1995

A computer tutorial and simulation system for teaching digital function minimization

Farn-Shing Chen
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A computer tutorial and simulation system for teaching
digital function minimization

by

Farn-Shing Chen

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Department: Industrial Education and Technology
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Signature was redacted for privacy.

In Charge of Major work

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For the Major Department

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For the Graduate Collage

Iowa State University
Ames, Iowa

1995
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CHAPTER I. INTRODUCTION

Computer-assisted instruction (CAI) is a relatively new field in which the pioneering efforts occurred around 1960, followed by the introduction of computers into higher education. A number of large-scale, heavily-funded CAI projects have been conducted since then, with the results having implications for the future use of CAI as a classroom tool.

The undergraduate curricula in electrical engineering are becoming increasingly complex due to the doubling transistor count every two to two-and-one-half years (Moore's Law). The engineering efforts required for semi-custom/custom Very Large Scale Integration (VLSI) design are growing exponentially with respect to the number of transistors per chip. Manual designs are prone to human errors, and the iterative design-silicon-modification-silicon process may result in a lengthy development period. In order to address this issue, the computer industry originated the concept and use of computer-aided design (CAD) tools. Such systems allow designs to be completed quickly, and their operation verified by simulation and timing analysis before fabrication (Shankar, Freytag & Alon, 1991).

Simulations are essential for meeting many instructional needs (Milner & Wildberger, 1974). They focus on the learning environment without usurping control from the learner, offering unique learning opportunities in nearly every subject area. As a result, simulations permit the attainment of learning goals which are beyond traditional and other computer-based instruction methods (Hooper & Thomas, 1991). In recent years, it has become necessary to evaluate how effective computer simulation is as an instructional method or strategy. Much research has focused on the use of computer simulation packages in teaching digital
electronics (Chu, 1994; Goldberg & Subbarao, 1990; Huang, 1991). However, in relationship to education, there is no consensus as to whether computer simulation should be implemented in the classroom (Banzhaf, 1991). Perhaps because of this uncertainty about the use of computer simulation, especially in entry level courses, more specialized studies should be conducted (Nejad, 1992).

It is very important to reduce the number of logic gates required to produce a given function in a combinational logic circuit. This simplification is desirable for several reasons, such as economy or cost, limitation of available power, and minimization of delay times by reduction of logic levels. Boolean algebra is essentially a set of rules, laws, and theorems by which logical operations can be expressed symbolically in equation form and manipulated mathematically. Minimization of Boolean algebra expressions results in the minimization of logic gates.

The purpose of teaching minimization of Boolean functions in a digital electronics course is to introduce students to some rules, laws, and methods to simplify Boolean functions and combine classroom lectures with laboratory experimentation. It is difficult for a novice to understand and learn minimization of Boolean functions in a short amount of time. Hence, the use of a series of computer-based programs may be helpful. Based on this perspective, a computer program based on minimization of Boolean functions was designed in the present research to establish a meaningful introduction to a digital electronics course for students.

The design of this program was rooted in the theories of learning and instruction. Based on an analysis of learning needs, this program was written both as a tutorial and as a
simulation employing CAI. All the learning environments were set up before students started the program. Some units used a simulation program to show a virtual view of how a logic circuit is executed and its function, as necessary. The computer aided instruction program was developed to provide an easier and more interesting way for novices to learn minimization of Boolean functions.

**Statement of the Problem**

The problem of this study was to evaluate students' achievement in minimization of Boolean functions, and compare learning effectiveness by two different instructional technologies, either computer tutorial/simulation techniques or the traditional lecture/practice method.

**Purpose of the Study**

The purpose of this study was twofold: (1) to evaluate the effectiveness of using a computer tutorial/simulation program to learn minimization of Boolean functions at the undergraduate level; and (2) to investigate whether learning the minimization of Boolean functions by two different instructional methods (traditional lecture/practice vs. computer tutorial and simulation system program) are equally effective.

**Need for the Study**

Traditional teaching methods (lecture/practice) have been used to teach the minimization of Boolean functions. These concepts are typically difficult to understand for
students taking digital electronics for the first time. A few factors which may account for this are:

1. a lack of vivid material which has been especially designed for this instruction;
2. the difficulty teachers and textbook authors have in clearly explaining the concepts and theory; and
3. a lack of sufficient review questions for student practice.

Some studies involving computer software packages have been conducted in an effort to improve the environment in which the student learns digital circuits. These software packages for digital simulations can be very easily implemented. For the purpose of this study, it was necessary to design a new instructional program that combines tutorial and simulation programs. This study was conducted in a effort to provide empirical evidence to guide the further development of computer tutorials and simulation programs at the undergraduate level of instruction in digital technology.

Questions of the Study

The questions addressed by the study are as follows:

1. Can a subset of concepts related to the minimization of Boolean functions be learned as effectively through a computer tutorial and a simulation program as knowledge gained through traditional classroom instruction, as measured by traditional test scores?
2. Do the concepts learned in basic electronics and basic logic gates have some degree of relationship for students who learned minimization of Boolean functions using the
computer tutorial and simulation program as compared to concepts learned through traditional lecture/practice methods?

**Assumptions of the Study**

This study was based upon the following assumptions:

1. The errors and the test scores are random, independent, and normally distributed.
2. The assigned sample size is sufficient for an estimation of population parameters.
3. The instruments (first four chapters, pretest, and post-test) have adequate reliability and validity.
4. The instruction time is sufficient to produce a measurable experimental effect on student performance.

**Limitations of the Study**

This study was subjected to the following limitations:

1. The participants of this study were limited to those students who enrolled in IEDT 246 Digital Electronics classes during the Spring semester of the 1995 school year in the Department of Industrial Education and Technology at Iowa State University.
2. The computer-based instruction program utilized in the experimental treatment group was limited in scope due to the time available for instruction in the following topics:
   a. Forms of Boolean Expression
   b. Rules and Laws of Boolean Algebra
   c. DeMorgan’s theorem
d. Karnaugh Map

e. Circuit Implementation

3. The unit of observation in this study was the student. Because students received the treatments concurrently, there was a possibility of violations of the assumption of independence by students sharing information with each other, both within groups and across treatment groups.

4. The pretest and post-test measurement instruments were samples of the knowledge domain and may have errors of measurement which might reduce their sensitivity to the treatments' effects.

**Procedures of the Study**

In conducting this study, the following procedures were followed:

1. Identify the research problem.

2. Review the literature related to minimization of Boolean algebra and computer-assisted instruction.

3. Identify the population and sample subjects for this study.

4. Identify and label dependent and independent variables.

5. Develop pretest and posttest instruments.

6. Develop and refine the computer teaching program.

7. Administer the pretest.

8. Implement instruction.

9. Administer the posttest.
10. Code research data.

11. Analyze the data by the SAS statistics package.

12. Write a final report, summary, conclusions and make recommendations based on the findings.

13. Pass a final oral examination.

**Definition of Terms**

The following terms are defined to clarify and standardize terms used in the research in this study:

*Boolean algebra* – A mathematical system for formulating logical statements using symbols, so problems can be written and solved in a manner similar to ordinary algebra. It was developed in the 1850s by the Irish logician and mathematician, George Boole.

*Boolean equation* – An algebraic expression that illustrates the functional operation of a logic or combination of logic gates.

*Truth table* – A tabular listing that is used to illustrate all the possible combinations of digital input levels assigned to a gate and the resulting output.

*Digital electronics* – Typically involves circuits and systems in which only two states are utilized. These two states are normally represented within the circuitry by two different voltage levels.

*Logic* – Applied to digital circuits used to implement logical functions.
Equivalent circuit – A simplified version of a logic circuit that can be used to perform the exact logic function of the original complex circuit.

Computer-assisted-instruction (CAI) – CAI is a category of educational software that refers to lessons written for educational purposes using computer technology. (Davis & Sprecher, 1986).

Karnaugh map – A two-dimensional table of Boolean output levels used as a tool to perform a systematic reduction of complex logic circuits into simplified equivalent circuits.

Tutorial – A method of presenting information by guiding the student through the initial uses of the information to develop a framework for familiarity or fluency. Tutorials have a broad horizon of application in most disciplines. They are appropriate for presentation of factual information, and learning rules and principles; or for learning problem-solving strategies (Gagné, Wager, & Rojas, 1981).

Simulation – Allows a student to learn about some aspects of the real world by imitating or replicating them. Students are not only motivated by simulations but also learn by interacting in a manner similar to the way they would react in real situations. In most instances, a simulation also simplifies reality by omitting or changing details. In this simplified world, the student solves problems, learns procedures, and comes to understand the characteristics of phenomena and how to control them; or learns what actions to take in different situations (Dennis, 1979).
CHAPTER II. REVIEW OF RELATED LITERATURE

The main purpose of this chapter is to identify related literature and discuss research on Boolean algebra in logic design and computer-assisted instruction, especially from a computer tutorial and simulation perspective. Initial sources of information came from the ERIC System and Dissertation Abstracts International, while further sources were identified from citations in books, journals, conference presentations and discussions with knowledgeable individuals.

This chapter begins by providing three topics which are discussed as follows: (1) Boolean algebra in logic design; (2) an overview of computer-assisted instruction; (3) an overview of computer tutorial; (4) an overview of computer simulation; (5) and studies of computer simulation in digital electronics.

**Boolean Algebra in Logic Design**

Traditionally, Boolean algebra is largely taught in connection with a computer programming course, logic, or set theory (De Villiers, 1987). Boolean algebra, developed by the Irish logician and mathematician George Boole in 1854, is a mathematical system for formulating logical statements with symbols so the problems can be written and solved in a manner similar to ordinary algebra (Floyd, 1977). Technical applications of Boole’s algebra of logic first appeared in the 1940s, when the American mathematician Claude Shannon used Boolean algebra to analyze switching circuits (Sangalli, 1989). A combinational logic design procedure for students is as follows (McMillan, 1987):
1. Statement of the problem;
2. Determine and assign input and output variables;
3. Derive a truth table for each input and output variable;
4. Derive a simplified Boolean function for each output variable;
5. Draw a logic diagram using logic gate symbols for each output function; and
6. Wire the logic diagram on the trainer using logic IC.

One follows the above procedures to design a particular circuit or network. First, specify a requirement as the system of Boolean function. In general, using a mathematical model provides a convenient form for exploring possible designs. Then, simplify the Boolean function by algebraic manipulation. Finally, the equations can be implemented using the appropriate hardware (Sangalli, 1989). Furthermore, the best design is generally the simplest design (Hill & Peterson, 1968). This simplest design is for economy or cost, limitations of available power, and minimization of delay times, etc. (Floyd, 1977).

**Boolean algebra teaching**

Research was conducted by De Villiers (1987) on the teaching of Boolean algebra who used an alternative approach which he had successfully used and developed since 1978 to supplement the traditional teaching of Boolean algebra. DeVilliers used Boolean algebra as a medium to teach pupils such mathematical processes as modeling and axiomatization. The first purpose of this research was to expose the gifted student to a gradual process of modeling. In this section, students were confronted with seven "motivational" problems of a practical nature. They were required to draw switching diagrams and to use switches or
switchboards to simulate and test their answers. After the problem was solved within the
mathematical framework of the model, they would analyze the solution in terms of the original
problem. The pupils were encouraged to discover for themselves the underlying mathematical
principles, which were gradually developed and presented in special activities. After the
teaching sessions, pupils could design a switching circuit to control a light. De Villiers
pointed out the students were then asked to record the logical relationships between a
statement and the statements from which it could be derived in an axiomatic diagram, or map.
Using axiomatic diagrams and combining them, students gradually realized which statements
would be a suitable axiom set for Boolean algebra.

An Overview of Computer-Assisted Instruction

The term "Computer Assisted Instruction" is easy to understand. There have been
many definitions suggested by educators which are consistent with one another. Computer
assisted instruction is a category of educational software that refers to lessons written for
educational purposes using computer technology. Tutorial, computer-based drill-and-practice,
and simulation lessons can all be referred to as computer assisted instruction (Davis & Budoff,
1986). Computer-supported instruction applications are currently classified as tutorial, drill
and practice, or simulation. Tutorials are programs which provide information in small units
and reinforce learning by asking factual questions. Drill and practice lessons present a series
of questions for the learner to answer. The program may select questions on the basis of
previous student responses. Simulations are computer models of physical or theoretical
systems (Thomas & Boysen, 1984).
A taxonomy of computer instruction

Thomas and Boysen (1984) classified computer instruction into five categories: experiencing, informing, reinforcing, integrating, and utilizing. Thomas and Hooper (1991) pointed out the definition and utilization of computer simulations for each category.

1. Experiencing – Experiencing programs are used to set the cognitive or affective stage for future learning. Use of these programs precedes the formal presentation of the material to be learned. Simulations are ideally suited for this purpose. They encompass a model of a concept, subject area, or situation that the student can manipulate in order to gain an intuitive understanding of the learning goal. Experiencing programs can be used to: (a) provide motivation; (b) provide an organizing structure; (c) serve as concrete example; or (d) expose misconceptions and areas of knowledge deficiency.

2. Informing – Informing programs are used to transmit information to the student. These programs supplement or replace the textbook and lecture as a means of initial formal exposure to a topic. Although simulations are sometimes used for this function, more common formats are tutorial, demonstration, inquiry, and dialog.

3. Reinforcing – A program is classified as reinforcing if the knowledge is applied in the same context in which it was learned. Students use reinforcing programs to strengthen specific learning objectives. The most common format for a reinforcing program is drill and practice, in which a sequence of stored or generated exercises is presented for the student to complete. These programs can be designed to adjust to the student’s knowledge level and to track the student’s progress. Simulations are sometimes used for reinforcing in training situations where the information or processes being learned require considerable practice to master.

4. Integrating – Isolated facts, concepts and principles are usually of little practical value to the student. These pieces of knowledge must be integrated into functional units and assimilated with other units in order to be useful. Integrating programs are designed to aid the student in making the necessary assimilation’s. They are appropriately used in any situation where several knowledge elements have been learned independently and need to be applied collectively. Computer simulations presenting a problem to be solved are commonly used for integrating. As the student understands and integrates the underlying concepts of the simulation, he becomes more adept at manipulating the model.

5. Utilizing – The utilizing category is intended to include both textual and numerical applications. For classroom use, these programs permit students to tackle more
complex and realistic assignments. They permit classroom focus on problems involving the subject being taught by minimizing the need to focus on computations. Proper use of these tools contributes significantly to computer literacy. (p. 497-513)

An understanding of the design intent of a lesson with respect to the taxonomy, as well as an understanding of the taxonomy itself, is critical if the teacher is to effectively use computer-based instruction. It should be recognized that informing and reinforcing applications are usually computer-directed, whereas experiencing, integrating and utilizing are learner-directed. It is through the use of the learner-directed applications that the student can and must develop the practice of asking, "What if?" It is through learner-directed applications that the highest levels of learning are achieved as well as the highest level of computer literacy. These applications also require the greatest degree of teacher competence and the deepest philosophy of education (Thomas & Boysen, 1984).

An Overview of Computer Tutorial

Computer tutorial lessons are computer programs that teach by carrying on a dialogue with the student. They present information, ask the student questions, and make decisions whether to move on to new information or to engage in review and remediation based on the student's comprehension. Tutorial instruction is, in a sense, the most basic form of computer-based instruction (Alessi & Trollip, 1985). Tutorials are used in almost every subject area from the humanities to the social and physical sciences. They are appropriate for presenting factual information, for learning rules and principles, or for learning problem-solving strategies (Gagné et al., 1981).
Format of tutorial

Formats are sometimes referred to as lesson designs, especially by designers trained in the programmed learning tradition and who essentially recognize only tutorials as being CAI modules (Chambers & Sprecher, 1983). Burke (1982) described a number of different formats which include the following:

1. Linear - the most common used and easiest to design. Linear formats provide only one route through the lesson. If students fail at one point, they simply branch back to an earlier point.

2. Spiral - formats encompassing multiple subjects and rotating the variables involved. An example would be to consider the respiration of organisms across a number of different types of species, and then to consider the concept of reproduction across the same species.

3. Branching - involves alternate tracks. The results of an initial assessment branches the student to whichever learning sequence is most appropriate to his or her skill level.

4. Multitrack - involves several distinctly different levels to permit individualization of the lesson.

5. Regenerative - in which the lesson can generate a different set of problems for each student or for each iteration for the same student.

6. Adaptive - represents the use of artificial intelligence concepts in which student responses are used by the computer as a basis for learning new materials.

Computer tutorial instructional strategies

A tutorial strategy is intended to emulate the “ideal” teaching situation of one learner with one or more teachers (Soulier, 1988). The ideal teaching environment includes more than just a teacher and student; it includes a vast number of resources including films, books,
worksheets, pictures, and so on. Steinberg (1991) noted that the techniques for presenting instruction in CAI including three phases:

1. Presentations – instructional techniques specific to a subject can frequently transfer directly to CAI;

2. Interactions – Question-response-feedback sequences are an integral part of instruction guidelines for writing good questions are as applicable to CAI as to other instructional modes;

3. Motivation – Motivation is obviously an important factor in learning. Classroom experience provides knowledge about motivators that are appropriate for particular student populations.

Based on the same theories, the general structure and sequence of a tutorial is shown in Figure 1 (Alessi & Trollip, 1985). It begins with an introductory section that informs the student of the purpose and nature of the lesson. After that a cycle begins where information is presented and elaborated. A question is asked that the student must answer. The program judges the response to assess

![Figure 1. The general structure and flow of a tutorial](Image)
student comprehension, and the student is given feedback to improve comprehension and future performance. At the end of each iteration, the program makes a sequencing decision to determine what information should be presented during the next iteration.

The cycle continues until the lesson is terminated by either the student or the program. At that point which is called the closing, there may be summary and closing remarks. Not all tutorials engage in all these activities. However, an effective tutorial will include all these components.

Merrill (1988) indicated that in most tutorial CAI, the student is first presented information, usually as a paragraph of text, perhaps accompanied by graphic information, and then asked questions about this text. Merrill also noted that much of traditional tutorial CAI is based on the branching programmed instruction model illustrated in Figure 2. The instructional strategy consists of the following events:

1. Present a page of text for the student to the student.
2. Ask a question.

![Diagram of the branching programmed instruction model](image)

Figure 2. The branching programmed instruction model
3. If the student's answer is correct, provide feedback saying you are correct, but if the student's response is incorrect provide feedback plus remedial material.

4. Repeat this cycle.

This model is employed in the various forms of branching programmed instruction. This form of branching is simplistic, because often the original question is a two-option branch, one of which leads to a remedial frame and the other sends the learner on through the program. In branching programmed instruction, the learner in principle must comprehend the information before answering a question, which is a confirmation of that comprehension rather than the response portion of an S-R connection (Jonassen, 1985). Simple branching sequences such as these generally produce processing which is just as shallow as linear programming, that is, processing that does not require deep comprehension by the learner.

Gagné (1981) identified five categories of learning outcomes that represent all types of learning: intellectual skills; cognitive strategies govern the individual's own learning, remembering, and thinking behavior; verbal information; motor skills; and attributes.

Within these various types of learning, Gagné believed that there must be nine events of instruction. The internal learning processes (expressed in terms of cognitive theory) and the external instructional events postulated by Gagné are listed in Table 1 (Gagné et al., 1981). The procedure for a tutorial sequence would be as indicated in Figure 3 (Gagné et al., 1981). Using these nine steps and ensuring their inclusion in tutorial sequences can be of significant help to most CAI designers.
Table 1. Internal processes of learning and the external instructional events

<table>
<thead>
<tr>
<th>Internal learning process</th>
<th>External instructional event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alertness</td>
<td>1. Gaining attention</td>
</tr>
<tr>
<td>2. Expectancy</td>
<td>2. Informing learner of lesson objective</td>
</tr>
<tr>
<td>3. Retrieval to working memory</td>
<td>3. Stimulating recall of prior learning</td>
</tr>
<tr>
<td>4. Selective perception</td>
<td>4. Presenting stimuli with distinctive features</td>
</tr>
<tr>
<td>5. Semantic encoding</td>
<td>5. Guiding learning</td>
</tr>
<tr>
<td>7. Reinforcement</td>
<td>7. Providing informative feedback</td>
</tr>
<tr>
<td>9. Generalizing</td>
<td>9. Enhancing retention and learning transfer</td>
</tr>
</tbody>
</table>

Figure 3. Procedure incorporating additional events of instruction
Chambers and Sprecher (1983) emphasized that designing modules that motivate students to enjoy learning is by far the most critical and desired outcome of any courseware development.

**Computer tutorial courseware design**

As indicated in Figure 4, the cycle is composed of five separate functions, each ending with a review. The functions may or may not represent different individuals or groups of individuals. However, they do represent different orientations such that individuals involved in multiple functions often require specialized training and experience. The success of development efforts in which budgetary or other constraints require key individuals to play multiple roles or handle functions independently is largely dependent on the ability of those individuals to wear “different hats.”

This need for differing viewpoints is often best satisfied through the use of a team effort within each function. The collective team viewpoint and sharing of knowledge and ideas in design specification or technical development, for example, are effective points of strategy for producing high-quality products even in an environment with limited resources. Although some highly skilled and experienced individuals can and have effectively performed specific development functions independently, it is often only a short-term solution, since this narrower focus can limit the number of products produced and also limit other potential team members who could benefit from the experience of the team interaction.
An Overview of Computer Simulation

Definitions of computer simulation

Computer simulation has a variety of definitions. To simulate means to imitate or pretend to do something. According to *Webster’s collegiate dictionary*, to simulate, is “to feign, to attain the essence of, without the reality.” Shannon (1975) defined simulation as the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system. Chambers and Sprecher (1983) indicate that computer simulation provides a model in which the student plays a role and interacts with the
computer. Alessi and Trollip (1985) stated that computer simulation is the use of a computer to simulate objects or phenomena and is a powerful tool in industry to test out new products without actually producing them. Perry and Hoover (1989) noted that simulation is the process of designing a mathematical or logical model of a real system and then conducting computer-based experiments with the model to describe, explain, and predict the behavior of the real system. As seen in the above definitions, several individuals offer different short definitions which may be confusing; thus, the word "simulation" carries a variety of meanings to different people.

Simulations have been used most often in higher education to model scientific processes. They are applicable to any field, and can be of significant help in illustrating concepts, in helping students to develop problem-solving techniques, or in allowing students to explore complex interactions.

Simulation allows a student to learn about an aspect of the world by imitating or replicating it. Students are not only motivated by simulations but also learn by interacting with them in a manner similar to the way they would react in real situations. In almost every instance, a simulation also simplifies reality by omitting or changing details. In this simplified world, the student solves problems, learns procedures, comes to understand the characteristics of phenomena and how to control them, or learns what actions to take in different situations (Dennis, 1979).

Computers can be used to simulate laboratory situations. An experimental situation can be represented by a set of questions programmed into the computer. The student enters a
set of initial values. The computer generates data similar to data the student would have collected in an actual laboratory experiment. The simulation program can be written so that the data generated by the computer reflect uncertainties corresponding to the experimental errors. The magnitude of these uncertainties can be varied from trial to trial through the use of the computer's random number generator.

The student activities in conducting a computer simulated experiment are similar to those involved when conducting an actual experiment. Both investigations are started by asking pertinent questions about the situation. An experiment is then designed that permits the student to answer his/her original question.

In a laboratory experiment, the student would manipulate the laboratory experiment or apparatus to obtain the data required. In a computer simulated experiment, the student would manipulate the input and output data through the use of a computer terminal. Once the data are obtained, whether by laboratory equipment or by computer, the objective is to determine relationships from the data by curve plots and data analysis (Hughes, 1974).

Bushnell and Allen (1967) suggested that computer simulation offers many advantages over natural events in that simulation brings a sense of immediacy to the learning task and challenges the student to participate more actively. Boblick (1970) noted that computer simulations of laboratory environments enable physics students to experiment with environments which are unattainable in any other form. Showalter (1970) suggested that computer simulations offer a medium for educational research into the problems associated with how individuals learn to inquire and how their strategies of inquiry develop and change.
Craig et al., (1971) noted that computer simulation provides a student with a richer experience in data interpretation and hypothesis making.

There is evidence to suggest that the instructional potential of laboratory simulations is substantial (Hughes, 1974). Simulations differ from interactive tutorials which help the student learn by providing information and using question-answer techniques. In a simulation, the student learns in a context that is similar to the real world (Alessi & Trollip, 1985). The CAI model of teaching has four phases: (a) presenting the student with information; (b) guiding the student in acquiring information or skill; (c) providing practice to enhance retention and fluency; and (d) assessing learning. Tutorials generally engage in the first two of these instructional phases. Simulations, in contrast with tutorials, may be used for any of the four phases of teaching. Initial presentation, guidance and practice, and assessment of learning are all capabilities of a simulation (Alessi & Trollip, 1985).

**Advantages of computer simulations**

Simulations typically have three major advantages over conventional tutorials drills and tests (Alessi & Trollip, 1985). A brief discussion of each advantage is stated.

*Motivation:* One would expect a student to be more motivated by being an active participant in a learning situation than by being relatively passive. Although the “learning by doing” philosophy has long been advocated (Bruner, 1973; Papert, 1972, 1980), the introduction of computers into the educational field is likely to make its implementation more widespread.
**Transfer of learning**: Transfer of learning refers to whether skills or knowledge learned in one situation apply in other situations. Simulation has good transfer of learning because what was learned in the simulation usually transfers well to the real situation. A book, however, only provides information and hints on how to do something. The student used a simulation would be expected to be better prepared.

**Efficient**: Through simulation not only can one measure how effectively knowledge, skills, or information transfer from one situation to another, but one can also measure how efficient the initial learning experience is with respect to the transfer.

Computer simulations are considered to be a valuable tool in aiding science students to achieve the educational goals. Marks (1982) emphasized computer simulation help students realize otherwise unobtainable educational goals. The benefits can be grouped into five categories:

1. **Problem solving**: Simulations allow effects of changes to be seen in a model before irrevokable changes are made in the real system. Often the valuable experience gained in problem solving closely approximates real life situations that may be encountered in the future. Simulations provide a much needed active learning experience as opposed to passive lecturing or reading one.

2. **Decision making**: Students are forced to make decisions on the basis of incomplete data. Along with decision making comes learning to accept the results as well as taking responsibility for previously made decisions.

3. **Opportunities for learning**: Simulations can present learning opportunities that may be otherwise either unfeasible or impossible for students. Since simulations may be inwardly complicated while appearing outwardly simple, concepts which are often frustratingly abstract can be introduced with a sense of realism.

4. **Social skills**: Simulations provide students with the opportunity to improve socialization skills. Students learn the importance of good communication skills, team work, and cooperation.
5. **Attitudes toward learning**: Simulations can increase student enthusiasm and motivation. (p. 18-20)

Pidd (1992) indicated the advantages of simulation versus real experimentation include cost savings, particularly if something goes wrong. Simulation also saves time, allows the precise replication of an experiment, and can be conducted safely.

Simulation used in digital network design provide advantages as mentioned above, and they help demonstrate the expected response from a circuit or system, without actually building it. Another advantage is computer simulations show the timing and loading effects which may have been ignored or neglected by the designers (Goldberg & Subbarao 1990). The computer industry originated the concept and use of computer-aided design (CAD) tools, in which systems allow designs to be completed quickly and their operation verified by simulation and timing analysis before fabrication (Shankar, Freytag, & Alon 1991).

The engineering effort required for semi-custom/custom VLSI design is growing exponentially with respect to the number of transistors per chip. Manual designs are prone to human errors, and the iterative designs-silicon-modification-silicon process may result in a lengthy development period (Shankar et al., 1991).

Chu (1994) stated that without software simulation provided in educational software packages, it is very difficult to assign large, open-ended projects. There is no easy way for students to validate and test their design. Although it is possible to implement the circuits in a breadboard, the wiring can be tedious, time-consuming and error-prone. Often students spend their time and effort in wiring rather than testing and refining the design. It is also difficult
and time-consuming for the instructor to grade and evaluate large projects because there is no single answer and many alternatives are possible.

**Disadvantages of computer simulations**

Mark (1982) investigated the limitations of simulation, and mentioned that a simulation of a pond cannot include all forces and effects on that complex environment. Unfortunately, after working through the simulation of the pond, students may think that only those factors presented affect all ponds. Another problem is the biases of the simulation designer, especially when the biases are not identified in the accompanied documentation. Students become so absorbed in simulation that they can easily fail to notice built in biases.

Thomas and Hooper (1991) noted the role of simulations requires a common understanding of the characteristics of the student-simulation interface. In using a pure simulation, students are presented with a goal and must perform actions they believe will achieve the goal. If the goal is achieved, the students have evidence that their understanding of the modeled system is accurate. A problem arises if the students cannot generate an appropriate action and if the goal is not achieved. If the goal is not achieved, the students know that their understanding is inaccurate or incomplete but are left with the challenge of determining where the problem resides. Thus, the strength of a simulation is that it forces the students to search their memory for knowledge that relates to the problem being solved, assimilate that knowledge into a solution, and evaluate the result. The weakness of a simulation is that it only indirectly indicates whether a student’s understanding is correct and provides no new knowledge beyond what the student possesses or can create.
Joseph (1970) mentioned that pure simulations must be driven by the student’s existing knowledge or knowledge the student can create from existing knowledge. Pure simulations are ideal for experiencing and integrating activities. Experiencing activities are designed to activate or exercise the student’s existing knowledge to form an anchor for the material to be learned. Integrating activities provide an opportunity to apply previously learned material in unique situations. The nature of these learning goals require that the responsibility for the learning task resides with the student.

Another researcher found a simulation to be helpful to low- and high-ability students, but not to the average students (Cox, 1974). However, Krishnamachari (1988) had different results in teaching probability wherein he found the use of computer simulations could be helpful to average mathematics students to understand basic concepts of probability. Lubert (1986) reported computer simulation was an effective mechanism for decreasing student misconceptions in physics. Oringer (1987) found gender was a factor for implementation of computer simulation, with males scoring higher than females. Contant (1987) noted gender, age and experience with computers were not related to student learning on computer simulation. However, pure simulations transmit little new knowledge and do not directly reinforce students’ correct behavior.

**Instructional roles of simulations**

Thomas and Hooper (1991) pointed out that, to eliminate the natural restrictions on simulation use and to make them stand alone curricular materials, many developers have modified the student-simulation interface. Modifications include providing detailed, explicit
feedback informing the student that an error has been made and inserting tutorial sequences to correct misunderstandings. In general, these modifications decrease the simulation's strengths significantly more than they decrease the weaknesses. However, three research studies reported positive effects due to modifications. Munro et al. (1985) increased effectiveness by allowing the students to request feedback; Stevens and Roberts (1985) used generalized feedback rather than specific feedback to improve performance on reinforcing simulations; and Woodward et al. (1988) used the simulation to focus teacher guidance. In other studies, Krahn and Blanchaer (1986) successfully inserted a knowledge refresher, and Tivers and Vockell (1987) inserted suggested strategies into the beginning of integrating simulations. In these studies, the introduction to the simulation was modified but the operational interface was not changed.

Thomas and Hooper (1991) stated that:

Many of the published studies on simulation involve interface modifications. The effect of these modifications appear to hold the key to simulation design and use. Pure simulations should be used for experiencing and integrating functions with external support provided to compensate for impasses students may encounter. Impure simulations, modified as unobtrusively as possible to encourage generalization, should be considered for reinforcing functions. Other methods of instruction would seem to be more appropriate for informing. (p. 510)

Simulation programs in logic circuits

There are many computer simulation programs available for teaching logic circuits and logical simulation, such as: Micro Logic; PALASM (Programmable Array Logic Programs), HELP (Harris Enhanced Logic Programs); B² Logic; Logic Work; Electronics Workbench and PSPICE simulation program on the IBM personal computer; DAZIX software runs under
Unix on SUN386i workstation; MacLab, Rocky’s Boots and High Wire Logic on the Apple computer, etc.

The more widely used software packages at the college level due to their reasonable cost are LogicWorks and Electronics Workbench. The Logic Works simulation software was developed by Capilano Computing Systems, Ltd. This software is also available for the Apple Macintosh. Logic Works offers students the opportunity to quickly draw general-purpose schematic diagrams using standard digital and discrete component symbols, create schematics for SPICE-based analog simulators and custom symbol libraries with the built-in drawing tools, generate simple netlists and bills of materials from the schematic, and interactively simulate the digital portions of the circuit.

Electronics Workbench was developed by Interactive Image Technologies, Ltd. This package includes analog and digital circuit models. The digital module contains an unlimited supply of logic gates, devices and displays. All components are ideal and have infinite slew rates and fan outs with propagation delays. Four instruments are contained for testing. The first one is a voltmeter used for measuring DC voltage. The second one is a word generator which provides input to drive a circuit wherein students can specify a word pattern of up to 16 8-bit words. The third one is a logic analyzer which displays waveforms for up to eight input channels. It also displays the binary and hexadecimal representations of the current word. The last one is a logic converter which can convert digital logic among gates, truth tables and Boolean representations.

The procedures for building and testing a digital circuit are as follows:
1. Start the digital module by a double-click;

2. Build a digital circuit by placing components on the workspace and wiring components, labeling a component if necessary;

3. Test a circuit by trying the word generator, activating a circuit, and trying the logic analyzer; and

4. Try some more features, such as using the logic converter, and starting a new circuit.

Studies of Computer Simulations in Digital Electronics

Early research in computer-aided instruction for Boolean algebra and logic design was implemented in the Rensselaer Polytechnic Institute by Dr. Roy (1968). Roy used an IBM 650 computer to prepare deficient college and graduate students for Boolean algebra and logic designs. The results of the examination of students who were taught by computer-assisted instruction showed the students had better retention of conceptual material than by conventional classroom instruction. However, the conclusion of this research was that CAI is unsuitable for engineering education due to both hardware and software restrictions. Today, it is easy to understand the contemporary situation of personal computer (PC) development versus the large cumbersome mainframe computers of the past.

Garren (1990) used computer simulation software to teach digital electronics to an experimental group and compare that group to a control group which used the actual components practice. The results of the post-tests indicated no significant difference between the two groups. The researcher also found that students who used computer simulation showed less interest in the subject than those who did not receive computer simulation.
Gokhale (1991) conducted a study to compare the effectiveness of computer simulation in contrast to laboratory activities in teaching students to understand the logic type. The researcher used the Apple II and the simulation program HIGH WIRE LOGIC which combined simulation and problem-solving techniques, and involved interactive computing and graphics. The student was provided with a facility to manipulate and test ideas and hypotheses while aided by the computer. In the laboratory group that used four different gates, students were urged to think about what they had observed in the process which they tested. The results indicated that no significant difference were found between the two methods of instruction.

Wilson (1993) used the Apple IIe computer to teach an experimental group of students to analyze digital circuits, while the control group participated in a formal lecture series and performed the same analysis without the aid of a computer. The results indicated that there were no significant differences in the test scores between the computer-based instruction and traditional methods instructional groups.

**Summary**

In this chapter the literature pertaining to Boolean algebra, computer tutorial and simulation instruction, and strategies in the design of computer-based instruction were presented. Boolean algebra is largely taught in connection with a computer programming course and logic circuit design. The best logic circuit design is generally the simplest design, that is, learning to simplify Boolean functions become an important chapter in a logic circuit design course.
Research shows that CAI satisfies many of the theoretical requirements for a "good" learning environment advanced by leading psychological theorists such as Skinner (1968). Thus, CAI actively involves the individual in the learning process, which supposedly facilitates learning. It also permits the learner to proceed at his or her own pace.

A successful instruction sequence must include the following activities:

1. Information is presented or skills are modeled.
2. The student is guided through initial use of the information or skills.
3. The student practices until familiarity or fluency is gained.
4. Student learning is assessed.

Tutorial lessons aim to satisfy the first two components of instruction, but usually do not engage in extended practice or assessment of learning. Some tutorials do not even guide the student through the information, but only present it. However, a good tutorial should include both presentation and guidance.

Simulation may be used for any of the four phases; that is, it may serve for initial presentation, for guiding the learner, for practice, for assessing learning, or for any combination of these. Combining tutorial lessons and simulation may serve four phases of instruction, especially in logic circuit design.
CHAPTER III. METHODS AND PROCEDURES

This chapter describes the experimental research design which used a quantitative model to examine the effects of tutorial and simulation programs for learning minimization of Boolean functions. A two-group comparison was conducted (control and experimental). In this chapter, the overview of the experimental research design is described at the beginning, followed by the description of the population and sample, location, limiting conditions, sampling technique, procedures, materials, variables of the study, statistical treatment, hypotheses of the study, and description of the computer tutorial and simulation program.

Overview of the Experimental Research Design

This study involved two groups of Iowa State University students enrolled in a Digital Electronics course in the Department of Industrial Education and Technology (IEDT 246). The contents of IEDT 246 were: analysis and application of logic gates, number systems and codes, Boolean algebra, counters, shift registers, memories, flip-flop, multivibrators, interfacing, data transmission, etc. The control group in this study used lecture and laboratory work, while the experimental group used a computerized simulation instruction program.

Subjects of the Study

The subjects participating in this study were students enrolled in Digital Electronics (IEDT 246) during the spring semester of 1995, in the Department of Industrial Education and Technology at Iowa State University. There were two sections of IEDT 246: Section A had 20 students; and section B had 13 students. All students enrolled in IEDT 246 had
already taken the IEDT 240 Fundamentals of Electronics class where they were exposed to the basic concepts of electronic circuits. The students in each section were randomly assigned to either the experimental or control group.

**Location**

This experiment took place in the Department of Industrial Education and Technology at Iowa State University. Two laboratories located in the department were used to conduct this experiment.

1. A computer laboratory located in IEDT Building II, Room 10; and
2. An electronics laboratory located in IEDT Building II, Room 10A.

**Limiting Conditions**

This study was limited to following factors:

1. Only students who were enrolled in IEDT 246 Digital Electronics during Spring of 1995 participated in the study.
2. Only thirty students were available to participate in this study.
3. This study was limited to selected laboratory and classroom activities.
4. This study was limited to instruction provided by one instructor.
5. The textbook use in this study was *Digital Electronics* by William Kleitz (1993).

**Sampling Technique**

The population of this study was comprised of the students who enrolled in the Digital Electronics classes (IEDT 246) at Iowa State University. Initially, 33 students enrolled in
IEDT 246, however, because two students in section A did not attend class in the pretest hour, and one student failed this class the previous semester, the sample from the population for this study was the 20 students enrolled in section A and 12 students enrolled in section B during the spring semester, 1995.

**Procedures**

The research schedule is shown in Table 2. The experimental phase of the study was implemented during the sixth and seventh week of the semester. Both groups were instructed on the same five topics covered in this study. In the fifth week, during the second hour of the class, the course syllabus for this research study was distributed and discussed. Then, during the third hour a pretest was administered. During the fourth hour of the class period, the students were randomly assigned to one of two groups: experimental or control.

During the sixth and seventh week, four hours were used to teach the control group the concepts and theories of minimization of Boolean functions by lecture, and another four hours were used to conduct laboratory experiments using the actual electronic components. On the other hand, the experimental group utilized the computer tutorial and a simulation

Table 2. Time schedule of the research design

<table>
<thead>
<tr>
<th>Week</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
<th>8th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>1 hour</td>
<td>2 hours</td>
<td>2 hours</td>
<td>2 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 hour</td>
</tr>
<tr>
<td>Experimental</td>
<td>Pretest</td>
<td>CAI program</td>
<td>CAI program</td>
<td>Post-test</td>
</tr>
<tr>
<td>Control</td>
<td>Pretest</td>
<td>Lecture</td>
<td>Lab.</td>
<td>Lecture</td>
</tr>
</tbody>
</table>
program for eight hours during the sixth and seventh weeks. During the eighth week, a post-test was administered to all subjects to measure the knowledge of minimization of Boolean functions.

Materials

The test instrument employed in this study was designed from the materials covered in the text. All administered tests were the same for both the control and experimental groups. No questions relating to computer simulation were given to either groups. Both the pretest and post-test consisted of 30 questions (See Appendix A & B). Cronbach Alpha reliability estimates for the pretest and post-test were .52 and .60, respectively. Considering the limited sample size and the heterogeneity of concepts covered in these tests, these reliabilities were judged to be adequate measures.

Laboratory equipment

The laboratory equipment used in this study accommodated two groups:

(a) the traditional group; and (b) the simulation group.

Traditional group The traditional group in this study used the following items in the electronics laboratory:

1. analog multimeter
2. digital multimeter
3. oscilloscope (50MHz)
4. power supplies
5. signal generators
6. logic circuit breadboard
7. 74 series integrated circuit
8. LED indicating circuit

**Simulation group**  The experimental group in this study used the following computers and software:

1. IBM compatible microcomputer (486DX 33MHz)
2. Microsoft DOS Version 5.0
3. Microsoft Windows Version 3.1
4. Electronics Workbench Version 3 (developed by Interactive Image Technologies LTD)
5. Microsoft Visual Basic Version 3.0

**Data collection instruments**

Two types of instruments were designed to measure a student’s knowledge regarding the minimization of Boolean function and logic circuits. These instruments were used to collect data pertinent to this study. They were the following:

**Pretest**  The pretest consisted of 30 multiple-choice items. Twelve items were developed to measure knowledge of basic electrical and electronic circuit theories; four items were developed to measure number system knowledge; eleven items were developed to
measure knowledge of logic gates and their characteristics; and three items were developed to measure student knowledge related to the concept of computer communication.

**Post-test**  The post-test was intended to measure whether students have acquired knowledge of minimization of Boolean functions during instruction. The test consisted of 30 multiple-choice questions which included the rules and laws of Boolean algebra, DeMorgan's theorem, the Karnaugh map, function simplification and circuit implementation, etc.

**Simulation program**

The computer simulation program used in this study was *Electronics Workbench*, developed by Interactive Image Technologies Ltd. This software requires a 386 or higher personal computer (PC) to be run, with at least 3 megabytes of random-access memory (RAM). This version of Electronics Workbench also requires Microsoft Windows version 3.1 or higher. The Electronics Workbench consists of two modules, one for analog circuits and one for digital.

**Variables of the Study**

The dependent variable in this study was the post-test score. The independent variables were: first four chapters exam, pretest, previous grade in IEDT 240, experimental/control group placement, section A/B placement and interaction, etc. The variables of this study and their scale types are shown in Table 3.
Table 3. Variables of the study

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Scale type</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>Posttest score</td>
<td>Interval</td>
<td>Dependent</td>
</tr>
<tr>
<td>X1</td>
<td>First four chapters exam</td>
<td>Interval</td>
<td>Independent</td>
</tr>
<tr>
<td>X2</td>
<td>Pretest</td>
<td>Interval</td>
<td>Independent</td>
</tr>
<tr>
<td>X3</td>
<td>Previous Grade in IEDT 240</td>
<td>Interval</td>
<td>Independent</td>
</tr>
<tr>
<td>X4</td>
<td>Experimental/control group placement</td>
<td>Nominal</td>
<td>Independent</td>
</tr>
<tr>
<td>X5</td>
<td>Section A/B placement</td>
<td>Nominal</td>
<td>Independent</td>
</tr>
<tr>
<td>X6=X4*X5</td>
<td>Interaction</td>
<td>Nominal</td>
<td>Independent</td>
</tr>
</tbody>
</table>

Statistical Treatment

The analysis of covariance (ANCOVA) was used to analyze the data. A "2 x 2" ANCOVA was used to compare the adjusted results of the control and experimental group's score, the differences due to sections, and the interaction of groups and sections.

Analysis

Type I and Type II error rate

Data were analyzed using the two-way, fixed-effects analysis of covariance procedure of the SAS (Statistical Analysis System) statistical software. Hypotheses were tested at the $\alpha$.
The estimate of a type II error at this type I level was .77 based on the post-test results and specification of an effect size of .5 standard deviation.

Hypotheses of the Study

For the purposes of this study, and to facilitate analysis, the following hypotheses were proposed:

**Hypothesis 1:** *There is no significant difference between the first four chapters examination (variable X1) means of the experimental and control groups at the 95% confidence level.*

This hypothesis examines the differences among the treatment groups regarding their prior knowledge of first four chapters.

\[ H_0 : \mu_{E,X1} = \mu_{C,X1} \]

\[ H_a : \mu_{E,X1} \neq \mu_{C,X1} \]

**Hypothesis 2:** *There is no significant difference between the pretest means (variable X2) of the experimental and control groups at the 95% confidence level.*

This hypothesis is included to assess the degree to which random placement in the experimental (learning minimization of Boolean functions with the computer tutorial and simulation program) and the control (learning minimization of Boolean function with traditional instruction) groups have created samples of subjects relatively equal in prior knowledge of basic electronics, electrical circuit number system and basic logic circuits.

\[ H_0 : \mu_{E,X2} = \mu_{C,X2} \]

\[ H_a : \mu_{E,X2} \neq \mu_{C,X2} \]

**Hypothesis 3:** *There is no significant difference in the experimental and the groups between the students' prior grade in IEDT 240 (variable X3) at the 95% confidence level.*
This hypothesis examines the degree to which random placement in the experimental and control groups has created samples of subjects relatively equal in prior knowledge.

\[ H_0 : \mu_{E, X3} = \mu_{C, X3} \]
\[ H_a : \mu_{E, X3} \neq \mu_{C, X3} \]

Hypothesis 4: There is no significant difference between the experimental and control groups' post-test means, adjusted for effects of the pretest, the first four chapters of the exam, and the students' prior grade, at the 95% confidence level.

This hypothesis examines the difference among the treatment groups regarding their knowledge of the concept of Boolean function minimization.

\[ H_0 : \mu^{*}_{E, \text{post}} = \mu^{*}_{C, \text{post}} \]
\[ H_a : \mu^{*}_{E, \text{post}} \neq \mu^{*}_{C, \text{post}} \]

Hypothesis 5: There is no significant difference between the post-test means of the section A and section B at the 95% confidence level.

This hypothesis examines the difference among sections A and B. Both different teaching methods were used simultaneously in each section.

\[ H_0 : \mu_{A, \text{post}} = \mu_{B, \text{post}} \]
\[ H_a : \mu_{A, \text{post}} \neq \mu_{B, \text{post}} \]

Hypothesis 6: There is no significant interaction effect between the group and the section on the post-test means at the 95% confidence level.

This hypothesis examines the difference between students in section A and section B in the traditional lecture versus the computer tutorial methods. Both teaching methods were used simultaneously in each section. The post-test means on each group and section as shown in Figure 5.
Figure 5. Post-test means on each group and section

\[
\begin{array}{ccc}
\text{Control} & & \text{Experimental} \\
\text{Section A} & \bar{Y}_{11} & \bar{Y}_{12} & \bar{Y}_1 \\
\text{Section B} & \bar{Y}_{21} & \bar{Y}_{22} & \bar{Y}_2 \\
\bar{Y}_1 & \bar{Y}_2 & \bar{Y}_. \\
\end{array}
\]

Hypothesis 7: The multiple linear correlation coefficient squared between the post-test and the weighted composition of measures 1, 2, 3, 4, 5 and 6 does not differ from 0.

\[
\begin{align*}
H_0 &: \mu_{AC} \cdot \mu_{BE} = \mu_{BC} \cdot \mu_{AE} \\
H_a &: \mu_{AC} \cdot \mu_{BE} \neq \mu_{BC} \cdot \mu_{AE}
\end{align*}
\]

Research Design

The design of the experiment consisted of two groups, one experimental group and one control group. The experimental group was comprised of 13 subjects who received instruction on minimization of Boolean functions using the computer tutorial and simulation.
program. The control group was comprised of 17 subjects who received instruction on minimization of Boolean functions using actual instruction (traditional lecture/practice). The assignment of the two groups is shown in Figure 6.

Description of the Computer Tutorial and Simulation Program

The computer tutorial/simulation program designed in this study used the Microsoft Visual Basic operating system. This software requires an IBM compatible machine with an 80286 processor or higher system, and with at least 1 megabyte of Random Access Memory (RAM). Microsoft Visual Basic also requires MS-DOS version 3.1 or later with SHARE.EXE running, and Windows version 3.0 or later in standard or enhanced mode.

The computer tutorial/simulation program attempted to enhance learning by providing the student an optimum level of interactively and control. Students could learn the program at their own pace, moving back and forth on the screen, controlling their progress. The

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Experimental</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEDT 246A</td>
<td>10</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>IEDT 246B</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>13</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 6. Research design of the study
computer tutorial/simulation program kept all student response information on a floppy disk automatically. The information included student's name, student's number, enter time or quit time of each unit, and the quiz score for each unit.

The computer tutorial/simulation program was set up in a computer laboratory with a IEDT 246 CAI group window and icon added to the Program Manager window. The simplest way to start this teaching program is to double-click on its icon in the Program Manager as shown in Figure 7. To present students with a clear, intuitive, and consistent view of the CAI program, the system created two boxes. The first box is a picture box which shows the circuits and figures, while the second box is a label box which show the teaching

![Program Manager Window](image)

Figure 7. The CAI group window and icon in the Program Manager window
contents. The teaching system, also called the simulation software: *Electronics Workbench* provides the simulation of logic circuit simplification and performance.

A Welcome page is shown when the student enters into the teaching program. The program requests the insertion of a floppy 3\(\frac{1}{2}\) disk and entry of some basic data as shown in Figure 8. There are five units in the instruction system. The five units are: (1) Introduction; (2) Forms of Boolean Algebra; (3) Rules and Laws of Boolean Algebra; (4) DeMorgan's Theorem; and (5) Karnaugh Map (shown in Figure 9).

Each teaching screen provides three buttons: the “PREV PAGE” button, which allows the student to return to the previous screen of the unit; the “NEXT PAGE” button,
Figure 9. The Main Menu page

which allows the student to continue to the next screen of the unit; and the "TO MENU" button, which allows the student to return to the Main menu and Exit to Windows (see Figure 10). There are three menus at the top of the screen: Backcolor, About, and Help. The Backcolor menu is provided for students to change the screen background color to their choice with five different color provided (see Figure 11). The About menu shows the copyright of this teaching program, which belongs to the Department of Industrial and Technology at Iowa State University (see Figure 12). The Help menu provides the students with information about how to use this teaching program. In addition, for each lesson, the
UNIT 1: INTRODUCTION

1. EXPRESSIONS FOR THE BASIC LOGIC FUNCTIONS

The NOT gate:

The operation of an inverter (NOT) can be expressed with symbols as follows: if the input variable is called \( A \) and the output variable is called \( X \), then

\[
X = \overline{A}
\]

Figure 10. A sample of unit 1

UNIT 1:

INTRODUCTION

Expressions for the Basic Logic Functions

Figure 11. The Backcolor menu
This teaching program belongs to Department of Industrial Education and Technology

Iowa State University

Designed by David Chen

Figure 12. The About menu

Page number and time are also displayed on the screen (see Figure 13).

One or two circuit simulations were designed for each unit, and the control system of the teaching program automatically calls the simulation software (Electronics Workbench). The simulation circuits and their descriptions were previously defined for this instruction. As shown in Figure 14, after simulation is completed, the teaching program will return to the tutorial unit. Each unit has at least one or two exercises with three questions. Students obtain an immediate response to each question (see Figure 15). The last part of each unit contains a ten questions quiz. The computer picks five of the ten-question by random, and each student receives different quiz questions (see Figure 16).
UNIT 1: INTRODUCTION

Figure 13. The Help menu

Exercise problem:

The Boolean equation for X is

\[ X = ((A + B) \cdot C) \cdot D \]

Please use rules and laws of Boolean Algebra to simplify this function, and confirm your answer.

Figure 14. A sample simulation
UNIT 3: RULES AND LAWS OF BOOLEAN FUNCTION

Review question:

1. Which Boolean law is used to transform the equation \((B+C)(A+D) = BA+BD+CA+CD\)?
   - 1. Commutative law
   - 2. Associative law
   - 3. Distributive law
   - 4. Conductive law

2. Which Boolean law is used to transform the equation \(A+BC+D = BC+D+A\)?
   - 1. Commutative law
   - 2. Associative law
   - 3. Distributive law
   - 4. Conductive law

3. Which Boolean law is used to transform the equation \(BCA = CAB\)?
   - 1. Commutative law
   - 2. Associative law
   - 3. Distributive law
   - 4. Conductive law

Figure 15. A sample exercise

UNIT 1: INTRODUCTION

Which factor must be considered when we minimized logic circuit?
   1. Propagation delay
   2. Cost
   3. Power dissipation
   4. All of above

Figure 16. A sample quiz
Unit 1 - Introduction, contains the introduction which teaches students the basic concepts of the expressions used in basic logic functions and the concepts of gate minimization. The main purpose of this unit is to provide a review of the basic concepts of logic gates, describe a logic function and how to determine the circuit required to implement or produce the function, and teach students the concepts of gate minimization.

Unit 2 - Form of Boolean Expression consists of two parts. The first part is how to design logic circuits from a Boolean expression. The form of a given Boolean expression indicates the type of gate network it describes. The form of the Boolean expression determines how many logic gates are used, what type of gates are needed, and how they are connected together. The more complex an expression is, the more complex the gate network will be. There are also certain forms of Boolean expressions that are more desirable or more widely used than others. The second part of this unit introduces the terms and forms of Boolean functions, such as a minterm, maxterm, sum-of products and the product-of-sums.

Unit 3 - Rules and Laws of Boolean algebra includes three of the basic laws of Boolean algebra (the commutative laws, the associative laws, and the distributive laws) and the ten basic rules that are useful in manipulating and simplifying Boolean algebra expressions.

Unit 4 - De Morgan's Theorem includes two forms. The theorem expressed can be stated as the complement of a product is equal to the sum of the complements, and The complement of a sum is equal to the product of the complements. There were several examples designed for students that provide students with exercises for practice.
Unit 5 - Karnaugh Map is another approach for reducing a Boolean expression to its simplest or minimum form. The method is systematic and easily applied. When students use it properly, it will always result in the minimum expression possible. The content of this unit involve the construction of a Karnaugh map, the concept of adjacent cells, factoring or grouping on a Karnaugh map, and writing representative terms of each group.
CHAPTER IV. RESEARCH RESULTS AND FINDINGS

The results of the data analysis are presented in this chapter. The primary purpose of this study was to determine if the computer tutorial/simulation program was an effective way of learning minimization of a logic function. The independent variables consisted of two tests, a prior electronics course grade, experimental/control group placement, section A/B placement, and the interaction between group and section. The dependent variable was the post-test score. These variables were used to examine the seven hypotheses presented in Chapter III. The purpose of the pretest was to test prior knowledge of electrical and electronics theories. The post-test was designed to test the knowledge of minimization of Boolean function. The exam covering the first four chapters determined prior knowledge of digital circuit theories. The results are presented using descriptive and inferential statistics. Descriptive statistics describe general statistical measures such as mean, standard deviation, etc. while inferential statistics employ a series of analyses of variance: one-way ANOVA, ANCOVA, two-way ANOVA, squared multiple correlations, and multiple regression.

General Characteristics of the Sample

The descriptive statistics are discussed in this section. The descriptive statistics resulting from the pretest are shown in Table 4. The means and standard deviations for the control and experimental groups were 60.29 (10.23) and 62.69 (11.19), respectively; and for sections A and B they were 62.33 (11.49) and 59.83 (9.19), respectively. The overall mean and standard deviation for all students were 61.33 and 10.54, respectively.
Table 4. Means and standard deviations on the pretest

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>17</td>
<td>60.29</td>
<td>10.23</td>
</tr>
<tr>
<td>Experiment</td>
<td>13</td>
<td>62.69</td>
<td>11.19</td>
</tr>
<tr>
<td>Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEDT 246A</td>
<td>18</td>
<td>62.33</td>
<td>11.49</td>
</tr>
<tr>
<td>IEDT 246B</td>
<td>12</td>
<td>59.83</td>
<td>9.19</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>61.33</td>
<td>10.54</td>
</tr>
</tbody>
</table>

The means and standard deviations for each group in both sections are shown in Table 5. Means and standard deviations for the control group, sections A and B, were 61.10 (12.52) and 59.14 (6.44), respectively. The means and standard deviations for the experimental group in sections A and B were 63.88 (10.71) and 60.80 (12.96), respectively.

Table 5. Means and standard deviations of the pretest for each group in each section

<table>
<thead>
<tr>
<th>Variable</th>
<th>IEDT 246A</th>
<th>IEDT 246B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>10</td>
<td>61.10</td>
</tr>
<tr>
<td>Experimental</td>
<td>8</td>
<td>63.88</td>
</tr>
</tbody>
</table>
The statistical results of the students' prior grades in IEDT 240 are shown in Table 6. All students enrolled in IEDT 246 should have already taken the IEDT 240 Fundamentals of Electronics class where they were exposed to the basic concepts of electronics circuits. However, there were six students who did not meet this requirement and were taking both courses in this semester. Only 24 students had prior grades in IEDT 240.

The means and standard deviations of the exam covering the first four chapters by group and section are shown in Table 7, with a breakdown by each group in each section shown in Table 8. The means and standard deviations for the control group in section A and section B were 87.90 (4.04) and 87.14 (5.11), respectively. The means and standard deviations for the experimental group in section A and section B were: 85.75 (9.59) and 88.00 (6.78), respectively.

Table 6. Means and standard deviations of the students' prior grades by group and section

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
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<td></td>
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<td>.87</td>
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<tr>
<td>Experiment</td>
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<td>2.933</td>
<td>.78</td>
</tr>
<tr>
<td>Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEDT 246A</td>
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<td>2.933</td>
<td>.80</td>
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<tr>
<td>IEDT 246B</td>
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<td>2.926</td>
<td>.89</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>2.930</td>
<td>.82</td>
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</table>
Table 7. Means and standard deviations on first four chapters exam

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>17</td>
<td>87.59</td>
<td>4.37</td>
</tr>
<tr>
<td>Experiment</td>
<td>13</td>
<td>86.62</td>
<td>8.38</td>
</tr>
<tr>
<td>Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEDT 246A</td>
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<td>86.94</td>
<td>6.91</td>
</tr>
<tr>
<td>IEDT 246B</td>
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<td>87.50</td>
<td>5.58</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>87.16</td>
<td>6.31</td>
</tr>
</tbody>
</table>

The mean and standard deviations of the post-test by group and section are shown in Table 9, with a breakdown by each group in each section shown in Table 10. The means and standard deviations for the control group in section A and section B were 59.70 (8.55) and 63.71 (13.07), respectively. The means and standard deviations for the experimental

Table 8. Means and standard deviations of first-four chapters exam for each group in each section

<table>
<thead>
<tr>
<th>Section</th>
<th>IEDT 246A</th>
<th>IEDT 246B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>10</td>
<td>87.90</td>
</tr>
<tr>
<td>Experiment</td>
<td>8</td>
<td>85.75</td>
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</tbody>
</table>
Table 9. Means and standard deviations on the post-test

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
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<td>Group</td>
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<td>Control</td>
<td>17</td>
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<td>13</td>
<td>63.46</td>
<td>13.48</td>
</tr>
<tr>
<td>Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEDT 246A</td>
<td>18</td>
<td>63.89</td>
<td>11.61</td>
</tr>
<tr>
<td>IEDT 246B</td>
<td>12</td>
<td>59.83</td>
<td>11.89</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>62.27</td>
<td>11.69</td>
</tr>
</tbody>
</table>

Table 10. Means and standard deviations of post-test for each group in each section

<table>
<thead>
<tr>
<th>Variable</th>
<th>IEDT 246A</th>
<th>IEDT 246B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Mean</td>
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<tr>
<td>Group</td>
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<td></td>
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<tr>
<td>Control</td>
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<td>59.70</td>
</tr>
<tr>
<td>Experiment</td>
<td>8</td>
<td>69.13</td>
</tr>
</tbody>
</table>

group in the section A and the section B were 69.13 (13.29) and 54.4 (8.32), respectively.

The average time spent in the computer tutorial/simulation program by student in the experimental group is shown in Table 11. The mean and standard deviation of was 142.69 and 66.29, respectively. The standard deviation in section B was 101.06, due to the longest and shortest time being in section B. The longest time spent was 303 minutes while the
Table 11. The average time spent in the CAI program

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean(min.)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section A</td>
<td>8</td>
<td>132.62</td>
<td>37.37</td>
</tr>
<tr>
<td>Section B</td>
<td>5</td>
<td>158.80</td>
<td>101.06</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>142.69</td>
<td>66.29</td>
</tr>
</tbody>
</table>

shortest time spent was 40 minutes. Figure 17 shows a histogram of student time spent studying the computer tutorial/simulation program. It is interesting to note than only one student spent the longest amount of time which was over 300 minutes, 100 minutes longer than the next longest time.

Figure 17. Histogram of time spent by students in experimental group
Tests of Hypotheses

This section is devoted to tests of the research hypotheses. Seven hypotheses were presented in Chapter 3. The results of the hypothesis testing are presented and discussed in considerable detail as follows.

Hypothesis 1: There is no significant difference between the first four chapters examinations’ means (variable XI) of the control and experimental groups at the 95% confidence level.

Ho : \( \mu_{E, XI} = \mu_{C, XI} \)

Ha : \( \mu_{E, XI} \neq \mu_{C, XI} \)

The purpose of this hypothesis was to confirm that the groups were not initially different in prior knowledge of basic digital theories. The mean score of the exam covering first four chapters by the control group was 87.59, while the mean for the experimental group was 86.62 (Table 5). As shown in Table 12, the results of the ANOVA revealed the difference between the two means was not significant: \( F(1, 29) = .17; p = .68 \). The p value was much greater than .05, therefore, hypothesis 1 was retained. It was concluded that the random placement of subjects in the experimental and control groups created samples with relatively equal prior knowledge of basic digital theories.

Another ANOVA was used to examine whether there was a significant difference between sections A and B on the exam covering the first four chapters (Table 13). The means for students in IEDT 246A and IEDT 246B were 86.94 and 87.5, respectively. These means were not significantly different, indicating students who enrolled in section A and B did not have significantly different levels of learning in the first four chapters.
Table 12. Results of the ANOVA of the exam on the first four chapters by group

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effect</td>
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<td>1</td>
<td>6.97</td>
<td>.17</td>
<td>.68</td>
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<tr>
<td>Residual</td>
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<td>28</td>
<td>41.04</td>
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</tr>
<tr>
<td>Total</td>
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<td>29</td>
<td></td>
<td></td>
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</tbody>
</table>

Table 13. Results of the ANOVA of the exam on the first four chapters by section

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
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<tr>
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<td>2.22</td>
<td>.05</td>
<td>.82</td>
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<tr>
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<td>1153.94</td>
<td>28</td>
<td>41.21</td>
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</tr>
<tr>
<td>Total</td>
<td>1156.17</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Hypothesis 2: There is no significant difference between the pretest means (variable $X_2$) of the control and experimental groups at the 95% confidence level.

$H_0 : \mu_{E,X_2} = \mu_{C,X_2}$

$H_a : \mu_{E,X_2} \neq \mu_{C,X_2}$

The purpose of this hypothesis was to assess the degree to which random placement in the experimental (learning minimization of Boolean functions with the computer tutorial/simulation program) and control (learning minimization of Boolean functions with traditional instruction) groups had created samples of subjects relatively equal in prior knowledge of basic electronics, electrical theories, number system and basic computer concepts. The overall mean of the pretest scores for the students in the control group was
60.29, and the mean for the experimental group was 62.6. The results of the analysis of variance is shown in Table 14. They revealed that the difference between two means was not significant, $F(1,29) = .37; p = .55$. The p value was much greater than .05, therefore, hypothesis 2 was not rejected.

Another analysis of variance was used to examine whether there was a significant difference between the two sections on the pretest (Table 15). The means for students in IEDT 246A and IEDT 246B were 62.33 and 59.83, respectively. These two means were not significantly different, $F(1, 29) = .40; p = .53$ (also shown in Table 15), indicating that students who enrolled in the two difference sections did not have different levels of

Table 14. Results of the ANOVA on the pretest by group

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
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<th>Prob. &gt; F</th>
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<tr>
<td>Main Effect</td>
<td>42.37</td>
<td>1</td>
<td>42.37</td>
<td>.37</td>
<td>.55</td>
</tr>
<tr>
<td>Residual</td>
<td>3180.30</td>
<td>28</td>
<td>113.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3222.67</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 15. Results of the ANOVA on the pretest by section

<table>
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<tr>
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<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effect</td>
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<td>1</td>
<td>45.00</td>
<td>.40</td>
<td>.53</td>
</tr>
<tr>
<td>Residual</td>
<td>3177.67</td>
<td>28</td>
<td>113.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3222.67</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
prior knowledge of basic electronics, electrical theories, number system and basic computer concepts.

**Hypothesis 3:** There is no significant difference between the students' prior grades in IEDT 240 (variable X3) of the control and the experimental groups at the 95% confidence level.

\[ H_0 : \mu_{E, X3} = \mu_{C, X3} \]

\[ H_a : \mu_{E, X3} \neq \mu_{C, X3} \]

The purpose of this hypothesis was to examine the degree to which random placement in the experimental and control groups created samples of subjects relatively equal in prior knowledge. For the students' prior grades in IEDT 240 as shown in Table 16, the total mean score was 2.93. The mean for the students in both the control group and experimental group was 2.93. An analysis of variance resulted in an \( F(1, 23) = .00; p = .99 \). Therefore, the difference between the two means was not significant.

Because 20% of the students did not have prior grades, a multiple regression table was constructed (shown in Table 17) and the 24 students' three tests score were used to predict the six other missing student's prior grades. The formula used to predict student's prior

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effect</td>
<td>0.00</td>
<td>1</td>
<td>.00</td>
<td>.00</td>
<td>.99</td>
</tr>
<tr>
<td>Residual</td>
<td>15.28</td>
<td>22</td>
<td>.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15.28</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 17. A GLM table to predict students' prior grades by three tests

| Parameter | Estimate | T for Ho | Pr > |T| | Std Error of Estimate |
|-----------|----------|----------|------|---|----------------------|
| Intercept | -1.654   | -.75     | .46  |   | 2.20                 |
| Exam      | .037     | 1.36     | .19  |   | .03                  |
| Pretest   | .013     | .60      | .55  |   | .02                  |
| Post-test | .008     | .55      | .59  |   | .01                  |

prior grade = -1.654 + .037*Exam + .013 * Pretest + .008 * Post-test

All 30 student's prior grade means, including the six predicted prior grades, are shown in Table 18. For the students' prior grades in IEDT 240 class, the total mean score was 2.90, the mean for students in both the control group and the experimental groups were 2.90. An analysis of variance revealed that F(1,23) = .00, p = .99. The difference between the two means was not significant. Therefore, hypothesis 3 was retained.

Table 18. Results of the ANOVA on students' prior grades of IEDT 240 by group, including all students

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effect</td>
<td>0.00</td>
<td>1</td>
<td>.00</td>
<td>.00</td>
<td>.99</td>
</tr>
<tr>
<td>Residual</td>
<td>16.06</td>
<td>28</td>
<td>.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16.06</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hypothesis 4: *There is no significant difference between the control and experimental group post-test means, adjusted for effects of the pretest, exam and prior grades at the 95% confidence level.*

\[ H_0 : \mu_{E, \text{post}} = \mu_{C, \text{post}} \]

\[ H_a : \mu_{E, \text{post}} \neq \mu_{C, \text{post}} \]

The purpose of this hypothesis was to examine the difference among the treatment groups regarding their knowledge of Boolean function minimization. The pretest, the exam on first four chapters, and students' prior grades were used as the covariates to reduce the error variance term of the analysis by the degree to which the post-test score correlates with the pretest score, first four chapters exam, and prior grades.

The means and standard deviations on the post-test were summarized in two categories as shown in Table 9 and Table 10. The means and standard deviations for the control and experimental group of IEDT 246 were 61.35 (10.46) and 63.46 (13.48), respectively. The means and standard deviations for the different sections A and B were 63.89 (11.61), respectively. The overall mean and standard deviation was 62.27 (11.69).

Table 19 shows the results of a one-way analysis of covariance on the post-test. The purpose was to adjust the post-test with the covariates of the pretest, the exam on the first four chapters, and students' prior grades. The analysis of the adjusted post-test scores indicate that there was no significant difference for the group main effect (\( F(1, 25) = .26; P = .62. \)) This indicates the subjects' performance was not affected by the instructional method (traditional lecture/practice vs. computer tutorial/simulation) in which they participated. Therefore, hypothesis 4 was retained.
Table 19. One-way ANCOVA on the post-test

<table>
<thead>
<tr>
<th>Source</th>
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<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
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<tr>
<td>Covariates</td>
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<td>678.62</td>
<td>5.33</td>
<td>.03</td>
</tr>
<tr>
<td>Exam</td>
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<td>16.34</td>
<td>0.13</td>
<td>.72</td>
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<tr>
<td>Prior grades</td>
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<td>54.99</td>
<td>0.43</td>
<td>.52</td>
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<tr>
<td>Main Effect</td>
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<td></td>
</tr>
<tr>
<td>Group</td>
<td>32.75</td>
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<td>32.75</td>
<td>.26</td>
<td>.62</td>
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<tr>
<td>Explained</td>
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<td>195.67</td>
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<table>
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<td>2.20</td>
<td>.02</td>
<td>.89</td>
</tr>
<tr>
<td>Prior grades</td>
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<td>1</td>
<td>54.99</td>
<td>.43</td>
<td>.52</td>
</tr>
<tr>
<td>Main effect</td>
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</tr>
<tr>
<td>Group</td>
<td>9.62</td>
<td>1</td>
<td>9.62</td>
<td>.08</td>
<td>.79</td>
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</table>

The type III sum of squares for the pretest, the exam on the first four chapters, and students' prior grades were 383.15, 2.20, and 54.99, respectively. Comparing the p values, it is obvious that pretest, exam and prior grades did not have a significant effect on the post-test scores. The Type I SS measures incremental sums of squares for the model as each variable is added. The Type III SS is the sum of squares due to adding that variable last in the model.
A two-way ANCOVA was used to examine whether there was an interaction between section and group. Table 20 shows the values of type I and type III sum of squares for the covariates pretest, exam on first four chapters, and students' prior grades. The experimental/control grouping, and section placement had no significant effect on the post-test scores. An interaction between group and section showed that there was a significant effect on the post-test scores.

Hypothesis 5: There is no significant difference between the post-test means of section A and section B at the 95% confidence level.

\[ H_0 : \mu_{A,post} = \mu_{B,post} \]

\[ H_a : \mu_{A,post} \neq \mu_{B,post} \]

The purpose of hypothesis 5 was to examine the difference between sections A and B. Both teaching methods were used simultaneously in each section. Table 21 shows that \( F(1, 28) = .86, p = .36 \), indicating that there was no significant difference between the two sections.

Table 22 shows the result of a one-way analysis of covariance on the post-test. The adjusted post-test scores were not significantly different for the sections (\( F(1, 25) = .95, p = .34 \)). This indicates subjects' performance was not affected by the section placement. Therefore, hypothesis 5 was retained.
Table 20. Two-way ANCOVA on the post-test

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<tr>
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<td>591.74</td>
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<tr>
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<td>70.85</td>
<td>.65</td>
<td>.43</td>
</tr>
<tr>
<td>Prior grades</td>
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<td>17.10</td>
<td>.16</td>
<td>.70</td>
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<th>MS</th>
<th>F</th>
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<tr>
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<td>282.12</td>
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<tr>
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<td>1</td>
<td>43.25</td>
<td>.40</td>
<td>.54</td>
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<tr>
<td>Prior grades</td>
<td>17.10</td>
<td>1</td>
<td>17.10</td>
<td>.16</td>
<td>.70</td>
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<tr>
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<td>115.11</td>
<td>1.05</td>
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<th>F</th>
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<tr>
<td>Interactions</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Group * Section</td>
<td>618.39</td>
<td>1</td>
<td>618.39</td>
<td>5.65</td>
<td>.03*</td>
</tr>
</tbody>
</table>

Explained: 1445.95  6  240.99  2.20  .08
Residual: 2517.92  23  109.47
Total: 3963.87  29

<table>
<thead>
<tr>
<th>Source Type</th>
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<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
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<tr>
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<tr>
<td>Group</td>
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<td>2.08</td>
<td>.02</td>
<td>.89</td>
</tr>
<tr>
<td>Section</td>
<td>147.43</td>
<td>1</td>
<td>147.43</td>
<td>1.35</td>
<td>.26</td>
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</table>

Interaction: Group * section 594.03  1  594.03  5.43  .03*

* P < .05
Table 21. Results of the ANOVA on the post-test by section

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
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<td>118.42</td>
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<td>.36</td>
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<tr>
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<td>137.38</td>
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<tr>
<td>Total</td>
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<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 22. Results of the ANCOVA on the post-test by section

<table>
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<tr>
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<th>DF</th>
<th>MS</th>
<th>F</th>
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</tr>
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<tbody>
<tr>
<td>Covariate</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
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<td>1</td>
<td>646.53</td>
<td>5.46</td>
<td>.03</td>
</tr>
<tr>
<td>Exam</td>
<td>19.82</td>
<td>1</td>
<td>19.82</td>
<td>.16</td>
<td>.69</td>
</tr>
<tr>
<td>Prior grades</td>
<td>57.53</td>
<td>1</td>
<td>57.53</td>
<td>.46</td>
<td>.50</td>
</tr>
<tr>
<td>Main Effect</td>
<td>118.42</td>
<td>1</td>
<td>118.42</td>
<td>.95</td>
<td>.34</td>
</tr>
<tr>
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<td>124.86</td>
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</tr>
<tr>
<td>Total</td>
<td>3963.87</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Hypothesis 6: There is no significant interaction effect between groups and sections on the post-test means at the 95% confidence level.

\[ H_0: \mu_{AC} \cdot \mu_{BE} = \mu_{BC} \cdot \mu_{AE} \]

\[ H_a: \mu_{AC} \cdot \mu_{BE} \neq \mu_{BC} \cdot \mu_{AE} \]

The purpose of hypothesis 6 was to examine the difference between the subjects in section A and section B on the traditional lecture versus computer tutorial methods. Both teaching methods were used simultaneously in each section.
Figure 18 shows that there was interaction between experiment and control groups on the post-test means. As was observed in Table 20, there was a significant interaction between groups and sections: $F(1,23) = 5.65, p = .03$. It was concluded that the interaction between groups and sections had a significant effect on the post-test scores.

![Figure 18. Interaction between groups and sections](image)

Hypothesis 7: The multiple linear correlation coefficient squared between the posttest and the weighted composition of measures 1, 2, 3, 4, 5 and 6 does not differ from 0.

\[ H_0 : R^2_{Y,X1,X2,X3,X4,X5,X6} = 0 \]

\[ H_a : R^2_{Y,X1,X2,X3,X4,X5,X6} \neq 0 \]  

where \( Y \) = Posttest  
\( X1 \) = Prior grades in IEDT 246  
\( X2 \) = First four chapters exam  
\( X3 \) = Pretest  
\( X4 \) = Experimental/control group placement  
\( X5 \) = Section A/B placement  
\( X6 \) = Interaction

The purpose of the last hypothesis was to examine the degree to which all the independent variables are related to the achievement of Boolean algebra minimization. The correlation coefficient was computed for all subjects. The value of the correlation for the full
model was $R^2 = .365$, $p = .08$ (Table 23). Thus, as already evidenced in Table 20, hypothesis 7 was retained.

The value of the correlation for the restricted model was $R^2 = .215$, $p = .29$ (Table 24). Comparing the full and restricted models again demonstrated support for rejecting hypothesis 6 supported by Table 20. The slight difference in sums of squares in these two analyses is due to the unbalanced sample sizes (disproportionally).

The two models from the Table 20 and Table 21 were compared using by formula:

$$F_{n,d} = \frac{(R^2_{\text{Full}} - R^2_{\text{Restricted}})}{[(1 - R^2_{\text{Full}}) / 23]}$$

So that, $F_{1,23} = (.365 - .215) / [1 - .365] / 23 = 5.44$, as previously shown in Table 20.

Table 23. Regression analysis for the full model on the post-test

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effect</td>
<td>1445.95</td>
<td>6</td>
<td>240.99</td>
<td>2.20</td>
<td>.08</td>
<td>.365</td>
</tr>
<tr>
<td>Residual</td>
<td>2517.92</td>
<td>23</td>
<td>109.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3963.87</td>
<td>29</td>
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</tr>
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</table>

Table 24. Regression analysis for the restricted model on post-test

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Prob. &gt; F</th>
<th>$R^2$</th>
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<tr>
<td>Main Effect</td>
<td>851.91</td>
<td>5</td>
<td>170.38</td>
<td>1.31</td>
<td>.29</td>
<td>.215</td>
</tr>
<tr>
<td>Residual</td>
<td>3845.44</td>
<td>28</td>
<td>137.38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3963.87</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The results indicate a significant difference between the two models. This confirms that the interaction between group and section affected the post-test. It should be noted that one model is slightly unbalanced, that is, the ratio of sample sizes of the experimental to control group is different for the two sections. Therefore, the interaction effects are not completely independent of section or experimental/control group effects.

**Summary of Hypothesis Testing**

This chapter reviewed the inferential statistics which included testing the seven hypotheses stated in Chapter 3. This section reviews the results of the hypothesis testing in a summary form.

*Hypothesis 1 (Retained)*: No significant difference was found between the first four chapters examinations' means of the control and experimental groups.

*Hypothesis 2 (Retained)*: No significant difference was found between the pretest means of the control and experimental groups.

*Hypothesis 3 (Retained)*: No significant difference was found between the students' prior grades in IEDT 240 of the control and experimental groups.

*Hypothesis 4 (Retained)*: No significant difference was found between the control and experimental group post-test means, adjusted for the pretest, exam and prior grades.

*Hypothesis 5 (Retained)*: No significant difference was found between the post-test means of section A and section B.

*Hypothesis 6 (Rejected)*: Significant interaction was found between groups and sections on the post-test means.
Hypothesis 7 (Retained): The multiple linear correlation coefficient squared between the post-test and the weighted composition of prior grades in IEDT 240, first four chapters exam, pretest, experimental/control group placement, section A/B placement, and interaction between groups and sections does not differ from 0.
CHAPTER V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Within the preceding four chapters of this study, the problem of the study, purpose, literature review, methodology, and data analysis were presented. The purpose of this chapter is to summarize the previous chapters, findings, and draw conclusions based on the findings and present recommendations.

Summary

The purpose of this study was to compare and evaluate the effectiveness of computer tutorial/simulation instruction versus traditional/practice instruction for educating college students about the minimization of Boolean algebra.

The sample for this study was comprised of 30 students: 17 students were in IEDT 246A, and 13 students were in IEDT 246B. The students were enrolled during the spring semester of 1995, in the Department of Industrial Education and Technology at Iowa State University.

Students in the two sections were randomly assigned to one of the two groups: 17 subjects and 13 subjects were in the control group and experimental group, respectively. The research design was a 2 (groups) x 2 (sections) factorial design in the post-test.

Boolean function minimization skills were taught during the sixth and seventh week of the semester. Four hours were used to teach the control group the concepts and theories of minimization of Boolean functions by lecture, and another four hours were used to conduct laboratory experiments using real electronic components. The experimental group used the
computer tutorial/simulation program for eight hours during the sixth and seventh weeks. During the eighth week, a post-test was administered to all subjects to measure the students' knowledge of minimization of Boolean functions.

The data were gathered and analyzed from the pretest, the first four chapters exam, students' prior grades from IEDT 246, and the post-test. The findings are discussed as follows:

1. Random placement of students in the experimental and control groups created samples of subjects relatively equal in prior knowledge of electrical and electronics theories, and basic logic circuit theories.

2. The average time spent for the computer tutorial/simulation program in the experiment group was 142.91 minutes (2.37 hours), which was a much shorter lapse of time as compared to the control group (8 hours).

3. Students not only learned the computer tutorial/simulation program at their own pace, but also studied or quit the teaching program at any time. Hence, most of the students in the experimental group did not attend the computer laboratory during the regular class time.

4. The means for the two groups on the first four chapters exam were somewhat high, with values ranging from 66 to 98, indicating a high degree of background knowledge prerequisite to the material to be learned during this experiment.
5. The scores for the experimental and control groups on the post-test varied in range, with values ranging from 40 to 94 in the experimental group, a 54 point difference as compared to 42 points in the control group.

6. Students in the experimental group had not learned how to use the *Electronic Workbench* simulation program before this research. Therefore, the researcher needed to spend about 20 minutes to explain the basic procedures on how to handle the simulation program.

**Findings by hypothesis**

Seven hypotheses were tested and the results of the tests are summarized as follows. Hypotheses 1, 2 and 3 were tested using the one-way ANOVA procedure. Hypothesis 4 and 5 were tested using the ANCOVA procedure. Hypotheses 6 was tested using the ANCOVA procedure and with a multiple linear regression procedure. Hypothesis 7 was tested using the ANCOVA procedure and with a multiple regression procedure. All the hypotheses were tested at the .05 level of significance.

*Hypothesis 1*  The purpose of this hypothesis was to determine if significant differences existed in the first four chapters examinations' means between the control and experimental groups. No significant differences were found between two groups.

*Hypothesis 2*  The purpose of this hypothesis was to determine if significant differences existed in the pretest means between the control and experimental groups. No significant differences were found between two groups.
Hypothesis 3 The purpose of this hypothesis was to determine if significant
differences existed in the students’ prior grades between the control and experimental groups.
No significant differences were found between the two groups.

Hypothesis 4 The purpose of this hypothesis was to determine if significant
differences existed in the post-test means, adjusted for effects of the pretest, exam and prior
grades between the control and experimental groups. No significant differences were found
between the two groups.

Hypothesis 5 The purpose of this hypothesis was to determine if significant
differences existed in the post-test means between section A and section B. No significant
differences were found between two sections.

Hypothesis 6 The purpose of this hypothesis was to determine if a significant
interaction existed in post-test means between the groups and sections. Significant
interactions were found between groups and sections.

Hypothesis 7 The purpose of this hypothesis was to examine the degree to which all
the independent variables were related to the achievement of dependent variables.

Discussion

The overall outcome of this study suggested that students who used computer
tutorial/simulation as a tool for enhancing achievement in IEDT 246 (digital electronics)
performed similarly with the students who had not received computer simulation. The
discussion is divided into two parts: observations and limitations.
Observations

During this study some additional observations were made by the researcher:

1. *The attitude of students* – The students in the experimental group did not have high motivation or show high expectation for this study and their grades due to the fact that students were told before this study that their participation was entirely voluntary, and did not affect their final grades at the end of semester. Therefore, most students spent little time on this teaching program, or read the materials only once for each teaching unit, and did not think in more detail about how the materials and simulation results in the computer. From the students’ records, only two students used this teaching program for more than three hours, four students took less than two hours, and one student took less than one hour. It may be possible that students would have achieved higher scores if they spent more time using the program or if students were asked to go to the computer laboratory to study as in the regular course hours. Nevertheless, a comparison of post-test scores between control and experimental groups revealed no significant difference.

2. *Prior knowledge of students about Boolean algebra minimization* – In the pretest, five questions had a very low response rate. Among 30 multiple choice items, the proportion of correct responses for items 4 and 18 were extremely low. These two items and their means and standard deviations are shown in Table 25.

For items 4 and 18, the correct answers are Mho and Demultiplexer, respectively. Students did not respond correctly for item 18 because they lacked prior background of digital circuits. It is not surprising that the correct answer was so low proportionately. Item 4
Table 25. The means and standard deviations of items 4 and 18 on the pretest (N = 31)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. The unit of conductance is</td>
<td>0.23</td>
<td>0.43</td>
</tr>
<tr>
<td>A. Farad</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Henry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Mho</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Ohm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Which component will be chosen when we want to select one bit data from several sources of data input?</td>
<td>0.13</td>
<td>0.34</td>
</tr>
<tr>
<td>A. Decoder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Encoder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Demultiplexer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Multiplexer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

is a basic electrical concepts question that students should have learned before this semester, but most students chose Farad and Henry which are the units of inductance and capacitance. From items 1 to 3, and items 5 to 9, students responded well. Obviously, students had a good background of direct current (DC) circuit theories, but had poor knowledge of alternating current (AC) circuit theories.

In basic electronics theories, items 10, 11, and 12 also had a poor response. The items and their means and standard deviations are shown in Table 26. The correct answers to those items are “C”. Items 10 is a basic operational amplifier concept, and items 11, and 12 are basic transistor circuit theories that most students were expected to learn before this semester. Obviously, students had poor background knowledge of electronic circuit theories.
Table 26. The means and standard deviations of items 10, 11, and 12 on the pretest (N = 31)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
</table>
| 10. Which attribute is not an ideal operational amplifier?  
A. Infinite gain  
B. Infinite input impedance  
C. Infinite output impedance  
D. All of the above | .42 | .50 |
| 11. In TTL families, the transistor function as a switch, the bias voltage among C, B and E are:  
A. C B forward bias, B E reverse bias  
B. C B reverse bias, B E reverse bias  
C. C B forward bias, B E forward bias  
D. C B reverse bias, B E forward bias | .39 | .50 |
| 12. To use a common-emitter transistor circuit as an inverter, the output signal is taken from the  
A. Base  
B. Emitter  
C. Collector  
D. Source | .35 | .49 |

3. Effects of computer tutorial/simulation program on the minimization of Boolean algebra – In the post-test, the results revealed that there were no differences between control and experimental groups. On the DeMorgan’s theorem items, the proportion of correct responses to items 10, 11, and 12 was very low. These three items and their means and standard deviations are shown in Table 27.

For items 10, 11, and 12, the correct answers are A, D, and B. Students in both groups were not proficient on the DeMorgan’s theorem. This theorem is very easily confused
with the Boolean algebra equation form if students do not practice it several times in the
exercises. Because only two weeks were allotted to teach this chapter, the students may not
have had enough time to practice this topic.

For the function simplification questions, item 18 received the lowest correct response
of all the test items (Table 28). The correct answer to item 18 is D. It may be that students
chose DeMorgan’s theorem method to simplify this item using their intuition. Due to the fact
that they were not proficient in use of DeMorgan’s theorem, most got the wrong answer. In
fact, rules of Boolean algebra may be used to simplify the Boolean equation. This method
provided an easier solution when compared to DeMorgan’s theorem. This kind of application
item requires students to select a solution method which seems a little difficult to a novice.

In circuit implementation items, the proportion of correct responses to item 30 was
also too low. The item and its mean and standard deviations are shown in Table 29. The
correct answer to item 30 is D (NOR gate). This item is an analysis question of three-variable
logic gates where students just write the truth table from the output waveform. They may use
the observation method or write the output Boolean function. To determine the kind of gate
represented, the easiest way to solve this item is to expand the function first, and then use
rules 4 and 5. Students were evidently not familiar with the output waveform of logic gates.

Among seven of the Karnaugh map items, the proportion of correct responses for
items 19 and 20 were very low. The items and their means and standard deviations are shown
in Table 30. For items 19 and 20, the correct answers are C and A, respectively. These two
Table 27. The means and standard deviations of items 10, 11, and 12 on the post-test (N = 30)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>.34</td>
<td>.48</td>
</tr>
<tr>
<td>11.</td>
<td>.31</td>
<td>.47</td>
</tr>
<tr>
<td>12.</td>
<td>.31</td>
<td>.47</td>
</tr>
</tbody>
</table>

10. For the circuit shown in follow, the function \( X \) is:

A. \( A + B \)  
B. \( \bar{A} + \bar{B} \)  
C. \( AB \)  
D. \( \bar{A} \bar{B} \)

11. For the circuit shown in follow, the function \( X \) is:

A. \( AB + \bar{C} \bar{D} \)  
B. \( \bar{A} \bar{B} + CD \)  
C. \( A + B + \bar{C} + \bar{D} \)  
D. \( \bar{A} + \bar{B} + C + D \)

12. For the circuit shown in follow, the function \( X \) is:

A. \( A + B \)  
B. \( \bar{A} + \bar{B} \)  
C. \( AB \)  
D. \( \bar{A} + \bar{B} \)
Table 28. The means and standard deviations of item 18 on the post-test (N = 30)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>18. The logic circuit for the following equation, the simplified equations is:</td>
<td>.14</td>
<td>.35</td>
</tr>
</tbody>
</table>

\[ X = A \overline{B} + A(\overline{A} + C) \]

A. \((A \overline{B})(A + A C)\)  
B. \((\overline{A} + \overline{B})(\overline{A} + \overline{A} C)\)  
C. \((A + \overline{B}) \overline{A}\)  
D. \(\overline{A}\)

Table 29. The means and standard deviations of item 30 on the post-test (N = 30)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>30. The output waveform at X shown as follows, the logic gate should be:</td>
<td>.34</td>
<td>.48</td>
</tr>
</tbody>
</table>

\[ \begin{array}{c}
\text{A} \\
\text{B} \\
\text{C} \\
\text{X} \\
\end{array} \]

A. AND gate  
B. NAND gate  
C. OR gate  
D. NOR gate
items not only test students' knowledge of the Karnaugh map in simplified concepts, but it also tests their application and analysis ability. Students seemed to grasp the basic concepts of Karnaugh map theories because they did a good job on the other five items. Unfortunately, they could not apply these theories to the higher level application question.

Table 30. The means and standard deviations of items 19 and 20 on the post-test (N = 30)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.</td>
<td>Which simplest Boolean equation results from this Karnaugh map?</td>
<td>.31</td>
</tr>
<tr>
<td>20.</td>
<td>How many simplest Boolean functions could you have from this K-map?</td>
<td>.24</td>
</tr>
</tbody>
</table>

**Table 30.** The means and standard deviations of items 19 and 20 on the post-test (N = 30)
4. *Reaction of students* – Two students in the experiment group showed no improvement in their post-test scores. They even regressed on the post-test as compared to the pretest score and first four chapters exam. One reason is that one student caught the flu at the end of the seventh week. Even though this student had a very high score on the pretest, he did not fully recover by the eighth week when he took the post-test. The other student only spent 40 minutes on all five units of the teaching program. Obviously, this student did not complete or grasp all the materials on the minimization of Boolean algebra functions.

Some students showed that they enjoyed studying with the computer tutorial/simulation program. They had very high curiosity and interest in this program, especially on the simulation part after they learned some concepts for minimization of Boolean functions. They could study by following the path and getting immediate responses and feedback from the simulation program.

**Limitations**

Several limiting factors were involved in this study:

1. *Bad experience with computer-assisted instruction* – There were two students who took one course in another department prior to this course. They had an unpleasurable experience because they felt they were controlled by computer, and they did not like the climate of the class as well. Although they signed the consent form, they told the instructor they did not want to be experimental subjects. Their attitude affected the other students, and the researcher and instructor needed to communicate with the students as a result.
2. **Student attendance** – In the first experimental class session in IEDT 246B, only two students attended the experimental group and five students attended the control group due to a conflicting field trip. The attendance rate during the regular class time in the experimental group was not good. Therefore, students were allowed to study outside of their regular class time.

3. **Students did not practice at the same time** – The schedule in the experimental group was flexible. Students could use the computer program at their own pace and their own schedule. Some students used the program during the daytime, while other students studied at night. As a consequence, some students may have had problems with the program without having access to an instructor for help and guidance as they studied.

4. **The limits of the computer program** – Although five instructional units of materials were chosen to be as clear as possible, minimization of Boolean algebra basically is a mathematics operation and students needed more practice on Boolean algebra. In the tutorial/simulation program, many exercises were provided for the learner, but students had to do some calculation by hand because the program did not provide for this function.

**Conclusions**

This study was designed to strengthen the concepts and skill using Boolean algebra function minimization. The computer tutorial/simulation program was developed to provide a more efficient method for teaching Boolean algebra function minimization.
This research has indicated that there were no differences between the computer tutorial/simulation program and lecture/practice methods, but less than one-half of instruction time was spent using the computer tutorial/simulation program for learning. Based on this research was concluded that the computer tutorial/simulation program is a more effective teaching method for minimization of Boolean algebra functions than the lecture/laboratory method.

The study was limited by the size of the samples (17 subjects were in the control group and 13 subjects were in the experimental group), the short period of time over which the experiment took place (2 weeks), and other factors (field trip, previous negative experiences). From the standpoint of a digital electronics instructor, teaching minimization of Boolean algebra function with a simulation software appears efficient and effective.

Recommendations

Based on the findings and conclusions of the study, the following recommendations are made by the researcher:

1. More examples and exercises should be provided in the computer tutorial/simulation program.

2. More circuit simulations should be provided in the tutorial/simulation program.

3. Computer simulation software other than the Electronics Workbench, may be used as educational software.
4. If this study is replicated, the experimental time needs to be extended. The learners should have sufficient time not only to learn the computer tutorial lessons, but also to learn to fully utilize the simulation program.

5. Future research should expand the sample size used in the investigation. In addition, simulation can also be used for more complex concepts of logic circuits and applications requiring actual analysis.

6. Modify the tutorial program to include Boolean algebra equation operators, perhaps in a manner analogous to the Microsoft Windows Calculator, that would permit the student to do Boolean algebra calculations.

7. Students’ learning attitudes and styles should be used as independent variables to determine other possible factors affecting success in using computer tutorials and simulation.

8. Other authoring systems should be explored for development of the instructional program which might enhance the exploratory aspects of learning.

9. Utilize a research design that uses equivalent pretest and post-test in order to estimate true gain scores of subjects.

10. A future research design should examine the effectiveness of CAI for learning content which varies on the dimension of abstractness or perhaps Bloom’s Taxonomy of Cognitive Development.

11. Future research should examine specific student reactions, achievement and attitudes resulting from use of CAI in contrast to examine only group data.
REFERENCES


ACKNOWLEDGMENTS

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My sincere thank to the members of my family, thank you for your support. In many ways, I want to express my regrets to my wife and two children whom I left for three years to pursue my doctoral degree. I missed you just as much as you missed me! Finally, this research is dedicated to my parents, Chao-hung Chen and Shu-tzu Huang, who encouraged and taught me to be a life-long learner, and to accept challenging situations as a part of life. Although you are not here with me now, you advice and teaching always guide my thought and action.
APPENDIX A. PRETEST
PRETEST OVER LOGIC CIRCUIT CONCEPTS

DIRECTIONS: Select the letter of the choice for each statement below which best completes the statement or answers the question. Circle the letter of your choice for each item number.

Basic information:

The grade you received in IEDT 240: _______; Semester_____; year_____.

Name:________________________________________ #SS: ______ - _____ - ______

1. A resistance of 300Ω has a current of 0.6 A flowing through it. What voltage is developed across the resistance?
   (a) 108V    (b) 120V    (c) 180V    (d) 240V

2. According Question 2. How many power dissipation in the resistance?
   (a) 108W    (b) 120W    (c) 180W    (d) 240W

3. A student used a 100W desk lamp while studying for 6 hours every day. If the average cost of energy is 10cent/KWh, what is the energy cost each month?
   (a) 1800 dollars    (b) 180 dollars
   (c) 18 dollars      (d) 1.8 dollars

4. The Unit of conductance is
   (a) Farad    (b) Henry    (c) mho     (d) ohm

5. An electromechanical relay, when the magnetic coil is energized the contacts will be close. This relay is call:
   (a) NC relay    (b) NO relay
   (c) open circuit relay    (d) close circuit relay

6. A 10Ω resistor and two 20Ω resistors are connected in series across a 100V source. What is the current flows?
   (a) 26A    (b) 20A    (c) 10A    (d) 2A

7. According Question 6, what power is dissipated by 10Ω resistor?
   (a) 20W    (b) 40W    (c) 100W    (d) 200W

8. A 10Ω resistor and two 20Ω resistors are connected in parallel, the circuit is supplied by 100V battery source. What is total current flows?
   (a) 5A    (b) 10A    (c) 15A    (d) 20A
9. According Question 8, How many voltage across the resistor 10Ω?
   (a) 20V  (b) 40V  (c) 60V  (d) 100V

10. Which attribute is not an ideal operational amplifier?
   (a) infinite gain
   (b) infinite input impedance
   (c) infinite output impedance
   (d) all of above

11. In TTL families, the transistor function as a switch, the bias voltage among C, B, and E are:
   (a) C B forward bias, B E reverse bias.
   (b) C B reverse bias, B E reverse bias.
   (c) C B forward bias, B E forward bias.
   (d) C B reverse bias, B E forward bias.

12. To use a common-emitter transistor circuit as an inverter, the output signal is taken from
   the
   (a) Base
   (c) Collector
   (b) Emitter
   (d) Source

13. The Decimal value of the fractional number 01011B is:
   (a) 9  (b) 10
   (c) 11
   (d) 12

14. The Decimal value of the binary number 10011001B is:
   (a) -103  (b) -102
   (c) -99  (d) -67

15. The Hexadecimal value of the binary number 01111001B is:
   (a) 121  (b) 79  (c) 86  (d) 87

16. Convert 0111 0111 BCD code to decimal value is:
   (a) 119  (b) 88
   (c) 77  (d) 89

17. How many separate OR gates are contained within the 7432 TTL IC?
   (a) 1  (b) 2
   (c) 3  (d) 4
18. Which component will be chosen when we want to select one bit data from several sources data input?
(a) decoder  (b) encoder
(c) demultiplexer  (d) multiplexer

19. What kind level is required at the input to an AND gate to enable the signal at the other input to pass to the output?
(a) HIGH  (b) LOW
(c) Don't Care  (d) Float

20. A NAND gate with inverted inputs functions as
(a) an AND  (b) a NAND
(c) a NOR  (d) an OR

21. A three-input NOR gate will have a HIGH output whenever
(a) one input is LOW
(b) Two inputs are LOW
(c) Three inputs are HIGH
(d) Three inputs are LOW

22. The input logic gate A and B, if A or B or both are HIGH, the output X is LOW, if both A and B are LOW, then X is HIGH. This logic gate must be:
(a) NAND gate  (b) XOR gate
(c) NOR gate  (d) AND gate.

23. Which two-input gate will produce the final output of this Boolean expression?
\[ X = AB + CD \]
(a) OR  (b) AND
(c) NOR  (d) NAND

24. What kind logic gate is the minimum power dissipation in logical families?
(a) ECL  (b) TTL
(c) CMOS  (d) NMOS

25. The fan out of a logic gate is affected by
(a) the noise margin restrictions.
(b) loading effect of the circuit.
(c) the input resistance of the load.
(d) all of the above.
26. Which characteristic is not in the combinational logic?
   (a) output is dependent on the input.
   (b) the circuit involve storage component.
   (c) immediately produce the desired output.
   (d) all of the above.

27. Which arithmetic combinational logic's execution time is most slow in same bit binary number operation?
   (a) adder  (b) substract
   (c) multiplier (d) divider

28. A periodic clock waveform whose frequency is 4 MHz, the clock cycle is:
   (a) 0.25 ms   (b) 0.025 ms
   (c) 0.25 μs   (d) 2.5 μs

29. If the clock period were 2μs, how long would be taken when transmit a 8-bit data in serial communication?
   (a) 2 μs   (b) 4 μs
   (c) 8 μs   (d) 16 μs

30. The one of advantages of serial communication between computers is:
   (a) fast  (b) inexpensive
   (c) frequency response (d) need more electrical conductors
APPENDIX B. POST-TEST
POSTTTEST

DIRECTIONS: Select the letter of your choice for each statement below that best completes the statement or answers the question. Circle the letter of your choice for each item number.

Name: ________________________  #SS: _____ - _____ - _____

MULTIPLE CHOICE: (90%)

1. Which of the following statements is not the purpose of a switching function minimization?
   (a) Saving cost
   (b) Decreasing stability
   (c) Decreasing propagation delay
   (d) Decreasing power dissipation

2. The equivalent gate of the OR gate connected is:
   \[ A \rightarrow \bigoplus \rightarrow X \]
   (a) NAND gate  (b) NOR gate
   (c) NOT gate    (d) XOR gate

3. The function of this gate is equivalent to which gate?
   \[ A \bigoplus B \rightarrow X \]
   (a) NAND gate  (b) NOR gate
   (c) AND gate   (d) OR gate

4. Which answer is an example of a SOP expression?
   (a) \[ X = AB + AC \]
   (b) \[ X = (A + B)(C + D) \]
   (c) \[ X = A + B \]
   (d) \[ X = (AB)(CD) \]

5. The minimum sum of the products form of the expression
   \[ X = ABC + ABC + ABC + ABC + ABC \]
   is:
   (a) \[ BC + BC + AC \]
   (b) \[ AB + AB + AC \]
   (c) \[ B + AC \]
   (d) \[ B + C \]
6. Which of the following law is not one of the basic laws of Boolean Algebra?
   (a) Commutative Law
   (b) Associative Law
   (c) Distributive Law
   (d) Combinative Law

7. Which Boolean equation expresses the commutative law?
   (a) \( AB = BA \)
   (b) \( A + B = B + A \)
   (c) \( XY = YX \)
   (d) all of the above

8. \((B + c)(A + D) = B \ A + B \ D + C \ A + C \ D\) is a representation of the
   (a) associative law.
   (b) conductive law.
   (c) commutative law.
   (d) distributive law.

9. Which of the logic functions below is the same as \( A + B + C \):
   (a) \( \overline{A} \overline{B} \overline{C} \)
   (b) \( A \ B \ C \)
   (c) \( \overline{A} + \overline{B} + \overline{C} \)
   (d) \( A + B + C \)

10. For the circuit shown below, the function \( X \) is:

\[ \begin{array}{c}
\text{A} \\
\text{B}
\end{array} \quad \text{X} \]

   (a) \( A + B \)
   (b) \( \overline{A} + \overline{B} \)
   (c) \( A \ B \)
   (d) \( A \ B \)
11. For the circuit shown below, the function X is:

(a) $AB + CD$  
(b) $AB + CD$

(c) $A + B + C + D$  
(d) $A + B + C + D$

12. For the circuit shown below, the function X is:

(a) $A + B$  
(b) $A + B$

(c) $AB$  
(d) $A + B$

13. How many cells of a Karnaugh map are required for a four-variable function?

(a) 8  
(b) 12

(c) 16  
(d) 20

14. Which is the simplest Boolean equation resulting from this Karnaugh map?

\[
\begin{array}{c|c|c}
\bar{A} & \bar{B} & B \\
\hline
1 & & \\
& & \\
1 & 1 & \\
\end{array}
\]

(a) $A\bar{B} + A\bar{B} + AB$  
(b) $\bar{B} + AB$

(c) $A\bar{B} + A$  
(d) $A + \bar{B}$
15. Which is the simplest Boolean equation resulting from this Karnaugh map?

\[
\begin{array}{c|c|c|c|c|c|c}
& \bar{C} & C & \bar{A} \bar{B} & \bar{A} B & A B & \bar{A} B \\
\hline
\bar{A} \bar{B} & 1 & 1 & & & & \\
\bar{A} B & & 1 & & & & \\
A B & & & 1 & & & \\
A \bar{B} & & & & 1 & & \\
\end{array}
\]

(a) \((\bar{A} \bar{B})+(\bar{A} C)+(\bar{A} C)\)  
(b) \((\bar{A} \bar{B})+(A \bar{B})+(\bar{B} \bar{C})\)

(c) \((A \bar{B})+(\bar{A} \bar{B})+(\bar{B} \bar{C})\)  
(d) \((\bar{A} \bar{B})+(\bar{B} \bar{C})+(\bar{B} \bar{C})\)

16. Which is the simplest Boolean equation resulting from this Karnaugh map?

\[
\begin{array}{c|c|c|c|c}
& \bar{C} & D & \bar{C} D & C D & \bar{C} D \\
\hline
\bar{A} \bar{B} & 1 & 1 & 1 & 1 & \\
\bar{A} B & 1 & 1 & 1 & 1 & \\
A B & & & & & \\
A \bar{B} & & & & 1 & 1 \\
\end{array}
\]

(a) \(A + B \bar{D}\)  
(b) \(A + A B \bar{D}\)

(c) \(A + B \bar{C} \bar{D} + B \bar{C} D\)  
(d) \(A + \bar{C} \bar{D}\)

17. The simplified form of \(X = A(B + C) + AC\) is

- (a) \(X = A + B + C\)
- (b) \(X = AB + AC\)
- (c) \(X = AB + C\)
- (d) \(X = AB + AC + C\)

18. In the logic circuit for the equation below, 
\(X = A B + A(A + C)\), the simplified equation is:

(a) \((AB)(A + AC)\)  
(b) \((\bar{A} + \bar{B})(\bar{A} + A \bar{C})\)

(c) \((\bar{A} + \bar{B}) \bar{A}\)  
(d) \(\bar{A}\)
19. Which is the simplest Boolean equation resulting from this Karnaugh map?

\[ \begin{array}{cccc}
\overline{AB} & 
\overline{A} & B & 1 \\
\overline{A} & 1 & 1 & \\
A & 1 & & \\
A & 1 & 1 & \\
\end{array} \]

(a) \( \overline{A} \overline{C} + B \overline{C} + A \overline{B} \)  
(b) \( B \overline{C} + \overline{A} \overline{B} + A \overline{C} \)  
(c) both a and b  
(d) none of above

20. How many simple Boolean functions could you have from this K-map?

\[ \begin{array}{cccc}
\overline{CD} & \overline{CD} & CD & \overline{CD} \\
\overline{A} & 1 & 1 & 1 \\
\overline{A} & 1 & 1 & 1 \\
A & & & \\
A & 1 & 1 & \\
\end{array} \]

(a) 1  
(b) 2  
(c) 3  
(d) 4
21. Which K-map has the same Boolean function as shown in the following K-map?

![K-map Diagram]

(a) 

![K-map Diagram]

(b) 

![K-map Diagram]

(c) 

![K-map Diagram]

(d) None of above
22. The Boolean equation for the logic circuit is:

(a) $ABC$
(b) $A + B + C$
(c) $AB + BC$
(d) $AC + BC + AB$

23. For the circuit shown below, the equivalent circuit is:

(a) $A \cdot \text{Not used} \quad (c) A \cdot B \cdot X$
(b) $A \cdot B \cdot X 
(d) A \cdot C \cdot \text{Not used}$

24. Which characteristic is not in the combinational logic?
(a) Output is dependent on the input.
(b) The circuit involves a storage component.
(c) Immediately produce the desired output.
(d) Using combinations of gates.

25. Which two-input gate will produce the final output of this Boolean expression?

$X = AB + CD$
(a) OR
(b) AND
(c) NOR
(d) NAND

26. In the input logic gate A and B, if A or B or both are HIGH, the output X is LOW, and if both A and B are LOW, then X is HIGH. This logic gate must be:
(a) NAND
(b) XOR
(c) NOR
(d) AND gate.
27. How many two-input gates of any type are needed to build this logic circuit after it is simplified?

\[ X = CD + EF + EG \]

- (a) seven
- (b) six
- (c) five
- (d) four

28. How many two-input AND gates are needed to build this logic circuit?

\[ X = CD + EF + EG \]

- (a) 3
- (b) 4
- (c) 5
- (d) 6

29. The simplified equation that will produce the output waveform at \( X \), given the input at \( A, B, \) and \( C \) is shown as follows:

(a) \( \overline{A} \overline{B} C + A \overline{B} C \)
(b) \( \overline{A} \overline{B} C + A \overline{B} C \)
(c) \( \overline{A} B C + A B \overline{C} \)
(d) \( A B \overline{C} + \overline{A} B \overline{C} \)

30. In the output waveform at \( X \) shown as follow, the logic gate should be:

(a) AND gate
(b) NAND gate
(c) OR gate
(d) NOR gate
APPLICATION QUESTIONS: (10%)

31. For the circuit shown as follows, determine the simplest output equation and draw the circuit.

32. Use DeMorgan's theorem and rules to simplify the circuit shown as follow:
APPENDIX C. FIRST FOUR CHAPTERS TEST
FIRST FOUR CHAPTERS TEST

DIRECTIONS: Select the letter of the choice for each statement below which best completes the statement or answers the question. Record the letter of your choice in the blank in front of the item number.

IEDT 246 Digital Electronics

Name: ________________________                       Last 4 Digit S.S.# _________

1. Which logic function accomplishes Boolean (logical) multiplication?
   (a) NOR          (b) OR
   (c) AND         (d) invert

2. Which logic function accomplishes Boolean (logical) addition?
   (a) AND         (b) OR
   (c) invert      (d) NAND

3. How many three-input NOR gates are in a 14-pin DIP integrated circuit?
   (a) two       (b) three
   (c) four      (d) five

4. How many inverters are in a 14-pin DIP integrated circuit?
   (a) two       (b) four
   (c) six       (d) eight

5. A three-input NOR gate will have a HIGH output whenever
   (a) one input is HIGH.       (b) two inputs are LOW.
   (c) three inputs are HIGH.   (d) three inputs are LOW.

6. What will be the output of a three-input NAND gate whose inputs are a HIGH, a HIGH, and a clock?
   (a) HIGH       (b) LOW
   (c) clock      (d) clock inverted

7. Give the decimal value of binary 10010.
   (a) 20_10      (b) 6_10
   (c) 18_10      (d) 9_10

8. Give the decimal value of binary 1010000.
   (a) 84_10      (b) 80_10
   (c) 78_10      (d) 96_10
9. Convert decimal 64 to binary.
   (a) 01001000
   (c) 00110110
   (b) 01000000
   (d) 01010010

10. Convert decimal 101 to binary.
    (a) 01110011
    (c) 00111011
    (b) 01100101
    (d) 01101111

11. Convert binary 1001 to octal.
    (a) 118
    (c) 108
    (b) 1018
    (d) 98

12. Convert binary 010101 to octal.
    (a) 158
    (c) 218
    (b) 58
    (d) 258

13. Convert octal 701 to binary.
    (a) 111000001
    (c) 1001111
    (b) 111000100
    (d) 11000001

14. Convert octal 100 to binary.
    (a) 10000000
    (c) 1100100
    (b) 01000000
    (d) 111111110

15. Convert octal 107 to decimal.
    (a) 9710
    (c) 7710
    (b) 10110
    (d) 7110

16. Convert octal 77 to decimal.
    (a) 8810
    (c) 4710
    (b) 5710
    (d) 6410

17. Convert decimal 19 to octal.
    (a) 278
    (c) 218
    (b) 238
    (d) 178

18. Convert decimal 64 to octal.
    (a) 778
    (c) 1008
    (b) 1048
    (d) 768
19. How many symbols are needed to represent each digit in hexadecimal?
   (a) six   (b) ten
   (c) twelve   (d) sixteen

20. Convert binary 11001111 to hexadecimal.
   (a) 8F₁₆  (b) CF₁₆
   (c) DF₁₆  (d) CE₁₆

21. Convert binary 11111110010 to hexadecimal.
   (a) FF₂₁₆  (b) FD₂₁₆
   (c) 2FF₁₆  (d) EE₂₁₆

22. Convert hexadecimal 2E to binary.
   (a) 00110111  (b) 00100111
   (c) 110001110  (d) 00101110

23. Convert hexadecimal 10 to binary.
   (a) 00010000  (b) 00110
   (c) 1010  (d) 11000

24. Convert hexadecimal DB to binary.
   (a) 10110011  (c) 11011100

25. Convert hexadecimal COB to binary.
   (a) 110100001100  (c) 110000001011

   (a) 25₁₀  (b) 32₁₀
   (c) 27₁₀  (d) 22₁₀

27. Convert hexadecimal 1E to decimal.
   (a) 29₁₀  (b) 35₁₀
   (c) 30₁₀  (d) 21₁₀

28. Convert decimal 77 to hexadecimal.
   (a) 5D₁₆  (b) 3D₁₆
   (c) 3E₁₆  (d) 4D₁₆

29. Convert decimal 64 to BCD.
   (a) 0110 0100 BCD  (b) 0111 0110 BCD
   (c) 0100 0000 BCD  (d) 0111 1110 BCD
30. Convert decimal 109 to BCD.
   (a) 0001 0000 1001 \text{BCD}  \quad (b) 0110 1011 \text{BCD}
   (c) 0001 0000 1101 \text{BCD}  \quad (d) 1110 1110 1100 \text{BCD}

31. Convert BCD 1001 0011 to decimal.
   (a) 98_{10}  \quad (b) 176_{10}
   (c) 147_{10}  \quad (d) 93_{10}

32. Convert BCD 0011 0110 1000 to decimal.
   (a) 172_{10}  \quad (b) 708_{10}
   (c) 616_{10}  \quad (d) 768_{10}

33. Which numbering format is the really codes rather than true number systems?
   (a) decimal and binary  \quad (b) binary and octal
   (c) BCD and ASCII  \quad (d) hexadecimal and octal

34. Which numbering format is the basis for digital electronic circuitry?
   (a) octal  \quad (b) decimal
   (c) binary  \quad (d) BCD

35. Which numbering format is most commonly used in a computer's machine language?
   (a) hexadecimal  \quad (b) ASCII
   (c) BCD  \quad (d) octal

36. Which numbering format is used to represent both numbers and letters on a keyboard?
   (a) octal  \quad (b) ASCII
   (c) BCD  \quad (d) hexadecimal

37. Which numbering format can only represent the ten decimal digits?
   (a) binary  \quad (b) ASCII
   (c) octal  \quad (d) BCD

38. The most typical voltage levels required for a digital circuit are
   (a) -12 V and +12 V.  \quad (b) -5 V and 0 V.
   (c) 0 V and +5 V.  \quad (d) -5 V and +5 V.

39. What is the period of a clock waveform whose frequency is 4 MHz?
   (a) 0.25 \mu\text{sec}  \quad (b) 250 \text{msec}
   (c) 25 \text{msec}  \quad (d) 40 \mu\text{sec}
40. Serial format means digital signals are
   (a) sent over many conductors simultaneously.
   (b) sent over many conductors sequentially.
   (c) sent in binary coded decimal.
   (d) sent in groups of eight signals.

41. Parallel format means that
   (a) both binary and hexadecimal can be used.
   (b) several digital signals are sent on each conductor.
   (c) no clock is needed.
   (d) each digital signal has its own conductor.

42. A relay whose contacts close when energized is
   (a) a NO relay.  (b) defective.
   (c) normally closed.  (d) an NC relay.

43. Which of the following is an advantage of a mechanical relay over semiconductor switches.
   (a) total isolation between source and output
   (b) low current needed to energize
   (c) high speed
   (d) all of the above

44. Which of the following is an advantage of a semiconductor switch over a mechanical relay.
   (a) total isolation between source and output
   (b) high speed
   (c) high speed and total isolation between source and output
   (d) can handle high current

45. When a NO relay is energized, its contacts are
   (a) at rest.  (b) closed and at rest.
   (c) closed.  (d) opened.

46. A solid state device which can act like a switch is
   (a) a transistor.  (b) a diode.
   (c) a diode and a transistor.  (d) a resistor.

47. When a transistor is used as a switch, the input signal is usually applied to the
   (a) collector.  (b) emitter.
   (c) cathode.  (d) base.
48. An NPN transistor will short from emitter to collector when
   (a) the base is more positive than the emitter.
   (b) the base is more negative than the emitter.
   (c) the collector is more positive than the emitter.
   (d) the emitter is more positive than the collector.

49. When the base is more positive than the emitter of an NPN transistor, it is
   (a) cannot tell.  (b) ON.
   (c) open.  (d) OFF.

50. The Boolean equation for an AND gate is
   (a) $AB = X$  (b) $A + B = X$
   (c) $A + B = X$  (d) $A - B = X$

51. In order to produce a one output, an AND gate requires
   (a) any input to be LOW.  (b) all inputs to be LOW.
   (c) any input to be HIGH.  (d) all inputs to be HIGH.

52. Which output is correct for this AND truth table?

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>?</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>?</td>
</tr>
</tbody>
</table>

   (a) 0  (b) 0
   0  1
   0  1
   1  1

   (c) 0  (d) 0
   0  1
   0  0
   0  1

53. The Boolean equation for an OR gate is
   (a) $A + B = X$.  (b) $AB = X$.
   (c) $A - B = X$.  (d) $A + B = V$.

54. In order to produce a zero output, an OR gate requires
   (a) any input to be LOW.  (b) any input to be HIGH.
   (c) all inputs to be LOW.  (d) all inputs to be HIGH.
55. Which logic circuit is represented by the equation $A + B = X$?
   (a) AND
   (b) OR
   (c) clock
   (d) switch

56. Which output is correct for this OR truth table?

<table>
<thead>
<tr>
<th>$A$</th>
<th>$B$</th>
<th>$X$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
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<td>0</td>
<td>?</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>?</td>
</tr>
</tbody>
</table>

(a) 1     (b) 0
   1
   1
   0
   1

(c) 0     (d) 0
   1
   0
   1
   1

57. Which logic gates does this truth table describe?

<table>
<thead>
<tr>
<th>$A$</th>
<th>$B$</th>
<th>$X$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
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<tr>
<td>0</td>
<td>1</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

(a) inverter     (b) AND
(c) cannot tell  (d) OR

58. At which point will output $X$ of this AND timing diagram be HIGH?

<table>
<thead>
<tr>
<th>$A$</th>
<th>$B$</th>
<th>$X$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
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<td>0</td>
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</tbody>
</table>

(a) point 5     (b) point 4
(c) point 1     (d) point 2
59. At which point will output X of this AND timing diagram be LOW?

A

B

X 1 2 3 4 5

(a) points 1 and 3  
(b) points 1 and 2

(c) points 1 and 4  
(d) points 2 and 3

60. At which point will output X of this OR timing diagram be LOW?

A

B

X 1 2 3 4 5

(a) points 1 and 3  
(b) points 1 and 4

(c) points 1 and 2  
(d) it is never low

61. At which point will output X of this OR timing diagram be LOW?

A

B

X 1 2 3 4 5

(a) point 3  
(b) point 5

(c) point 1  
(d) point 4

62. At which point will output X of this OR timing diagram be HIGH?

A

B

X 1 2 3 4 5

(a) never  
(b) point 4

(c) points 2 and 3  
(d) points 3 and 5
63. At which point will output X of this AND timing diagram be HIGH?

\[
\begin{align*}
\text{A} & : & : & : \\
\text{B} & : & : & : \\
\text{X} & : & 1 : & 2 : 3 : 4 : 5 \\
\end{align*}
\]

(a) point 1  (b) point 3  
(c) point 5  (d) point 4

64. If one input of an AND gate is LOW while the other is a clock signal, the output is:

(a) LOW  (b) cannot tell  
(c) a clock signal  (d) HIGH

65. If one input of an OR gate is HIGH while the other is a clock signal, the output is:

(a) cannot tell  (b) LOW  
(c) HIGH  (d) a clock signal.

66. If one input of an OR gate is LOW while the other is a clock signal, the output is:

(a) HIGH  (b) LOW  
(c) cannot tell  (d) a clock signal.

67. If both inputs of an OR gate are normally HIGH but one of them momentarily dips LOW, the output will

(a) momentarily dip LOW.  (b) stay HIGH.  
(c) go LOW and remain LOW.  (d) be LOW.

68. How many two-input gates are in a signal 14-pin DIP integrated circuit?

(a) six  (b) four  
(c) two  (d) eight

69. The ground and power pins on a typical TTL 14-pin DIP are:

(a) pins 1 and 14.  (b) pins 7 and 8.  
(c) pins 7 and 14.  (d) pins 1 and 8.

70. Inversion is indicated by

(a) a triangle on a gate output.  (b) a bubble on a gate output.  
(c) a bar (line) over a Boolean equation  (d) all of the above

71. The Boolean equation for a NOR function is:

(a) \( X = \overline{A} + \overline{B} \)  (b) \( X = A + \overline{B} \)  
(c) \( X = \overline{A} + B \)  (d) \( X = A + B \)
72. A NOR gate with one HIGH input and one LOW input
   (a) will output a HIGH. (b) functions as an AND.
   (c) will output a LOW. (d) will not function.

73. Which logic gate does this truth table describe?

<table>
<thead>
<tr>
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<th>X</th>
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</thead>
<tbody>
<tr>
<td>0</td>
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<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

(a) OR (b) NAND
(c) NOR (d) AND

74. Which logic function results if an OR gate output is connected to an inverter?
   (a) AND (b) OR
   (c) inverter (d) NOR

75. Which logic function results if a NOR gate output is connected to an inverter?
   (a) AND (b) NAND
   (c) OR (d) NOR

76. If input A of a NAND gate is connected to a clock and input B is LOW, the normal output would be
   (a) inverted clock. (b) HIGH.
   (c) clock. (d) LOW.

77. If both of its inputs are connected to the same signal, a NOR gate functions as
   (a) NOR. (b) inverter.
   (c) OR. (d) AND.

78. At which point will output X on this NAND timing diagram be LOW?

   A ___________
   B ___________
   X 1 : 2 : 3 : 4 : 5

(a) point 2 (b) points 2, 3, and 4
(c) points 2 and 3 (d) never
79. At which point will output X on this NAND timing diagram be HIGH?

\[ \begin{align*}
A & : \quad \Box \\
B & : \quad \Box \\
X & : 1 : 2 : 3 : 4 : 5
\end{align*} \]

(a) point 5  
(b) points 1 and 2  
(c) points 1, 2, 4, and 5  
(d) point 3

80. At which point will output X on this NAND timing diagram be HIGH?

\[ \begin{align*}
A & : \quad \Box \\
B & : \quad \Box \\
X & : 1 : 2 : 3 : 4 : 5
\end{align*} \]

(a) point 5  
(b) points 4 and 5  
(c) point 4  
(d) points 1, 2, and 3

81. At which point will output X on this NOR timing diagram be LOW?

\[ \begin{align*}
A & : \quad \Box \\
B & : \quad \Box \\
X & : 1 : 2 : 3 : 4 : 5
\end{align*} \]

(a) never  
(b) points 1 and 5  
(c) points 2, 3, and 4  
(d) all points

82. At which point will output X on this NOR timing diagram be HIGH?

\[ \begin{align*}
A & : \quad \Box \\
B & : \quad \Box \\
X & : 1 : 2 : 3 : 4 : 5
\end{align*} \]

(a) point 3  
(b) points 1 and 2  
(c) points 1, 2, 3, and 4  
(d) point 5
83. At which point will output X on this NOR timing diagram be HIGH?

A
B
X

1 : 2 : 3 : 4 : 5

(a) points 2 and 3  
(b) never  
(c) points 2, 3, and 4  
(d) point 2

84. What will be the output of a three-input NOR gate whose inputs are a clock, a HIGH, and a LOW?

(a) clock  
(b) cannot tell  
(c) HIGH  
(d) LOW

85. Convert the fractional decimal number 10.5 to binary.

(a) 1010.0101  
(b) 1010.1000  
(c) 1100.1000  
(d) 1011.1000

86. Convert the fractional binary number 0001.0010 to decimal.

(a) 1.20  
(b) 1.40  
(c) 1.125  
(d) 1.80

87. What is the binary representation of $2^{-2}$?

(a) 0000.1000  
(b) 0000.0100  
(c) 0010.0000  
(d) 0000.0010

88. What is the binary representation for $2^{0}$?

(a) 1000  
(b) 1000  
(c) 0000  
(d) 0001

89. What is the decimal value of $2^{-2}$?

(a) 0.2  
(b) 0.125  
(c) 0.5  
(d) 0.25

90. What is the decimal value of $2^{5}$?

(a) 10  
(b) 32  
(c) 20  
(d) 16
APPENDIX D. THE POST-TEST SCORE FOR THE CONTROL AND EXPERIMENTAL GROUPS
The post-test score for the control and experimental groups

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APPENDIX E. HUMAN SUBJECTS APPROVAL FORM
Checklist for Attachments and Time Schedule

The following are attached (please check):

12.☐ Letter or written statement to subjects indicating clearly:
   a) purpose of the research
   b) the use of any identifier codes (names, #’s), how they will be used, and when they will be
      removed (see Item 17)
   c) an estimate of time needed for participation in the research and the place
   d) if applicable, location of the research activity
   e) how you will ensure confidentiality
   f) in a longitudinal study, note when and how you will contact subjects later
   g) participation is voluntary; nonparticipation will not affect evaluations of the subject

13.☐ Consent form (if applicable)

14.☐ Letter of approval for research from cooperating organizations or institutions (if applicable)

15.☐ Data-gathering instruments

16. Anticipated dates for contact with subjects:
   First Contact                        Last Contact
   2/15/95                             3/5/95
   Month / Day / Year                  Month / Day / Year

17. If applicable: anticipated date that identifiers will be removed from completed survey instruments and/or audio or visual
   tapes will be erased:

   Month / Day / Year

18. Signature of Departmental Executive Officer  Date  Department or Administrative Unit
   ☐ John C. Peay  2/15/95  IND ED & TECH

19. Decision of the University Human Subjects Review Committee:
   ☑ Project Approved        ☐ Project Not Approved        ☐ No Action Required

   Patricia M. Keith  2/15/95
   Name of Committee Chairperson  Date  Signature of Committee Chairperson
APPENDIX F. CONSENT FORM
CONSENT FORM

Dear student:

As part of my doctoral research, I am asking that you participate in an experiment to
determine which of two methods of instruction (traditional lecture and computer tutorial) is
most effective, if any.

To complete this research, the Human Subjects Research Committee at Iowa State University
requires that you voluntarily consent to participate. If you participate, your test scores and
other information will be kept confidential. Only group data will be published in the
dissertation. Should you choose not to participate, you will receive the normal instruction
from your instructor. If you have any questions regarding this study, please feel free to
contact me at 294-8529.

Thank you for your consideration

Farn-Shing Chen