of learners in four quadrants. The characteristics of these four types of learners were described in detail in Chapter 2.

Description of the Research Methods

This section describes the research design, the data collection procedures, and the methods used for analyzing the data.

Research design

In an attempt to determine the effects of the independent variables on the dependent variable, an experimental research design was used. The two independent variables for this study were: (1) method of instruction, a

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nominal variable with two categories (computer-based simulation and laboratory experience); and (2) sequencing of instruction, a nominal variable with two categories (reading following lab or simulation experience and reading prior to lab or simulation experience). The dependent variable was the posttest score. Random assignment was used in this study to ensure absence of systematic bias in group composition. However, random assignment does not establish initial equivalence between groups. A modified form of the pretest-posttest control-group design was used in the study. Figure 16 represents the design (Borg & Gall, 1983). 'R' stands for random assignment, 'O' represents either the pretest or the posttest, and 'X' represents the treatment.

R	O	X	O
R	O	X	O
R	O	X	O
R	O	X	O

FIGURE 16. Pretest-Posttest Control-Group Design

The essential features of the pretest-posttest control-group design are: formation of an experimental treatment group, a control treatment group, and administration of a pretest and a posttest to each group. In this study, a modified form of this design was used. The intent was to investigate the relative effectiveness of the computer-based simulation program as compared to the laboratory procedure, and also the most effective sequence of instruction. The author was equally interested in the two levels of both independent variables. Hence, rather than two experimental groups and two control groups, there were four experimental groups, and this calls for a modified form of the pretest posttest control group design (Borg & Gall, 1983).

The level of significance which is the Type I error rate (alpha) was Also, the Type II error rate (beta) was set at 0.05. Also, the Type II error rate (beta) was set at 0.05. In other words, the statistical power of the test was 0.95. If the values of alpha and beta are known, sample size N can be calculated. The meaningful difference or effect size was one standard deviation. Since the significance criterion, effect size, and power were already specified, sample size tables were used to determine the sample size N. These tables are designed primarily for use in the planning of experiments, during which the decision on sample size is made. The sample size was determined to be twenty-five (Cohen, 1977).

Data collection procedures

The subjects were randomly assigned to one of the four experimental treatments. A pretest was administered to all subjects prior to instruction. The paper and pencil pretest was helpful in assessing the subjects' prior knowledge of logic circuits. A posttest was administered to measure treatment effects. A description of the four treatments is given in Figure 17.

Group 1	R	Pretest	Lab	Reading	Posttest
Group 2	R	Pretest	Sim	Reading	Posttest
Group 3	R	Pretest	Reading	Lab	Posttest
Group 4	R	Pretest	Reading	Sim	Posttest

R: Random assignment
Pretest: Pretest administered
Lab: Laboratory procedure
Reading: Reading assignment
Sim: Computer-based simulation program
Posttest: Posttest administered

FIGURE 17. Treatment Groups

Data analysis procedures

Borg and Gall (1983) observed that researchers often use the wrong statistical procedure to analyze such data. The incorrect procedure is to do a t-test on the pretest and posttest means of the experimental group and another t-test on the corresponding means of the control group. If the 't' value for the experimental group is statistically significant, but the 't' value for the control group is not, the researcher would conclude wrongly, that the experimental treatment was superior to the control treatment. This method of statistical analysis is wrong because it occasionally yields statistically significant differences that do not really exist between the experimental and control groups. In other words, it has a tendency to produce Type I errors.

The preferred statistical method is analysis of covariance in which the posttest means are compared using the pretest scores as a covariate. If the assumptions underlying analysis of covariance are not satisfied, one might consider an analysis of variance of the posttest means. Another approach is to do a two-way analysis of variance. The data in this study were analyzed using the analysis of variance (ANOVA) procedure which is most appropriate for this two-factor design (Borg & Gall, 1983).

Analysis of covariance procedure was also conducted since there was a significant correlation between the pretest and the posttest. The regression analysis procedure was used for exploratory purposes. The objective was to identify variables that accounted for a significant portion of the variance in the criterion variable: posttest score. The level of significance (alpha) was set at 0.05.

Summary

This chapter describes the methods and procedures used to conduct this study. The following paragraphs highlight the key points from each of the preceding sections.

The first section described the characteristics of the sample. There were a total of ninety-six participants, and sixty-three of them were females. Majority (77%) of the participants were either sophomores or juniors in college, and had an average grade point average of 2.99 on a four-point scale. More than 96% of the students had no background in logic circuits or digital electronics either in high school or in college. Based on Kolb's Learning Style Inventory, majority (71%) of the participants were either Type II or Type III learners.

The second section discussed the HIGH WIRE LOGIC program developed by Sunburst Corporation which was used as one of the experimental treatments. In this program, students are challenged to write as many logic rules as they can, that fit the shapes on the wire, but do not fit the shapes in the net. The rules must be based on the logic types: AND, OR, AND-OR, AND-AND, OR-OR, and XOR. Thus, this program deals with the applications and general concepts involved in logic gates.

The third section described the laboratory procedure that was administered as the second experimental treatment. As part of this activity, students were instructed to work at each of the four experiment stations. The students manipulated the input configurations of already built AND, OR, NOT and Exclusive-OR logic gates. However, the students were not informed about the type of logic gate they were working with. Step-wise instruction sheets were provided at each station. The objective of each activity was to explore the operation of that particular logic gate. The students were urged to think about what they had observed in the process.

The fourth section dealt with the reading assignment that was common to all participants. The booklet elaborated on the following concepts: digital levels, AND, OR, NOT, Exclusive-OR, NAND, and NOR logic gates, and combination logic. The fifth section specified the instruments used to measure students' understanding of logic circuits. Both the pretest and the posttest were paper and pencil tests. The posttest was administered to measure treatment effects. The pretest was helpful in assessing subjects' prior knowledge of logic circuits. Kolb's Learning Style Inventory was also administered to gain additional information about the subjects. The sixth section described the research design, the data collection procedures, and the statistical methods employed for data analysis.

CHAPTER IV. RESULTS AND DISCUSSION

The problem of this study was to determine the effectiveness of computer simulation versus laboratory experience, and the sequencing of instruction, in teaching logic circuits. The criterion variable was the posttest score. The first section describes the general characteristics of the sample. The second section restates the statistical hypotheses of this study. The third section describes the treatment effects and the findings of the analysis of variance procedure. The fourth section analyzes the predictor variables and contains the results from regression analysis. The fifth section describes the findings of the analysis of covariance procedure. The sixth section discusses the implications of these findings.

Characteristics of the Sample

The population for this study consisted of undergraduate students who had no background in logic circuits, enrolled at Iowa State University, Ames, Iowa. The sample was confined to students enrolled in the Summer semester of 1989. A total of ninety-six subjects participated in this study. The distribution of the participants into four treatment groups is depicted in Table

1. There were 24 subjects in each cell, and this yielded a power of 0.94 and a Type II error rate of 0.06. An eleven-item questionnaire was developed to collect descriptive data on the participants.

Results of the questionnaire revealed that the average age of the participants was twenty-five years with a range of eighteen to fifty-four years. The mean grade point average was 2.99 on a four-point scale, with a range of 1.92 to 3.96. The participants were employed for an average of eighteen hours per week and the work hours ranged from zero to forty-eight hours. Table 2 summarizes these data.

Sixty-three participants were females and the remaining thirty-three were males. Six students were currently classified as freshman, forty were sophomores, thirty-four were juniors, and sixteen were seniors. Ninety-two participants reported that they had no formal education in logic circuits either in high school or in college. Four students stated that they had taken a course in digital electronics in high school but not in college. Only two participants indicated that they had studied logic circuits in both high school and college. Kolb's Learning Style Inventory was used to classify the participants into four types of learners. Seventeen students were Type I learners, twenty-five were Type II, forty-three were Type III, and eleven were Type IV. Table 3 summarizes these data.

TABLE 1. The 2 x 2 Factorial Design

	Laboratory Activity	Computer Simulation
Before Reading	N = 24	N = 24
After Reading	N = 24	N = 24

TABLE 2. Descriptive Statistics for Continuous Variables

Variables	Mean	SD	Min	Max
Age	24.55	6.10	18.00	54.00
GPA	2.99	0.52	1.92	3.96
Hours Employed	17.50	13.49	0.00	48.00

TABLE 3. Frequency Counts for Categorical Variables

Variables	Classification	N
Gender		
	Females	63
	Males	33
Year in College		
	Freshman	6
	Sophomore	40
	Junior	34
	Senior	16
Kolb's LSI		
	Type I Learner	17
	Type II Learner	25
	Type III Learner	43
	Type IV Learner	11
Experience in High School		
	Yes	4
	No	92
Experience in College		
	Yes	2
	No	94

Statement of Research Hypotheses

The hypotheses examined in this study were as follows:

<u>Research Question I</u>

Will there be a significant difference in achievement on a test of application of logic circuits between students using the computer simulation program and students doing the laboratory procedures?

<u>Statistical Hypothesis I</u>

H_O : $\mu_{computer} = \mu_{lab}$

H_A : $\mu_{computer} \neq \mu_{lab}$

The criterion variable for this hypothesis was the posttest score.

<u>Research Question II</u>

Will there be a significant difference in achievement on a test of application of logic circuits between students who receive a reading assignment before the laboratory or simulation experience and students who receive identical material in the reverse sequence?

<u>Statistical Hypothesis II</u>

H_O : $\mu_{before} = \mu_{after}$

H_A : $\mu_{before} \neq \mu_{after}$

The criterion variable for this hypothesis was the posttest score.

Research Question III

Will there be a significant interaction between sequencing of instruction and method of instruction in teaching of logic circuits?

Statistical Hypothesis III

H_O : $\mu_{seq} + \mu_{method} + \mu_{seq*method} - \mu_{total} = 0$

H_A : $\mu_{seq} + \mu_{method} + \mu_{seq*method} - \mu_{total} \neq 0$

The criterion variable for this hypothesis was the posttest score.

Analysis of Treatment Effects Using ANOVA

The research design that was used in this study was a 2 X 2 factorial design. Factorial designs are a type of experiment in which the researcher determines the effect of two or more independent variables (or factors), each by itself and also in interaction with each other, on a dependent variable (Borg & Gall, 1983). The effect of each independent variable on the dependent variable is called a main effect. The effect of the interaction of the two independent variables on the dependent variable is called an interaction effect.

In the 2 X 2 factorial design, two variations of one factor (A_1 and A_2) and two variations of another factor (B_1 and B_2) are manipulated at the same time. This factorial design requires the formation of four treatment groups: A_1B_1, A_1B_2, A_2B_1, and A_2B_2. Subjects are randomly assigned to the four treatment groups. Table 1 represents this design and also specifies the cell size.

The Analysis of Variance (ANOVA) procedure was conducted on the posttest scores of the four treatment groups to determine whether one treatment produced achievement scores superior to the other treatment. The pretest and posttest were not parallel forms of the same test. Hence, the difference between the pretest and posttest scores was not meaningful. The posttest score was used as the criterion variable. The mean, standard deviation, and range of the pretest and the posttest scores for the four treatment groups are reported in Tables 4 and 5, respectively. In Table 5, 'NMax' refers to the number of students who achieved a maximum score of 25 on the posttest.

For Research Questions I and II, the two independent variables were:

1. Computer Simulation versus Laboratory Experience, and

2. Sequencing of Instruction.

Research Question III pertained to the interaction effect between the two independent variables. The dependent variable was the posttest score.

The level of significance which is the Type I error rate (alpha) was set at 0.05. The sample size was twenty-four per cell. The meaningful difference or effect size was one standard deviation. Since the significance criterion, effect size, and sample size were already known, power tables were used to determine the power of the test. The statistical power of the test was found to be 0.94 (Cohen, 1977). In other words, the Type II error rate (beta) was 0.06.

Initially, a one-way analysis of variance was done on the pretest scores for the four treatment groups. The purpose of one-way ANOVA was to determine whether the groups differed significantly among themselves at the start of the experiment. Since the one-way procedure yielded a F-ratio that was not statistically significant ($F = 1.52$, $p > 0.05$), it was concluded that pretest differences among treatment groups were not significant. Table 6 contains the results of this analysis.

One of the underlying assumptions in Analysis of Variance is homogeneity of variance. This means that the variances of the distributions in the populations are equal. This assumption was tested using Bartlett's test for homogeneity of variance which is available as part of the Oneway procedure in the SPSSx statistical package. It was found that the variances were not significantly different ($F = .335$, $p > 0.05$). Thus, the assumption of homogeneity of variance was satisfied by these data. The ANOVA procedure was then conducted. After deleting the four participants that had prior experience in digital electronics, ANOVA was again used to determine the treatment effects. But the results remained the same. The results presented henceforth are based on all 96 subjects.

Research Question I

The overall mean of the posttest scores for the participants in the group that did the laboratory procedure was slightly higher than the group that did the computer simulation. The mean for the group that did the laboratory procedure was 17.28. The mean for the group that did the computer simulation was 16.64. The analysis of variance on the data, relating to Research Question I did not substantiate the difference between the laboratory group and the computer simulation group ($F(1,92) = 1.04$, $p > 0.05$).

The statistical null hypothesis of Research Question I was hence retained. In other words, the difference between the means of the laboratory group and the computer simulation group was not statistically significant. These results are shown in Table 7.

Research Question II

The overall mean of the posttest scores for the participants in the group that did the activity (laboratory procedure or computer simulation) before the reading assignment was higher than the group that did the activity after the reading assignment. The mean score on the posttest for the group that did the activity prior to reading was 18.07 and the mean for the group that did the activity after the reading assignment was 15.84. The analysis of variance on the data relating to Research Question II substantiated the difference between the group that did the activity prior to the reading assignment and the group that had the same treatment in the opposite sequence ($F\ (1,92) = 12.35,\ p < 0.05$). This difference was significant at the 0.001 level. The statistical null hypothesis of Research Question II was hence rejected. In other words, the difference between the means of the two sequentially reversed groups was statistically significant. These results are shown in Table 7.

In order to identify where the differences occurred, the items on the posttest were analyzed and classified into two categories: (1) knowledge, and (2) transfer. The 'knowledge' items pertained to logic symbols and truth tables for different logic gates. The 'transfer' items dealt with applications of logic gates in real life situations, and synthesis or analysis of the concepts. A t-test was used to determine the differences between the two sequential groups for both types of items. On the 'knowledge' items, there was no significant difference between the two groups ($t = 1.71$, $p > 0.05$). However, on the 'transfer' items, the posttest difference between the two sequential groups was significant ($t = 3.53$, $p < 0.05$). The results of this analysis are presented in Table 8. Thus, the transfer items on the posttest contributed to the difference between the two sequential groups.

<u>Research Question III</u>

The means of the posttest scores for the four experimental groups were 18.11 for lab prior to reading, 17.98 for simulation prior to reading, 16.32 for lab after reading, and 15.71 for simulation after reading. An analysis of variance on the data relating to Research Question III did not substantiate the interaction effect due to method of instruction and sequence of instruction ($F = .27$, $p > 0.05$). The results are provided in Table 7.

TABLE 4. Summary of Pretest Scores by Treatment Groups

Treatment	N	Mean	SD	Min	Max
Lab-Reading	24	9.04	2.69	4.0	15.0
Sim-Reading	24	9.83	2.81	4.0	17.0
Reading-Lab	24	9.75	2.64	5.0	14.0
Reading-Sim	24	8.46	2.08	4.0	13.0

TABLE 5. Summary of Posttest Scores by Treatment Groups

Treatment	N	Mean	SD	Min	Max	NMax
Lab-Reading	24	18.04	2.69	12.0	25.0	1
Sim-Reading	24	18.10	2.83	13.0	25.0	1
Reading-Lab	24	16.32	3.44	10.0	22.0	0
Reading-Sim	24	15.71	3.16	10.0	25.0	1

TABLE 6. Oneway Analysis of Variance on Pretest Scores

Source of Variation	df	Mean Square	F-value	p
Between Groups	3	10.07	1.52	.214
Within Groups	92	6.62		

TABLE 7. Analysis of Variance on Posttest Scores

Source of Variation	df	Mean Square	F-value	p
Method of Instruction	1	10.01	1.04	.311
Sequence of Instruction	1	119.26	12.35	.001***
Method x Sequence Interaction	1	12.04	1.25	.267
Residual	92	9.66		

***$p < .001$.

TABLE 8. Results of t-test on the two Sequential Groups

Item Classification	Sequential Group	N	Mean	SD	t	p
Knowledge	1	48	9.19	1.76	1.71	.09
	2	48	8.73	1.69		
Transfer	1	48	8.88	2.47	3.53	$.001^{***}$
	2	48	7.03	2.66		

Sequential Group 1: Activity before Reading

Sequential Group 2: Activity after Reading

$^{***}p < 0.001$.

Analysis of Predictor Variables Using Regression

Though treatment effects were analyzed using ANOVA procedure, no information was obtained regarding the relationship between the posttest score and other independent variables. The purpose of multiple regression analysis was to determine the correlation between the criterion variable and some combination of two or more predictor variables. Borg and Gall (1983) support the use of multiple regression technique for analyzing data from experimental research. Multiple regression provided estimates both of the magnitude and statistical significance of relationships between variables.

For Research Questions I and II, the two independent variables were:

1. Computer Simulation versus Laboratory Experience, and
2. Sequencing of Instruction.

Research Question III pertained to the interaction effect between the two independent variables. The criterion variable was the posttest score.

Procedure REGRESSION in the SPSSx statistical program, calculates multiple regression equations and associated statistics and plots. The stepwise method was used to enter the independent variables. In the stepwise solution, at each step after a new predictor variable is added to the model, a second significance test is conducted to determine the contribution of each of the previously selected predictor variables, as if it were the last variable entered.

The Pearson correlation coefficients for the variables are given in Table 9. There was a significant correlation between the posttest and pretest scores ($r = .41$, $p < .001$). The student grade point average (GPA) correlated significantly with both the pretest score ($r = .18$, $p < .05$), and the posttest score ($r = .19$, $p < .05$). The number of hours that the participants worked per week correlated negatively with both the pretest score ($r = -.18$, $p < .05$), and the posttest score ($r = -.25$, $p < .01$). Male participants did significantly better on the posttest as compared to female participants ($r = .25$, $p < .01$). There was also a significant positive correlation between GPA and age ($r = .47$, $p < .001$), GPA and year in college ($r = .19$, $p < .05$), and age and year in college ($r = .31$, $p < .01$). The correlation between sequence of instruction and posttest was very significant ($r = .35$, $p < .001$). Thus, sequence accounted for 12 percent (r^2) of the variance in the posttest.

In multiple regression, R^2 (the coefficient of determination) is interpreted as the proportion of the variation of scores on the criterion variable that can be attributed to the variation of the scores on the linear combination of the predictor variables. In other words, the shared variance between the criterion variable and the combined predictor variables is determined.

It was found that the pretest score accounted for maximum variance in the posttest score. Hence pretest entered the equation in the first step. In the second step, in addition to the pretest score, sequence of instruction entered the equation. In the final step, gender was the additional variable that entered the regression equation.

The multiple correlation coefficient (R) was 0.52 and the coefficient of determination (R^2) was 0.27. This R^2 indicates that approximately 27 percent of the variance in the posttest score is attributable to the variance of the combined predictor variables: pretest score, sequence of instruction, and gender. The results of the regression analysis are given in Table 10.

Since gender entered the regression equation, it was necessary to determine the number of females and males in each of the four treatment groups. The results of this analysis are shown in Table 11. The first and second groups consisted of sixteen females and eight males, and seventeen females and seven males, respectively. The third and fourth groups comprised of fourteen females and ten males, and sixteen females and eight males, respectively. The distribution of females and males in the four treatment groups is not significantly different. However, there could be a potential for confounding effects because of the disproportional distribution of the females and males in the treatment groups.

Based on the results of regression analysis, the learning style of the subjects was not a significant factor in predicting the posttest scores. Learning style was chosen as an independent variable because literature dealing with method of instruction points out the significant relationship between learning style of the student and the method of instruction (Kolb, 1984). However, in the present study the correlation between learning style of the student and the method of instruction was not significant ($r = 0.16$, $p = 0.06$). Also, the learning style did not correlate significantly with any of the other independent variables.

The distribution of the four types of learners (based on Kolb's Learning Style Inventory) into the four treatment groups is given in Table 12. Group 3 contained a significantly large number of Type I learners. Also, Type III and Type IV learners were disproportionately distributed into the four treatment groups. Overall, 45 percent of the subjects were Type III learners while only 11 percent of the subjects were Type IV learners.

Research has shown that 'learning style matching' can and does have a positive impact on student achievement, interest, and/or motivation (Smith and Renzulli, 1984). In the present study, the subjects in the treatment groups were not matched with respect to their learning style preferences. That may have been one reason why learning style did not emerge as a significant factor in predicting the posttest scores.

TABLE 9. Pearson Correlation Coefficients

	Pre	Post	Age	Sex	Year	GPA	Work	Seq
Pre	1.00	.41***	.02	.14	.10	.18*	-.18*	-.06
Post		1.00	-.04	.25**	.11	.19*	-.25**	-.35***
Age			1.00	-.13	.31**	.47***	.04	-.13
Sex				1.00	-.10	-.09	-.14	.15
Year					1.00	.19*	.04	.03
GPA						1.00	.06	-.12
Work							1.00	-.01
Seq								1.00

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 10. Stepwise Regression Analysis on Posttest Scores

Steps	Variables in the equation	R^2	F-value	p
1	Pretest	.12	12.27	.0007***
2	Pretest Sequence	.21	11.55	.0000***
3	Pretest Sequence Gender	.27	10.46	.0000***

***$p < 0.001$.

TABLE 11. Distribution of Females and Males by Treatment Groups

Group	Treatment	Females	Males
1	Lab - Reading	16	8
2	Sim - Reading	17	7
3	Reading - Lab	14	10
4	Reading - Sim	16	8

TABLE 12. Distribution of Types of Learners by Treatment Groups

Group	Treatment	Type I	Type II	Type III	Type IV
1	Lab - Reading	3	6	10	5
2	Sim - Reading	3	5	15	1
3	Reading - Lab	9	6	8	1
4	Reading - Sim	2	8	10	4

Statistical Control Using ANCOVA

Multiple regression analysis showed that the posttest score was significantly related to other factors besides the treatment variables. Hence, it was necessary to do an analysis of covariance (ANCOVA) that controls for other differences that may exist in the samples being compared. This statistical technique was used to control for initial differences among groups. After the effect of the control variables has been removed, if the groups still differ on the criterion variable, then this difference cannot be attributed to the control variables. Analysis of covariance procedure was used in this study because it was not possible to select comparison groups that were matched with respect to all relevant variables.

The covariates (Pretest, Gender, Work, GPA, LSIX, and LSIY) used in this procedure were not likely to be affected by other independent variables. LSIX and LSIY represent the scores on the x-axis and y-axis of the Kolb's Learning Style Type Grid. When analysis of covariance was conducted it was found that the sequence of instruction still emerged as a very significant factor ($F = 9.39$, $p < 0.01$). There was no significant difference between the two methods of instruction ($F = .42$, $p > 0.05$). The results of the analysis of covariance procedure are given in Table 13.

TABLE 13. Analysis of Covariance on Posttest Scores

Source of Variation	df	Mean Square	F-value	p
Covariates				
Pretest	1	56.22	7.30	.008**
Gender	1	31.65	4.11	.046*
Work	1	29.26	3.80	.055
GPA	1	27.83	3.61	.061
LSIX	1	4.32	.56	.456
LSIY	1	1.33	.17	.678
Main Effects				
Sequence	1	72.30	9.39	.003**
Method	1	3.21	.42	.520
Interaction				
Sequence x Method	1	1.82	.24	.628
Residual	81	7.69		

*$p < 0.05$, **$p < 0.01$.

Discussion of the Findings

In this section are discussed the implications of the findings. The posttest score was used to measure the effectiveness of different treatments. It was found that the sequence of instruction was an important factor in teaching logic circuits. The students who did the activity (laboratory or computer simulation) first, followed by the reading assignment, scored significantly higher on the posttest as compared to those who received identical instruction in the opposite sequence. No significant difference was found between the two methods of instruction: laboratory or computer simulation.

Sequencing of Instruction

The participants were instructed that the objective of laboratory or simulation activity was to explore the operation of logic gates. When these activities occurred prior to the reading assignment, they could be classified as 'experiencing' based on the taxonomy developed by Thomas and Boysen (1984). According to Thomas and Hooper (1989), experiencing activities precede the formal presentation of the material to be learned. They provide an opportunity for the student to manipulate a given situation in order to gain an intuitive understanding of the concepts in the to-be-learned material. Thus, experiencing activities set the cognitive or affective stage for future learning.

Based on the above discussion (Thomas & Hooper, 1989), the effect on the students of the laboratory or simulation activity used in the 'experiencing' mode may have been to:

1. provide motivation,
2. alert them to the overall nature of the process,
3. provide an organizing structure,
4. serve as a concrete example, or
5. expose areas of knowledge deficiency.

Students who did the laboratory procedure prior to reading, observed that only certain input combinations produce a nonzero output. They also may have observed that these input combinations that result in a nonzero output are different for different logic gates. This probably aroused their curiosity regarding the working of logic gates. They may have understood some general concepts:

- not all input combinations result in a nonzero output, and
- input combinations that result in a nonzero output are different for different logic gates.

When these students read the booklet, they could relate the material with already existing ideas about the working of logic gates. Since they could understand what they were reading and relate it to prior experience, they were more interested in the material. Also, while doing the activity, they had some questions which were later answered by the material in the booklet. In essence, they read the booklet more attentively and gained better understanding of the subject matter. Thus they did better on the posttest than the students who received the same treatment in the opposite sequence.

The computer simulation program that was used in this study, employed a 'discovery' approach where the learner was required to figure-out the generality by studying a prototypical example. The program did provide hints and prompts to assist the learner with the discovery process. The primary element of the 'Practice' option was divergent practice with applications of the concepts involved in logic gates. In the 'Play' option, the program presented new items that included the full range of difficulty and divergence.

The program exposed the student to general concepts involved in logic circuits. The students may have observed that:

- when the word 'AND' connects two or more conditions, the consequence will be true if and only if all the conditions are true,
- when the word 'OR' connects two or more conditions, the consequence will be true if either one or all conditions are true, and

- when the word 'XOR' connects two conditions, the consequence will be true only when either one of the conditions is true.

Students who did the simulation first, had some idea about the technical meaning of AND, OR, and XOR words. When these students read the booklet, they understood how these general concepts applied to logic circuits. This sequence helped the students to better understand the material. Hence, they obtained higher scores on the posttest as compared to the students who did the same activities in the reverse sequence.

Students who read the booklet first, had no exposure to logic gates and were probably overwhelmed with numerous facts. They tended to memorize the material while reading because they probably could not relate it to any prior experience. When these students later did the laboratory procedure or the computer simulation, it only served to reinforce their knowledge. However, some questions that were raised in their mind while they were reading were probably left unanswered during the laboratory or simulation activity. These activities gave the students an opportunity to apply what they had learned in the booklet. However, the laboratory or simulation activity did not really serve as an integrator but only as a reinforcer. Thus, there was significantly less meaningful learning as compared to the students who read the booklet after doing the activity.

This discussion supports the learning theories proposed by Wittrock, Bruner, Ausubel, and Mayer. Several of Bruner's writings (1966) describe the operation and the importance of discovery learning. He has been one of the most outspoken advocates for the development of discovery strategies designed to facilitate transfer. According to Wittrock (1966), a majority of discovery strategies have employed inductive sequencing procedures. Primary elements of these inductive sequencing methods have included questioning, experiential exploration, reflection, or evaluation. A main goal of discovery strategies has been the development of problem-solving skills. The student is required to put the bits of information that he "discovers", together for himself.

According to Gagne (1987), proponents of discovery learning have believed that such strategies instill greater degrees of autonomy and intuition in the learner. They increase the student's ability to integrate information. By providing opportunities for students to apply this integrated information to new problem-solving situations, discovery strategies have claimed better transfer results.

When items on the posttest were analyzed and classified into two categories: (1) knowledge, and (2) transfer, it was found that students in both sequential groups had done well on the 'knowledge' type of items. These items pertained to logic symbols and truth tables for different logic gates. However, items that involved 'transfer' (applications of logic gates in real life situations, synthesis or analysis of the concepts) produced different results. Students who did the laboratory or simulation prior to reading did significantly better on these 'transfer' items as compared to the students who received identical material in the opposite sequence. Thus, items that involved 'transfer' contributed to the difference between the two groups. This finding is in agreement with the views expressed by proponents of discovery learning.

Ausubel's (1968) theory emphasizes the interactive-constructive nature of the learning process rather than the process of remembering. He introduces an important distinction between two types of learning processes involving either assimilation of new information to a meaningful structure of existing experiences (meaningful learning set) or to a much narrower set (rote learning set). According to this view, a meaningful learning set requires the fulfillment of three conditions:

1. reception of the to-be-learned material,
2. availability of a meaningful structure of familiar ideas that can be used to organize and assimilate new incoming material, and

3. activation of this meaningful set during learning.

According to Ausubel (1968), advance organizers when used in appropriate situations will result in better conceptual learning and hence better transfer.

Mayer's (1977) assimilation theory proposes that advance organizers have an effect only when the subjects would not have otherwise had prior knowledge subsumers available during learning. Thus, the best test of advance organizers occurs when material is unfamiliar, technical, or otherwise difficult for the learner to relate to his or her existing knowledge. However, advance organizers are not very effective when subjects are familiar with the general concepts involved in the to-be-learned material (Mayer, 1979).

Since the participants in this study had no background in logic circuits, they benefited significantly from the laboratory or simulation activities that set the stage for subsequent learning. It must be noted that the results may have been different if the participants had some prior knowledge of the concepts involved in logic circuits.

Method of Instruction

No significant difference was found between the two methods of instruction. It will be appropriate here to analyze the characteristics of these two methods: laboratory and computer simulation activities. Laboratory activity is considered more concrete as compared to computer simulation which is more abstract in nature. However, the laboratory activity also had an abstract component: students were not given any information regarding the outcome of each procedure but were instructed to observe and analyze the outcomes. Thus, both laboratory and simulation activities were at a higher level of abstraction.

The objective of both activities as described in the instructions to the students, was to explore the operation of logic gates. In other words, both activities were exploratory in nature. Both laboratory and simulation activities provided a means of generating the logical relationships among the elements in the reading assignment. Based on the above discussion, it can be concluded that although there was some variation in the nature of laboratory and simulation activities, their overall effect on the students' thinking process was very similar.

In order to gain greater insight into the students' thinking process, the posttest items were analyzed individually. A significant difference was found on item eleven. This item involved the application of an Exclusive-OR logic gate to a real life situation. Out of forty-eight students who did the computer simulation activity, twenty-nine students answered the item correctly. But out of the forty-eight students who did the laboratory activity, only eighteen students answered the item correctly. This item involved far-transfer: application of knowledge to previously unencountered, totally new situation.

In the laboratory activity, the students arrived at an outcome and then thought about why the outcome occurred. This involved a post hoc logical reasoning process. In the simulation program, students had to do a priori logical reasoning in order to arrive at a solution to the given situation. This required the student to do more vigorous investigative thinking. In addition, these students had to use post hoc reasoning to understand why the answer was right or wrong. Thus, the extent of thinking done by the students who did the simulation activity may have been greater as compared to the students who did the laboratory activity. This may have been one reason for the superior performance of the simulation group on the far-transfer item as compared to the laboratory group.

However, as mentioned before, when all the items on the posttest were considered, computer simulation was not found to be more effective than the laboratory experience. One reason could be that the posttest comprised of: knowledge, near-transfer, and far-transfer items. According to Thomas and Hooper (1989), the positive effects of computer simulations are not detected by tests of knowledge but by tests of transfer. Another reason could be that the simulation program had very limited user or system control:

- the level of complexity of the simulation could not be controlled for each learner,
- learner's progress from one level to the next did not ensure that mastery was achieved at the previous level, and
- the level of 'Help' available to the learners was not controlled.

These factors may have contributed to the limited effectiveness of the computer simulation technique, in teaching logic circuits.

In summary, though the computer simulation and the laboratory activity had different characteristics, both methods were found to be equally effective in teaching logic circuits. However, these activities were significantly more effective when they occurred prior to a reading assignment as compared to the opposite sequence.

CHAPTER V. SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

This chapter provides an overview of the research study. It has been classified into three major sections. The first section gives a summary and presents conclusions based on the findings of the study. The second section discusses the theoretical and practical implications of the findings of the study in relation with other research studies conducted in this field. The third section makes recommendations for future research regarding sequencing of instruction and effective use of computer simulation and laboratory activities.

Summary

In this section are described the objectives, methodology and findings of the study.

Objectives

Very few studies have attempted to investigate the effectiveness of computer simulation versus laboratory experience, and the sequencing of instruction, in teaching logic circuits. The purpose of this study was fourfold. The first was to examine the computer as an instructional tool integrated into, rather than apart from classroom activities. The second was to assist the Industrial

Technology profession in identifying whether computer-based simulation or laboratory experience helps students better understand the underlying concepts of logic circuits. The third was to evaluate the effectiveness of sequencing computer simulation or laboratory activities prior to or after a reading assignment, in teaching logic circuits. The fourth was to provide developers of computer-based instructional materials with information which would be useful in the design of computer-based lessons.

This study attempted to compare two methods of instruction. Dewey's (1938) problem-solving theory outlines the importance of experiential activities. Laboratory procedures represent the traditional type of instruction that involve "hands-on" experience. Computer-based simulation is an effective way of applying technology to learning. The cognitive learning theory stresses the importance of computer simulations that improve problem-solving skills. In addition to method of instruction, this study focused on sequencing of instruction. The learning theories developed by Wittrock (1966), Bruner (1966), Ausubel (1968), Mayer (1977), Papert (1980) and others formed the basis for this investigation. The objective was to compare achievement of subjects who did the experiential activities prior to formal instruction with subjects who received identical material in the opposite sequence.

The three research questions of this study are mentioned below:

1. Will there be a significant difference in achievement on a test of application of logic circuits between students using the computer simulation program and students doing the laboratory procedures?

2. Will there be a significant difference in achievement on a test of application of logic circuits between students who receive a reading assignment following the laboratory or simulation experience and students who receive identical material in the reverse sequence?

3. Will there be a significant interaction between sequencing of instruction and method of instruction in teaching of logic circuits?

Methodology

The two independent variables in this study were: (1) method of instruction, a nominal variable with two categories (computer-based simulation and laboratory experience); and (2) sequencing of instruction, a nominal variable with two categories (reading following lab or simulation experience and reading prior to lab or simulation experience). The dependent variable was the posttest score.

The computer simulation program used in this study was called HIGH WIRE LOGIC and was developed by Sunburst

Corporation. In this program, students are challenged to write as many logic rules as they can, that fit the shapes on the wire, but do not fit the shapes in the net. The rules must be based on the logic types: AND, OR, AND-OR, AND-AND, OR-OR, and XOR. Thus, this program deals with the applications and general concepts involved in logic gates. The students did this activity for fifty minutes.

Laboratory activity was the alternate experimental treatment. As part of this activity, students were instructed to work at each of the four experiment stations. The students manipulated the input configurations of already built AND, OR, NOT and Exclusive-OR logic gates. However, the participants were not informed about the type of logic gate they were working with. Step-wise instruction sheets were provided at each station. The objective of each activity was to explore the operation of that particular logic gate. The participants were urged to think about what they had observed in the process. The participants took fifty minutes to complete this activity.

The reading assignment was common to all participants. This booklet consisted of nineteen pages. The booklet elaborated on the following concepts: Digital levels, AND, OR, NOT, Exclusive-OR, NAND, and NOR logic gates, and combination logic. The description for each logic gate included a conversational example, logic symbol, truth table, and boolean operator. The participants were required to read the booklet for forty minutes.

The study was conducted using a 2 X 2 factorial design. It is a modified form of the pretest posttest control group design. In this design, two variations of one factor (A_1 and A_2) and two variations of another factor (B_1 and B_2) are manipulated at the same time. Ninety-six subjects participated in this study. There were twenty-four subjects in each of the four groups.

The subjects were randomly assigned to one of the four experimental treatments. Random assignment of subjects eliminated selection bias in group composition, but did not ensure initial equivalence among groups. A pretest was administered to all subjects prior to instruction. The paper and pencil pretest was helpful in assessing the subjects' prior knowledge of logic circuits. Kolb's Learning Style Inventory was also administered as part of the pretest. A posttest was administered to measure treatment effects. A description of the four treatment groups is given in Table 14.

TABLE 14. Treatment Groups

Group 1	R	Pretest	Lab	Reading	Posttest
Group 2	R	Pretest	Sim	Reading	Posttest
Group 3	R	Pretest	Reading	Lab	Posttest
Group 4	R	Pretest	Reading	Sim	Posttest

R: Random assignment

Pretest: Pretest administered

Lab: Laboratory procedure

Reading: Reading assignment

Sim: Computer-based simulation program

Posttest: Posttest administered

The data in this study were analyzed to determine the treatment effects using the analysis of variance (ANOVA) procedure which is most appropriate for this two-factor design. At first, Oneway ANOVA was conducted on pretest scores to ensure that there were no initial differences among groups. The data were also tested for the assumption of homogeneity of variance using Bartlett's test. The results of the ANOVA procedure are presented in the next section.

Though treatment effects were analyzed, no information was obtained regarding the relationship between posttest score and other independent variables. The objective of Regression analysis was to determine the correlation between the criterion variable and some combination of two or more predictor variables. In other words, the regression analysis procedure was used for exploratory purposes. The posttest score was significantly related to other factors besides the treatment variables. Hence, analysis of covariance procedure was used to control for initial differences among groups. Pretest and student demographics that correlated significantly with the posttest score were entered as the covariates in this procedure. The results are presented in the next section.

Findings

The analysis of variance procedure was used to determine the effects of the treatments. It was found that the sequence of instruction was an important factor in teaching logic circuits. The students who did the activity (laboratory or computer simulation) first, followed by the reading assignment, scored significantly higher on the posttest as compared to those who received identical instruction in the opposite sequence. No significant difference was found between the two methods of instruction:

laboratory, and computer simulation. Also, there was no significant interaction between method of instruction and sequence of instruction.

Results from regression analysis showed that the posttest score correlated highly with the pretest score, gender, number of hours the participants worked per week, and student grade point average. It was found that males did significantly better on the posttest as compared to the females. It should be noted that the distribution of males and females in the four treatment groups was not significantly different. The variables that entered the regression equation were: pretest, sequence of instruction, and gender. Approximately twenty-seven percent of the variance in the posttest score was attributable to the variance of the combined predictor variables.

Analysis of covariance was used to gain statistical control. In this procedure, the variables: Pretest, Gender, Work Hours, GPA, LSIX, and LSIY, were used as the covariates. LSIX and LSIY represent the scores on the two dimensions of the Kolb's Learning Style Type Grid. It was found that the sequence of instruction still emerged as a very significant factor. There was no significant difference between the two methods of instruction.

Implications

The traditional sequence of instruction for teaching logic circuits has been: formal presentation of material followed by experiential activities. However, based on the findings of the present study, it can be concluded that advance exposure to experiential activities aided in the learning of unfamiliar, technical-problem-solving material, and resulted in significantly better posttest performance.

In order to better understand the effects of sequencing of instruction on the students' cognitive process, the posttest items were analyzed and classified into two categories: (1) knowledge, and (2) transfer. It was found that both sequential groups did well on the 'knowledge' type of items. However, items that involved 'transfer' contributed to the difference between the two groups. These 'transfer' items dealt with the applications of logic gates in real life situations, or synthesis or analysis of concepts.

Hence, it can be concluded that if the objective of instruction is for students to learn the facts without their application or transfer, then the sequence of instruction is not a significant factor. But if the educational goal is for students to be able to apply and transfer the knowledge, then the experiential activities should occur prior to the formal presentation of the material. Also, these activities should be exploratory in nature, designed to stimulate the students' thinking process.

This conclusion is in agreement with the learning theories proposed by Wittrock (1966), Bruner (1966), Ausubel (1968), Mayer (1977), Papert (1980), and others. These educators employ a cognitive approach in the planning of instructional strategies. Themes repeatedly discussed in their writings have included:

1. the role of cognitive structures in learning,
2. learner readiness in terms of prior knowledge, and
3. the desire to learn and how it may be stimulated.

Instructional strategies proposed by each of these educators are based upon the premise that existing cognitive structures play an important role in meaningful learning and transfer. Furthermore, these researchers have stressed the need for experiential activities early in the sequence of instructional events. Such instructional strategies fall under the 'inductive sequencing' category (Kolb, 1985).

According to Gagne (1987), proponents of inductive sequencing have reported that discovery strategies have been found to:

- promote better transfer, and
- be more effective as the difficulty of the transfer task increases.

Regarding method of instruction, there was no significant difference between computer simulation and laboratory activities. In order to gain greater insight into the effect of these activities on the thinking process of the students, the posttest items were analyzed individually. A significant difference was found on item eleven of the posttest. This item dealt with the application of an Exclusive-OR gate to a previously unencountered, totally new situation. It was found that sixty percent of the students who used the computer simulation program were able to answer the item correctly, whereas only thirty-seven percent of the students who did the laboratory activity answered the item correctly. One reason could be that the extent of thinking and logical reasoning done by the students who used the simulation program was greater than that done by the students who did the laboratory procedure. Thus, it can be concluded that computer simulation programs have a positive effect on the higher-order thinking skills utilized by the students. This result points out the large amount of information still to be uncovered in the effective use of computer simulations and laboratory activities.

Recommendations for Future Research

The following recommendations are based upon the findings of this study and the experiences gained from conducting this experiment.

The educational and professional goals of the students participating in research studies may influence the results. The approach to logic circuits of an Industrial Technology student is different from a student in Education. Future research studies need to be sensitive to the perceptions which students have toward logic circuits.

The use of student demographics other than the ones used in this study merit investigation, e.g., student ability. Learning style is only one of several dimensions of cognitive style. It was chosen as an independent variable for this study because of its prominence in literature dealing with the method of instruction. It failed to produce a significant effect on the posttest scores. Instruments designed to measure a student's ability or inductive/deductive aptitudes may provide more information about the student's cognitive style in relation with sequencing of instruction. It is, therefore, recommended that a student ability measurement be used in addition to Kolb's Learning Style Inventory if this study is replicated.

The use of student elaboration techniques may provide additional insights into the student's thinking. Student elaboration techniques could range from informal chats, to formal interviews, to written summaries. By individually asking the students what they did and why they did those particular things during the activities, may provide invaluable information regarding the student's mental activity. However, there are several disadvantages of using student elaboration techniques: (a) the elaboration itself may have an effect on subsequent learning, (b) novice students may not have the means to articulate these behaviors, and (c) the implementation of elaboration techniques would not be trivial.

Future research studies need to investigate the mental models or schemata which students employ for understanding the concepts involved in logic circuits. The posttest should be designed to identify the differences in the mental models utilized by students in different treatment groups. Such a study would be able to provide information regarding the cognitive structure utilized by the student in understanding logic circuits.

It is also recommended that research studies be designed to investigate the effectiveness of computer simulations for improving higher-order thinking skills. The tests should comprise of items that involve transfer rather than knowledge. Also, future research needs to establish specific criteria to classify the items into "knowledge" or "transfer" categories. There is a possibility that in the present study the pretest may have alerted the learner to the instruction that was to follow. Future research should be done to investigate the effectiveness of the same treatments with and without administering the pretest.

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Most of all, I am thankful to my husband, Ashok, for his faith in my abilities, and immense help and patience during the completion of my studies. I am indebted to my mother, Alaka, for her love and sacrifice. A warm thank you to all my family members for their encouragement and moral support. Gratitude is extended to my school teachers and my professors at the University of Bombay, India, for preparing me to meet the challenges of higher education. A sincere thank you to Drs. Jack Kossler and Roy Champion, at the College of William and Mary, where I received a master's degree in Physics.

Finally, I cannot thank God enough for making this dissertation a reality.

APPENDIX A: HUMAN SUBJECTS COMMITTEE APPROVAL

INFORMATION ON THE USE OF HUMAN SUBJECTS IN RESEARCH
IOWA STATE UNIVERSITY
(Please follow the accompanying instructions for completing this form.)

Title of project (please type): To investigate the effects of different types of instruction (computer simulation vs. lab experiences) in teaching logic circuits.

I agree to provide the proper surveillance of this project to insure that the rights and welfare of the human subjects are properly protected. Additions to or changes in procedures affecting the subjects after the project has been approved will be submitted to the committee for review.

ANU A. GOKHALE	4-24-89	Anu A Gokhale
Typed Named of Principal Investigator	Date	Signature of Principal Investigator
101AA I.ED.II	4-8528	
Campus Address	Campus Telephone	

Signatures of others (if any).	Date	Relationship to Principal Investigator
DR. WILLIAM D. WOLANSKY	4-24-89	Major Professor
William Wolansky	5-11-89	

ATTACH an additional page(s) (A) describing your proposed research and (B) the subjects to be used, (C) indicating any risks or discomforts to the subjects, and (D) covering any topics checked below. CHECK all boxes applicable.

RECEIVED MAY 12 '89 ISU GRADUATE COLLEGE

- [ ] Medical clearance necessary before subjects can participate
- [ ] Samples (blood, tissue, etc.) from subjects
- [ ] Administration of substances (foods, drugs, etc.) to subjects
- [ ] Physical exercise or conditioning for subjects
- [ ] Deception of subjects
- [ ] Subjects under 14 years of age and(or) [ ] Subjects 14-17 years of age
- [ ] Subjects in institutions
- [ ] Research must be approved by another institution or agency

ATTACH an example of the material to be used to obtain informed consent and CHECK which type will be used.

- [ ] Signed informed consent will be obtained.
- [XX] Modified informed consent will be obtained.

	Month	Day	Year
Anticipated date on which subjects will be first contacted:	6	19	89
Anticipated date for last contact with subjects:	7	30	89

If Applicable: Anticipated date on which audio or visual tapes will be erased and(or) identifiers will be removed from completed survey instruments: 8 (Month) 21 (Day) 89 (Year)

Signature of Head or Chairperson	Date	Department or Administrative Unit
DR. TREVOR G. HOWE Trevor G. Howe	4-24-89	Industrial Education and Technology

Decision of the University Committee on the Use of Human Subjects in Research:

- [X] Project Approved
- [ ] Project not approved
- [ ] No action required

Patricia M. Keith	5-22-89	PMKeith
Name of Committee Chairperson	Date	Signature of Committee Chairperson

APPENDIX B: PRETEST

PRETEST

NOTE: All information provided on this test will be kept in strict confidence and will have no bearing in determining your course grade. To protect your anonymity, DO NOT PUT YOUR NAME ON THE TEST. Your participation is of course voluntary. However, by participating in this study you will help in the continuing process of creating more effective teaching and learning methods for students. Your responses will remain confidential. The identification number which is the second item on the test will be used to link your pretest and posttest scores. But no one involved with the research including me knows who you are.

1. Group Number: ____________________

2. Identification Number: ____________________
   (Last four digits of your social security number)

3. Age: ____________________

4. Sex: ____________________

5. Year in college: ____________________

6. Major: ____________________

7. College GPA: ____________________

8. How many hours per week are you employed? ____________
   (Also include volunteer work)

9. Have you had any formal education in logic circuits or boolean algebra or digital electronics in high school? (please circle one):

   YES NO

10. Have you had any formal education in logic circuits or boolean algebra or digital electronics in college? (please circle one):

    YES NO

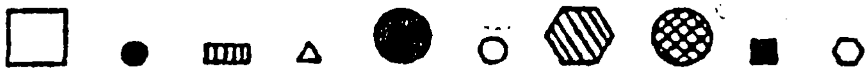
11. What experience have you had with logic gates? (List any course-related or job-related activities)

RULES

CIRCLE ALL THE CORRECT EXAMPLES THAT SATISFY THE RULE

1. large <u>and</u> black

2. round <u>and</u> small



3. round <u>and</u> small <u>and</u> black

4. large <u>or</u> white <u>or</u> triangle

5. square <u>or</u> triangle

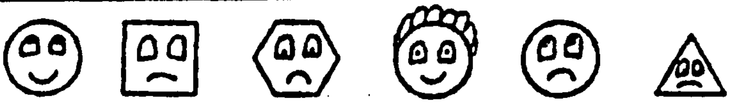
6. looking up <u>and</u> hair

7. looking up <u>or</u> a smile

8. small <u>and</u> square <u>or</u> black

9. round <u>and</u> black <u>or</u> small

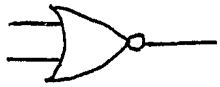
10. smile <u>and</u> round <u>or</u> frown

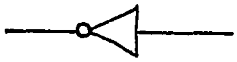


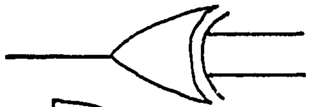
11. large <u>XOR</u> square

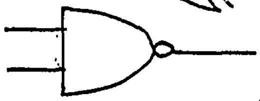
12. small <u>XOR</u> triangle

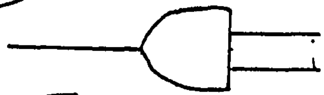
13. Match the following:

_______ NAND gate A. 

_______ OR gate B. 

_______ NOT gate C. 

_______ NOR gate D. 

_______ AND gate E. 

_______ Exclusive-OR gate F. 

14. The output of an OR gate is binary 0 when:

    a. all inputs are binary 0
    b. any one or more inputs are binary 0
    c. all inputs are binary 1
    d. any one or all inputs are binary 1

15. The logic AND function when expressed in algebraic terms is analogous to the:

    a. product
    b. sum
    c. difference
    d. quotient

16. If the input to an inverter is logic 0, then its output is:

    a. logic 0
    b. logic 1
    c. cannot be determined from information given

17. The output of an Exclusive-OR gate is binary 1 when:

    a. both inputs are binary 0
    b. both inputs are binary 1
    c. one input is binary 0 and the other is binary 1

PLEASE NOTE:

Copyrighted materials in this document have not been filmed at the request of the author. They are available for consultation, however, in the author's university library.

These consist of pages:

141

U·M·I

APPENDIX C: COMPUTER AND LAB INSTRUCTIONS

OBJECTIVE

The objective of this activity is to explore the use of different logic functions.

Follow the directions given in the program very carefully.

TURNING ON THE COMPUTER

(1) Turn on the television/monitor.

(2) Insert the diskette into the disk drive with the label facing up and on the right.

(3) Close the door to the disk drive.

(4) Turn on the Apple II. (The on-off switch is on the back left side of the computer.)

(5) You will see a red light on the disk drive turn on. If the disk drive light does not turn off after about 10 seconds, turn the Apple off and make sure your diskette is placed correctly in the disk drive.

(6) SUNBURST will appear on the screen.

(7) Follow directions given in the program

TURNING OFF THE COMPUTER

(1) Remove the diskette from the disk drive and return it to its place of storage.

(2) Turn off the Apple.

(3) Turn off the television/monitor.

OBJECTIVE

The objective of this activity is to learn the operation of this logic gate.

PLEASE FOLLOW THIS PROCEDURE

1. Switch ON the POWER (bottom right of the board).
2. The CLOCK is located on the bottom left of the board. The switch marked RUN is in the "OFF" position.
3. Now turn RUN "ON" and observe what happens.
4. Rotate the RATE switch of the clock from 'slow' on the left to 'fast' on the right and observe what happens.
5. Now turn RUN "OFF".
6. Flip the switch S1 in the other position.
7. Repeat steps 3 through 6.
8. Think about what you have learned regarding the working of this logic gate.

OBJECTIVE

The objective of this activity is to learn the operation of this logic gate.

PLEASE FOLLOW THIS PROCEDURE

1. Switch ON the POWER (bottom right of the board).
2. The CLOCK is located on the bottom left of the board.
   The switch marked RUN is in the "OFF" position.
3. Now turn RUN "ON" and observe what happens.
4. Rotate the RATE switch of the clock from 'slow' on the left to 'fast' on the right and observe what happens.
5. Now turn RUN "OFF".
6. Flip the switch S1 in the other position.
7. Repeat steps 3 through 6.
8. Flip the switch S2 in the other position.
9. Repeat steps 3 through 6.
10. Repeat steps 3 through 5.
11. Think about what you have learned regarding the working of this logic gate.

OBJECTIVE

The objective of this activity is to learn the operation of this logic gate.

PLEASE FOLLOW THIS PROCEDURE

1. Switch ON the POWER (bottom right of the board).
2. The CLOCK is located on the bottom left of the board. The switch marked RUN is in the "OFF" position.
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6. Flip the switch S1 in the other position.
7. Repeat steps 3 through 6.
8. Flip the switch S2 in the other position.
9. Repeat steps 3 through 6.
10. Repeat steps 3 through 5.
11. Think about what you have learned regarding the working of this logic gate.

APPENDIX D: READING ASSIGNMENT

READING ASSIGNMENT

NOTE:

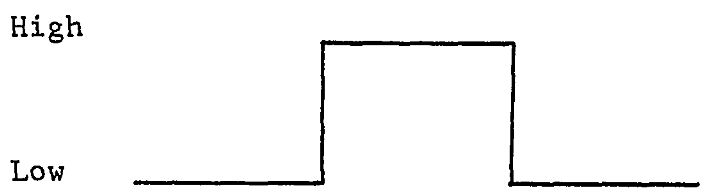
One of your tasks in this experiment is to read and study this section. Please study the booklet CAREFULLY, because you are going to take a test on it. By trying to learn the material as well as you can, to the best of your ability, you will help us to fairly and accurately evaluate the effectiveness of these materials. You must read and study the booklet individually. You may turn back and reread sections if you wish.

You will need approximately forty minutes to read the booklet. When you are done with the booklet, please bring it to the proctor at the front.

INTRODUCTION TO LOGIC GATES

Review of Digital Levels

A digital signal will be either a 'logic 1' or a 'logic 0'. In most systems a 'logic 1' will refer to the higher voltage whereas a 'logic 0' will refer to the lower voltage. A square wave is a perfect example of a digital signal; at any instant in time, it is either high or low.



By convention, a logic 0 is associated with a false condition and a logic 1 is associated with a true condition:

Logic 0	Logic 1
0 V	5 V
False	True

The Logic Gate

The term "logic" is a common word in conversational English. Have you ever considered the formal definition of "logic"? Logic means the study of reason.

"logs" - words, reason
"ic" - relating to, the study of
"logic" - the study of reason

The Greek philosophers developed many simple laws of logic that were applied to the study of natural phenomena. In the nineteenth century, George Boole developed a branch of mathematics especially designed to handle these logical arguments. This math, called Boolean algebra, is an important tool used in the development of digital circuits.

"Gate" is another word in common use. In technical English, common words are often taken and given very specific definitions. In common usage, "gate" means: an opening in a wall or fence, a means of entrance or exit.

The technical definition of "gate" is a natural extension of its common form:

a device that outputs a signal when specified input conditions are met.

We now know that a logic gate is:
"a digital device that performs a predetermined process".

A Structured Introduction to Logic Gates

Each type of gate will be introduced by noting the following characteristics:

1. A conversational example of how we use this logic function in everyday conversation.

2. A common schematic symbol that is used to represent the logic gate.

3. A truth table for the logic gate. A truth table contains all the possible combinations of input values and the output value that corresponds to each input combination. Because digital signals are either low or high, the total number of input combinations possible for any gate will be equal to
   number of unique input combinations = 2^n, where n is the number of inputs.
   For example: a two-input gate will have $2^2 = 4$ unique input combinations. Similarly, a three-input gate will have $2^3 = 8$ unique input combintions.

4. The Boolean operator which is an arithmetic function that describes the logic function.

The "AND" gate

1. Conversational Example

We often use sentences that fit into the following form:

If <condition 1 is true> AND <condition 2 is true>, THEN <consequence is true>.

For example:

1. If my car is running AND I get the day off, THEN I'll go to the beach.

Notice that both conditions must be true before the day at the beach will become a reality. We could easily add further conditions to the above statement.

For example:

1. If my car is running AND I get the day off AND I have some money THEN I'll go to the beach.

Remember that in a sentence that uses the word AND to connect two or more conditions, the consequence of the sentence will be true (or logic 1), if and only if all the conditions stated in the sentence are true. Thus, the consequence will be false (or logic 0), when either one or all conditions are false.

2. Logic Symbol

Logic symbols for 2-input and 3-input AND gates are given below:

3. Truth Table of a 2-input AND gate

Inputs		Output
A	B	
0	0	0
0	1	0
1	0	0
1	1	1

If input A is high AND input B is high, then the output will be high; otherwise, the output will be low.

4. Boolean Opeartor

Examine the AND truth table closely. Is there a common arithmetic function that describes this truth table closely? Yes, there is: simple multiplication. For that reason the logic AND function is represented by the multiplication symbol - a dot (.).

$$0 . 0 = 0$$

$$0 . 1 = 0$$

$$1 . 0 = 0$$

$$1 . 1 = 1$$

NOTE: As is common in algebraic equations, the dot representing the Boolean algebra AND function is optional and most often is not used. If two Boolean algebra variables are adjacent with no separating operation symbol, you should assume that the two variables are being ANDed together.

The "OR" gate

1. Conversational Example

The other common connector that we use in compound sentences is the term OR. The following statement shows the typical structure of an OR sentence.

If <condition 1 is true> OR <condition 2 is true>, THEN <consequence will be true>.

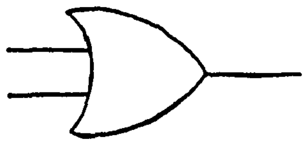
For example:

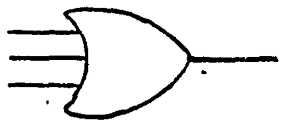
1. If I get a raise OR the bank gives me a loan,
   THEN I can buy a new car.

If either or both conditions are true, the consequence will be true. This type of OR is called an inclusive OR, because it includes the case when both statements are true. Thus, the consequence will be false (or logic 0) if and only if all conditions are false. An exclusive OR does not include the case when both conditions are true. We shall study the exclusive-OR gate later.

2. Logic Symbol

Logic symbols for 2-input and 3-input OR gates are given below:





3. Truth Table of a 2-input OR gate

Inputs		Output
A	B	
0	0	0
0	1	1
1	0	1
1	1	1

If input A is high OR input B is high, then the output will be high; otherwise, the output will be low.

4. Boolean Operator

Now examine the OR truth table. The simple math function that best describes logical OR is addition. The plus sign (+) is used to symbolize the logical OR function.

$$0 + 0 = 0$$

$$0 + 1 = 1$$

$$1 + 0 = 1$$

$$1 + 1 = 1$$

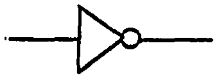
The "NOT" gate

The NOT logic function is simple. It inputs a logic level, and outputs the logic level that the input is not. If the input for the NOT function is logic 0, the output would be a logic 1, the logic value that the input is not. On the other hand, if the input for a NOT function is a logic 1, the output would be a logic 0. The NOT gate is also referrred to as an INVERTER.

Thus, you can see that the NOT gate has only one input.

2. Logic Symbol

The logic symbol of a NOT gate is given below:



3. Truth Table of a NOT gate

Input	Output
0	1
1	0

If the input is high, then the output will be low. If the input is low, then the output will be high.

4. Boolean Operator

The NOT function is indicated with a bar ($\bar{}$). This bar symbolizes inversion. Also, a bubble (O) implies inversion.

$$\overline{0} = 1$$
$$\overline{1} = 0$$

The "exclusive-OR" gate (XOR)

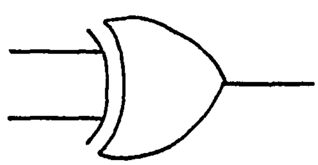
The OR function that we studied before is true if: A is true OR B is true OR both A and B are true. This is formally called an inclusive OR because it includes the case where both A and B are true.

The exclusive-OR function excludes the case where both A and B are true. An exclusive-OR function, abbreviated XOR, outputs a logic 0 whenever both inputs have the same value. It outputs a logic 1 whenever both inputs have different values. Other than the inverter, which is a unary function, every gate that we have seen can be expanded to any number of inputs.

The XOR gate comes in only one form, and that has two inputs.

Logic Symbol

Logic symbol of an exclusive-OR (XOR) gate is given below:



Truth Table of a XOR gate

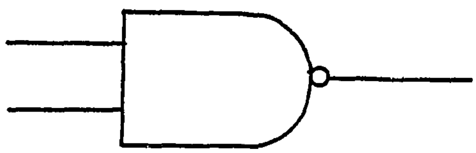
Inputs		Output
A	B	
0	0	0
0	1	1
1	0	1
1	1	0

The output is logic 1 only when the two inputs have different values. The output is logic 0 when the two inputs have same values.

The "NAND" gate

The NAND gate is in fact a combination of the NOT and AND functions. The word "NAND" stands for NOT-AND. A NAND gate can be modeled as an AND with an inverter on its output. Just like an AND gate, a NAND gate can have more than two inputs.

Logic Symbol



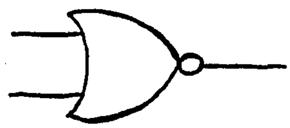
Truth Table of a 2-input AND and NAND gate

Inputs		Output	Output
A	B	(AND)	(NAND)
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

The "NOR" gate

The NOR gate is in fact a combination of the NOT and OR functions. The word "NOR" stands for NOT-OR. A NOR gate can be modeled as an OR with an inverter on its output. Just like an OR gate, a NOR gate can have more than 2 inputs.

Logic Symbol



Truth Table of a 2-input OR and NOR gate

Inputs		Output	Output
A	B	(OR)	(NOR)
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

Combination of Logic Gates

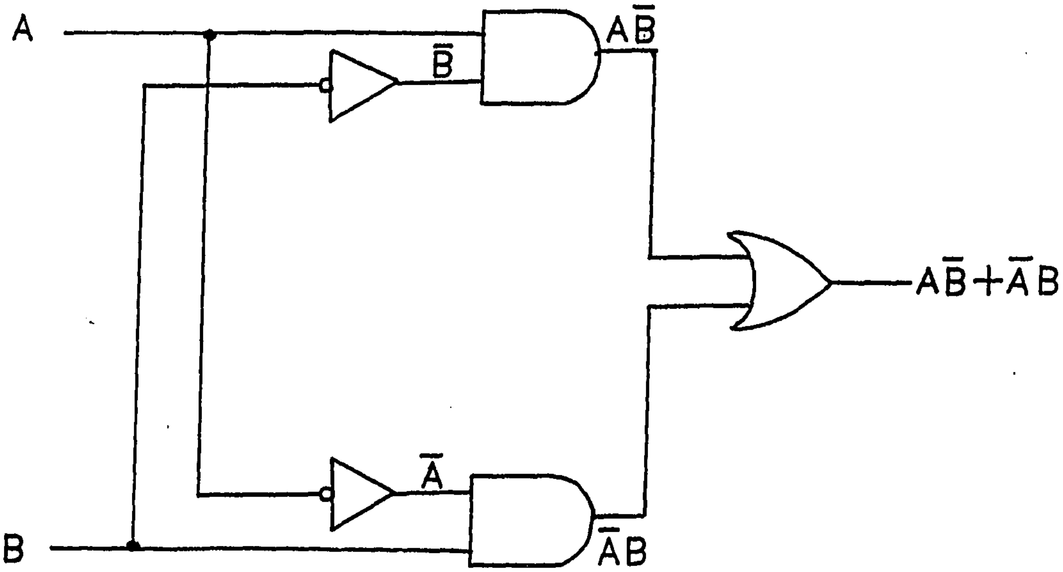
Consider the figure on the next page, which illustrates a simple circuit composed of five gates. Because this circuit has two inputs, there are four possible input combinations. To establish what output logic level should exist for each of these four input combinations, we must follow these steps:

Step 1. Construct a Boolean equation from the logic diagram.

Start at the inputs on the left side of the schematic. Follow each input or group of inputs as it is applied to the various gates. At the output of each gate write the Boolean equation that describes the action of the gate. This output equation will now be used as an input to the next gate. This process will continue until you reach the final output.

Step 2. Create a truth table

This truth table should contain the input variables, each intermediate equation, and the final equation for the output of the circuit. Fill in the truth table from left to right. Each intermediate answer will become the input value for the next equation. When the truth table is complete you will know what each logic level in the circuit should be for any set of input values.



Inputs		Intermediate values				Output
B	A	$\bar{B}$	$\bar{A}$	$A\bar{B}$	$\bar{A}B$	$A\bar{B}+\bar{A}B$
0	0	1	1	0	0	0
0	1	1	0	1	0	1
1	0	0	1	0	1	1
1	1	0	0	0	0	0

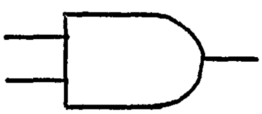
3-input Logic Gates

Only AND, OR, NAND, and NOR gates can have more than two inputs. The total number of input combinations for a three-input gate will be $2^3 = 8$. The 8 unique input combinations along with the outputs corresponding to different logic gates are given in the truth table below. Read the truth table carefully.

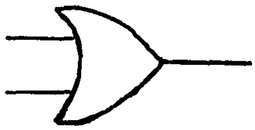
Inputs			Output			
C	B	A	AND	OR	NAND	NOR
0	0	0	0	0	1	1
0	0	1	0	1	1	0
0	1	0	0	1	1	0
0	1	1	0	1	1	0
1	0	0	0	1	1	0
1	0	1	0	1	1	0
1	1	0	0	1	1	0
1	1	1	1	1	0	0

SUMMARY

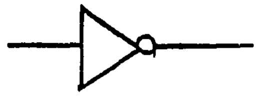
Logic symbols of different logic gates are given below:



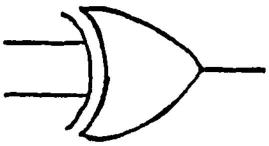
AND



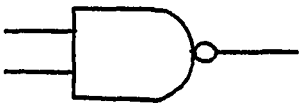
OR



NOT

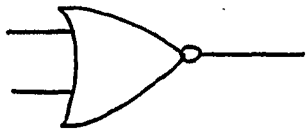


XOR



NAND

(NOT-AND)



NOR

(NOT-OR)

APPENDIX E: POSTTEST

POSTTEST

NOTE: This is a test over the material on logic circuits that you have studied. Please answer the questions to the best of your ability. All information provided on this test will be kept in strict confidence and will have no bearing in determining your course grade. To protect your anonymity, DO NOT PUT YOUR NAME ON THE TEST. The identification number which is the second item on the test will be used to link your pretest and posttest scores. But no one involved with the research including me knows who you are.

When you are done with the test please bring it to the proctor. The proctor will check to see if you have completed the test. Then the proctor will give you a card to fill out. Make sure that you fill out this card correctly, it is the only way you can receive your extra credit point for this study. Thank you for your participation!

1. Group Number: ____________________

2. Identification Number: ____________________
   (Last four digits of your social security number)

3. Age: ____________________

4. Sex: ____________________

5. Year in college: ____________________

6. Major: ____________________

7. College GPA: ____________________

8. How many hours per week are you employed? ____________
   (Also include volunteer work)

9. Have you had any formal education in logic circuits or boolean algebra or digital electronics in high school? (please circle one):

   YES NO

10. Have you had any formal education in logic circuits or boolean algebra or digital electronics in college? (please circle one):

    YES NO

11. What experience have you had with logic gates? (List any course-related or job-related activities)

1 Match the following:

______ NAND gate

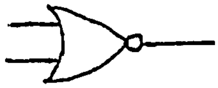
______ OR gate

______ NOT gate

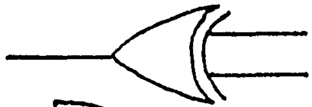
______ NOR gate

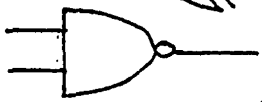
______ AND gate

______ Exclusive-OR gate

A. 

B. 

C. 

D. 

E. 

F. 

2. The output of an AND gate is binary 1 when:

a. all inputs are binary 0
b. any one or more inputs are binary 0
c. all inputs are binary 1
d. any one or all inputs are binary 1
e. none of the above

3. The logic OR function when expressed in algebraic terms is analogous to the:

a. product
b. sum
c. difference
d. quotient
e. none of the above

4. If the input to an inverter is logic 0, then its output is:

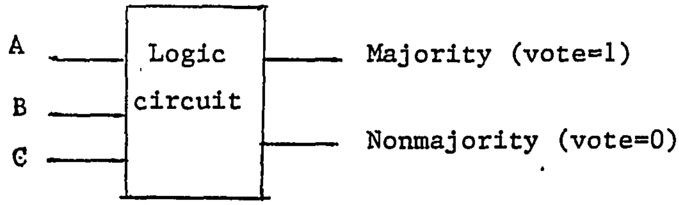
a. logic 0
b. logic 1
c. cannot be determined from information given

5. The output of an Exclusive-OR gate is binary 1 when:

a. both inputs are binary 0
b. both inputs are binary 1
c. one input is binary 0 and the other is binary 1

6. A stairway is illuminated by one light. There are 2 switches that control the light: one at the top and one at the bottom of the stairway. A person should be able to control the light from either switch. Answer which logic function can perform this task, or draw the symbol of the logic gate.

7.



The block diagram given above will analyze the votes of 3 judges and indicate whether a majority of the judges has voted in favor for the motion in question. A majority will occur whenever two or more judges vote yes on an issue. There are 3 inputs, one from each judge. There are two outputs, one to indicate a majority vote (logic 1) and another to indicate a nonmajority vote (logic 0). Complete the truth table given below:

A	B	C	VOTE
0	0	0	___
0	0	1	___
0	1	0	___
0	___	___	1
___	0	0	___
1	0	1	___
1	1	0	___
___	___	___	___

8. The Boolean equation of the wired AND circuit in Figure 5-123 is:

A. $D = \overline{A}BC + A\overline{C} + B$
B. $D = \overline{(\overline{A}BC) + (A\overline{C})} + (\overline{B})$
C. $D = \overline{(A\,\overline{C})\,(\overline{A}BC)\,\overline{B}}$
D. $D = (\overline{A\overline{\overline{C}}})\,(\overline{\overline{A}BC})\,(B)$

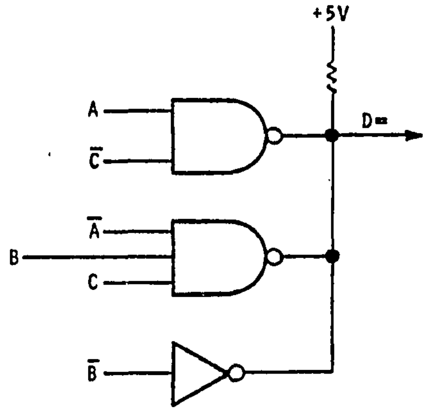
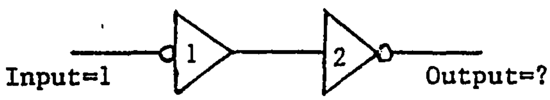


Figure 5-123

9. The output of the inverter 2, in Figure 1-1 with a input of binary 1 will be



a. binary 0
b. binary 1
c. cannot be determined with information given