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Effectiveness of Simulation versus Hands-on Labs: A Case Study for Teaching an Electronics Course

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Abstract

The use of Simulation-based labs has been gaining currency in the domains of engineering and technology programs. How effective is simulation-based teaching methodology in comparison to traditional hands-on activity based labs? To answer this question a study was conducted to explore the impact of the use of computer simulation design methods on students' learning for circuit construction in an undergraduate technical course. A mixed method research design was employed to identify the presence or absence of learning patterns using qualitative and quantitative modes of data evaluation viz a viz cognitive apprenticeship instructional methodology.

This paper presents the findings of the research study which tested the hypothesis by investigating three key questions: 1) Does the use of simulation improve students 'learning outcomes? 2). How do faculty members perceive the use and effectiveness of simulation in the delivery of technical course content? 3). How do students perceive the instructional design features embedded in the simulation program such as exploration and scaffolding support in learning new concepts?

The paper also discusses the other aspects of findings which reveal that simulation by itself is not very effective in promoting student learning. Simulation becomes effective only when it is followed by hands-on activity. The paper presents the qualitative findings of the study, the quantitative findings have been reported previously. Furthermore, the paper presents recommendations for improving student learning, viz a viz simulation-based and hands-on labs.

Introduction

Simulations are recognized as an efficient and effective way of teaching complex and dynamic engineering systems. A simulation-based teaching environment enables students to acquire experience and consider their previous results.[1] In particular, the gaming approach utilizing interactive media and/or simulation has been shown to be effective in improving teaching and learning of various subjects.[2] By reducing practical learning time for students, and for schools and programs, simulation reduces costs for practice oriented educational methodology.

In constructing a simulation, guidelines provide an appropriate model: a physical or mathematical abstraction of a real world process, device, or concept. Because simulation is concerned with modeling of real-world problems, simulation in engineering usually refers to the process of representing the dynamic behavior of a "real" system by an idealized, more manageable model-system implemented through computation via a simulator. These relations are, by definition, mathematical relations, whether numerical or not.

Engineering is the art of applying scientific and mathematical principles, experience, judgment, and common sense to make things that benefit people.[3] It is the process of producing a technical product or system to meet a specific need in a society. Engineering education is higher education through which knowledge of mathematics and the natural sciences are gained, followed by a lifetime of self-education where experience is combined with practice.

Engineering is based on practice gained in labs during the undergraduate education; however, the cost of building undergraduate labs in an engineering program may be a few orders of magnitude higher than turning a regular PC into a virtual lab with the addition of a card or two. Consequently, engineering faculties are constantly faced with the dilemma of establishing a balance between virtual and real labs to address cost problems while graduating sophisticated engineers with enough practice. One advantage of virtual experimentation and computer simulation is that engineers are better equipped to understand and use mathematical expressions as well as graphics effectively.

The advantages of using engineering simulation-based training also include reducing the gap between the learning environment and the "real" environment, and making available training “real world” situations that are difficult to simulate in a hands-on lab. Traditionally for teaching technology-based courses, laboratory experiments were offered using a hands-on approach. With the miniaturization of integrated circuits, it is becoming very difficult to construct a PC board or assemble surface mount chips in a lab environment. This shortcoming of the hands-on approach has led professors and teachers to incorporate simulation in place of hands-on in technology-based lab courses.

In spite of the advantages of simulations, hands-on labs remain tremendously important in the technology curriculum, which is based on Dewey’s experiential learning theory. The basic premise of this theory is that students learn as a result of doing or experiencing things in the world, and learning occurs when mental activity is suffused with physical activity.[5] The professional success of a technologist is directly related to her/his ability to transfer knowledge gained in the academic environment to real-world situations. Acquisition of manipulative skills is only possible through the use of real instruments and real experimental data. Therefore, to enhance student learning, the technology curriculum must integrate the effective characteristics of both computer simulations and hands-on lab activities.

A primary objective of today’s teachers is to prepare students for the world of tomorrow. Pogrow (1994) indicated that if students are to be competitive in the years to come, faculty need to be able to provide their students with the cognitive strategies that will enable them to think critically, make decisions, and solve problems.[6]

Furthermore the definition of “hands-on” has changed drastically in the last couple of decades. Today, design means endless rounds of modeling and simulation.[3] Design engineers have effectively become computer programmers. Engineers who build systems, whether chips or boards, seem to be doing less actual design of circuits and more assembly of prepackaged components. Still, students need to have good hands-on experience to understand the circuit behavior and to troubleshoot circuits or equipment in case of a problem. Design models are the "soft technologies" that influence and activate the thought processes of the learners rather than the "hard technology" of the computer.[7] The proper use of soft technologies (simulation software) as a tool can improve student performance in gaining hands-on experience.

According to Leutner (1993), in traditional education, the teacher is responsible for the students' learning. Teachers typically lecture to students who take notes and then memorize and recall the material to perform well on examinations.[8] This type of learning environment is not appropriate for college students who bring life skills and increased reasoning ability to the classroom. In such a situation, it may be appropriate for students to take responsibility for their own education. One method of transferring the responsibility from the teacher to the student is through guided discovery. Discovery is "in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights." [9]

Guided discovery was developed by Dr. Charles E. Wales at the Center for Guided Design at West Virginia University.[8] Guided discovery has been found to be an effective learning method that stimulates group interaction and is challenging enough to force students to use resources beyond what are available in the classroom.[10] Menn (1993) evaluated the impact of different instructional media on student retention of subject matter.[11] It was found that students remember only 10% of what they read; 20% of what they hear; 30% if they see visuals related to what they are hearing; 50% if they watch someone do something while explaining it; but almost 90% if they do the job themselves even if only as a simulation. In other words, guided discovery through labs and computer simulations that are properly designed and implemented could revolutionize education.

Purpose of the Study

The purpose of this comparative case study was to explore the impact of the use of computer simulation design methods on students' problem-solving skills for circuit construction using Multisim-8 in an undergraduate ECET (Electronic Computer Engineering Technology) course. The design methods included cognitive apprenticeship domains of modeling, scaffolding, articulation, and exploration in traditional lecture-lab activities on students' problem-solving skills for circuit construction. The present research study employed a case study approach.

Research Questions

The following are the research questions of this study.

Question 1. Does the use of simulation improve students' learning outcomes?

Question 2. How do faculty members perceive the use and effectiveness of simulation in the delivery of technical course content?

Question 3. How do students perceive the instructional design features (IDF) in simulation that support their knowledge comprehension?

3a. How does the design feature of exploration embedded in the simulation program support learning new concepts?

3b. How does the design feature of scaffolding embedded in the simulation program support students in learning new concepts?

Theoretical Framework

Significance/Contribution of Simulation to Instructional Technology:

What are simulation-based instructional design strategies?

According to Veenman, Elshout, and Busato (1994), problem-oriented simulations help develop higher-order thinking strategies and improve the students' cognitive abilities employed in the service of recall, problem-solving, and creativity.[10] Computer-based simulation software enables the students to experiment interactively with the fundamental theories and applications of electronic devices.[10] It provides instant and reliable feedback and, thus, gives students an opportunity to try out different options and evaluate their ideas for accuracy almost instantly. Lab students often assume that lab equipment is not always accurate and reliable, and they sometimes make the mistake of attributing their design errors to experimental errors. By focusing mainly on the mental activity that takes place within the learner, simulation can direct students' attention to their own designs.

The proposed study described in this paper offers several contributions to the literature of instructional technology, including expanding of the problem solving literature, verify simulation as an instructional strategy for teaching complex problem solving, integrating virtual reality into technology education labs, and helping design instruction for technology-enhanced learning. Jonassen (2000) specifically called for future research to "prescribe instructional analysis and design process" and "articulate cognitive, affective, and cognitive process required to solve each type of problem."[7] The research herein aimed to address these suggestions, focusing on instructional strategies. Sherin et al., (2004) observe that the analysis of the features of simulations in terms of scaffolds and their functions calls for empirical attention that will take the form of an understanding of how specific kinds of scaffolds function to enable certain changes in outcomes within the context of a particular design. Finally, the relationship between computer simulation and instructional strategies in problem solving is not well documented in the literature, while literature related to simulation and virtual reality (Fishwick, 1995) indicates that simulation has enormous potential, especially with distributed interactive simulation, a direction pioneered by the Department of Defense.

Simulations promote active learning. As experiential learning, simulations generate student interest beyond that of traditional classroom lectures and thereby provide insight. Additionally, simulations develop critical and strategic thinking skills. The skills of strategic planning and thinking are not easy to develop, and the advantage of simulation is that they provide a strong tool for dealing with this problem.[12]

Simulation is a problem-solving exercise that is undertaken collaboratively and may be solved through a combination of character identification, shared decision making, investigative inquiry, and reflective practice within a scenario context (Fisher, 2005). Although the importance of hands-on labs to the technology curriculum cannot be denied, Garcia (1995) cites several advantages of computer simulations compared to laboratory activities.[13] First, there appear to be important pedagogical advantages of using computer simulations in the classroom. Second, the purchase, maintenance, and update of lab equipment is often more expensive than computer hardware and software. Also, there is no concern for students' physical safety in the simulation learning environment.

The domain of simulation deals with cognitive apprenticeship.[14] Cognitive apprenticeship emphasizes generalizing knowledge so that it can be used in many different settings. Cognitive apprenticeship extends practice to diverse settings and articulates common principles so students learn how to apply their skills in varied contexts.

Methodology

The research questions described in the introduction are designed for exploring the impact of computer simulation design methods/features on students' problem solving skills in a technology-based course. This instructional strategy is used in a problem solving learning environment in engineering. In addition, the simulation software Multisim-8 (Electronic Workbench) used explores learner and domain knowledge growth.

A comparative case study methodology was chosen to investigate the research questions. According to Eisenhardt (1989), case study research can be defined as *"a research strategy which focuses on understanding the dynamics present within single settings"* (p. 534). Following this definition, case study research is often said to be mainly suitable for research seeking to answer "how" and "why" question.[15] Typically case study research aims at generalizing a particular set of results to some broader theory.

Eisenhardt (1989) and Yin (2003) show that case study evidence does not necessarily need to originate from purely quantitative data. Evidence can just as well be based on purely qualitative data (e.g. from interviews), or on a combination of qualitative and quantitative data. For the proposed study, a combined approach was employed. Case study research recommends the use of multiple methods (Yin 2003; Meredith 1998; Eisenhardt 1989). Parallel use of several research methods and sources enables what is often called *data triangulation*, and thereby contributes to enhanced internal validity of the study. [15]

In the present research study, a case study approach was employed since the student group was small in size. Yin (2003) observes that the case study methods involve three roles: exploratory/descriptive, evaluation, and hypothesis testing.[15] The most common use of the case study research methodology is the "evaluation" form, which deals with the goal of identifying potential explanations for successes or failures of any project. The second type, exploratory and descriptive case studies, examines the development and characteristics of phenomena often with the goal of developing hypotheses of cause–effect relationships. Finally, the use of case study research for hypothesis testing involves tests for causal relationships by comparing generalizations from case study findings with the underlying theory. For the present case study, hypothesis testing was employed. Specifically, this proposed study employed a two-phase mixed-method approach as identified in Creswell's (2003) research. In this research framework, investigators first conduct a quantitative study to address the research questions, and then collect and analyze the data quantitatively. Next, to further strengthen the quantitative findings, qualitative methods are used to explain the unexpected results, significant or non-significant quantitative findings, and the description of the context within which the findings are situated.

Study Context

The sample for this study was drawn from the freshman class of engineering technology students at a midsized university who enrolled in an eight-week Electronics and Computer and Engineering Technology (ECET) course. The primary objective of this course was to prepare students to acquire skills in building or constructing basic DC circuits and to develop an understanding of electronic fundamentals. This course was a pre-requisite for all of the advanced electronic courses in the three-year degree program. The students came from varied educational backgrounds and experience, mostly recent high school graduates, or with no college experience yet they all received the same instruction using the same instructional strategies and the same content. This course, designed by the university's technical faculty, is taught in the ECET (Electronic Computer Engineering Technology) program. The program was accredited by the Technology Accreditation Commission/Accreditation Board of Engineering and Technology (TAC/ABET), the leading accreditation agency in the United States. The course consisted of a lecture part, a lab part, and an online part; all three parts were supported by a prescribed text.

Participants

Students were selected from the ECET-110 (Electronic-I) course taken during their first semester in the ECET program. The group consisted of 24-29 students from a wide range of demographic attributes: their age ranged from 18 to 30 years; their educational background varied from as little as a recent high school education to 3-5 years of work experience or having completed an undergraduate degree prior to enrolling in the technical program; 96% were males and 4% were females; and majority were whites and rest belonged to various minority groups including Asian, African American, and Latino.

Research Procedure

The case study employed a group of 24-29 students enrolled in a technical class of a technology-based undergraduate program. Students first attended and completed the lecture part that gave them knowledge/understanding in building circuits using both techniques of breadboarding (hardware) and Multisim-8 (Simulation software). After practicing the circuits in the class, the whole group was given a simulation lab of building circuits using Multisim-8 for each of the topics covered in the class. The labs were given on a specific topic after covering the corresponding lecture component of that topic. All of the students in the participating class were also given lab assignments that provided an equal and independent chance to build circuits using simulation software. After completing all practice labs (using Multisim-8) on each of the topic, students were given a two—hour mid-term (problem solving exercise) to assess the acquisition of domain knowledge. The grades of the students who completed the mid-term (simulated lab) were then compared to the grades of students who took the midterm (hands-on lab using breadboarding) teaching techniques (baseline reference group). The grades were then analyzed using the ANOVA test. Table I illustrates the implementation schedule for the case study.

Table I: Case Study Schedule.

Date	Event/treatment	Duration	Data Collection/Measures (Group)
Week 1	Intro to Electronic Fundamentals	50 minutes	
	Ohm's Law – Problem solving	50 minutes	
	Simulation Lab#1 – Ohms Law	2 hours	Quiz 1 (Simulation)
Week 2	Series Circuit – Problem solving	2 hours	
	Simulation Lab#2 – Series circuit	2 hours	Quiz 3
Week 3	Parallel Circuit – Problem solving	2 hours	
	Simulation Lab#3 – Parallel circuit	2 hours	Quiz 4
Week 4	Combination Circuit – Problem solving	2 hours	
	Simulation Lab#4 – Combination circuit	2 hours	Quiz 5
Week 5	Practice Problem solving and circuit building	2 hours	
	Test learning gain	2 hours	Mid-Term Exam (Simulation and Hands-on, and hands-on only)
Week 6	Hands-on Lab#5 – Ohms Law	2 hours	Quiz 2(Hands-on)
Week 7	Focus group interview	2 hours	Measuring students confidence level to operate the Multisim-8 (simulation and Hands-on)
Week 8	Data Analysis (Quiz and Exam score). Final Exam Interview	4 hours 2 hours	ANOVA (Simulation & Hands-on (Hybrid) , and hands-on only Gauging students' attitude towards the use of Simulation Software (Simulation and Hands-0n)

Setting

Following is the description of data collection sources used in the study:

1. Simulation Software

According to Veenman, Elshout, and Busato (1994), problem-oriented simulations help develop higher-order thinking strategies and improve student cognitive abilities employed in the service of recall, problem-solving, and creativity.[10] In constructing the simulation, Smith and Boyer's (1996) guidelines provided an appropriate model. The teaching goals of the simulation played an important role in its development. The primary goal of the simulation software (Multisim-8) was to help students understand basic engineering concepts. Additional simulation goals focused on encouraging student-to-student contact outside the classroom and on promoting student research beyond classroom assignments. Thus, the simulation activity focused mainly on the mental activity that took place within the learner. The lab activity focused on the physical as well as mental activity.

A virtual prototype software-simulation model with the same capabilities as the hardware prototype, created the same real-world effects, ensuring that the hardware prototypes worked when built and minimized the hardware-software integration effort in later stages of the course work. The model included processors, buses, and hardware components. It allowed the students to debug their circuits long before the detailed hardware design was complete, and thus enabled true parallel development of hardware and software. Using a virtual environment of Multisim-8 as a reference allowed simultaneous verification of hardware and software, ensuring they worked together as intended. It also reduced the amount of work that hardware designers had to do to verify their circuits, since they could leverage the system-level environment rather than develop independent test benches that were likely to be inconsistent. The software simulation (Multisim-8) tool, which was an integration of hardware, software and architecture into a single development environment, had profound effects on every aspect of learning.

The students were introduced to the concept of circuits, circuit components, circuit building techniques, and measuring tools through labs. The simulation software used in this experiment was Multisim-8. Multisim-8 provided the students with a virtual environment that gave them the ability to do virtual (simulation) labs and arrive at results that were similar to results obtained through the hand-on labs. The simulation labs were designed to prepare students to identify components, build circuits using different techniques, and connect different types of wires. In additions to circuit building, students learned how to use measuring instruments while following safety standards.

2. Problem solving activity

The students were given in-class assignments that included practice and drill type exercises to re-enforce the concepts they learned in class as a problem solving activity (class work, home work, and online assignments). After completion of the class work activities, students were given homework and online assignments to master the concepts covered in class. To further enhance the understanding of topics covered in class, simulation labs were given to foster hands-on experience. Each lab was followed by a quiz on that particular topic to assess the understanding of the concepts learned.

3. Design treatment

In the baseline reference group, students performed all similar class activities except for the lab exercises, where they used hands-on breadboard circuit construction techniques. In the case study group, the students used simulation based lab exercises. The treatment consisted of lectures on new topics delivered weekly according to the syllabus. After the completion of a topic, a simulation lab corresponding to the covered material was given followed by a quiz to check domain knowledge. This process continued for the first four weeks to explain and test the concept of Ohm's Law, series circuit, parallel circuit and combination circuits. To further enhance the understanding of the new concept, class work covering the new material was given and simulation software was used to enhance students' skills in understanding the basics of electronics. The simulation labs were designed to expose students to the learned concepts of Ohm's Law, series circuit, parallel circuit, and combination circuits.

Data Sources

To conduct the study, the following data collection methods were employed:

1. Quizzes and Mid-Term Exam

Quizzes were given to the students on each topic after students went through the lecture component, problem solving component and the simulation lab component. Quizzes were used as an assessment tool to gauge the knowledge learned on a particular topic. Then after a four-week period, a comprehensive mid-term exam was given to test the knowledge gained in all the modules.

2. Interview

The interview measured students' attitudes *vis-à-vis* their perceptions of the effectiveness of the simulation (Multisim-8) in promoting learning. Students were asked to comment specifically on their experience about the Multisim-8 and asked for suggestions on improvement. The interview was conducted for all of the students The interviews focused on the following areas to acquire data for the case study research questions:

- Prior experience with the simulation software
- Future use of simulation software
- Role of simulation software in preparation for the real world
- Prior hands-on experience
- Level of learning (skill acquisition)
- Effectiveness of instructional design feature (IDF)
- Effectiveness of exploring elements of simulation software
- Effectiveness of modeling elements of simulation software
- Top five strengths of simulation software
- Top five limitations of simulation software
- Effectiveness of simulation software on articulation of new concepts

3. Focus Group Interview

An open-ended interview was conducted to acquire data that might not have been collected earlier in the individual interview. A focus group interview approach was adopted to solicit opinions and attitudes toward the use of simulation and the feasibility/practicability of simulation as a useful tool for real world application. Ten students volunteered from the participating class for interviews. Interviews were conducted by audio taping, oral questions and field notes. Confidentiality of participants was maintained and a written consent was obtained from each of the participants.

Data Analysis

Qualitative Data: The qualitative data acquired through the interviews were first coded. These codes were then used to identify emerging patterns, recognize trends and form generalizations about the outcomes.

Hypothesis

A hypothesis is simply a prediction of the possible outcomes of a study. It enables one to make specific prediction based on prior evidence or theoretical arguments. In the present study, the expectation was that the test results would improve significantly by using Multisim-8 in comparison to the standard bread boarding method. Test results were evaluated by comparing the scores from the breadboard method to the scores from the Multisim-8 method. The expectation was that Multisim-8 would produce better results because of the ease of using the software, elimination of mistakes by students in selecting the wrong components, and the prospect of human error in measuring values using the measuring instruments. It was also expected that the students using Multisim-8 would have higher mid-term grades. If difference of the means between the two methods was significant and in the proper direction, the hypothesis would be supported; and if not, it would be rejected.

Validity Issues

Validity refers to the appropriateness, meaningfulness, correctness, and usefulness of the inferences a researcher makes and validation is the process of collecting and analyzing evidence to support such inferences.

The case study method provides four criteria for ensuring that the research and analysis is of sufficient quality for the complexity of the project: construct validity, internal validity, external validity, and reliability.[15] Construct validity is the degree to which a test accurately measures its intended subject. The construct validity for the present case study was established by using the expertise of skilled professionals who were specialists in the specific subject matter. Construct validity was tested using several sources of evidence (quizzes, exams and interviews) and examining conclusions to ensure that the conclusions followed logically from suppositions. A chain of evidence was established and tested for logical consistency. Furthermore, in order to establish validity for the present case study, the interviews were conducted by subject experts. Multiple sources (quizzes, exam and interviews) were used to see if conclusions converged around a common theme.

Internal validity describes how a study is shown to follow logically from hypothesis to evidence to conclusions. The present case study established the internal validity by conducting quizzes and exams under the supervision of selected trained personnel in the field of electronics. The results were then evaluated by content-experts in the field of electronics.

The third test, external validity, demonstrates the veracity of induced conclusions. For the present case study, a triangulation design procedure was used to establish external validity. More specifically the convergence model of a mixed method triangulation design was. First the qualitative and quantitative data were collected and analyzed separately. Next, the different results were converged, by comparing and contrasting, during the interpretation.

Findings

This case study was designed to analyze the potential impact of the use of computer simulation design methods on students' problem-solving skills for circuit construction in an undergraduate ECET (Electronic Computer Engineering Technology) course. As discussed in the Methodology section, a comparative case study methodology was employed to investigate the research questions. A mixed method research design was used in which quantitative data were collected to identify potential patterns or lack thereof, and supplementary qualitative data were used to explain the results with an emphasis on the participating students' and teachers' perspectives.

Qualitative Analysis

The purpose of this qualitative analysis is to explore the impact of using computer simulation on Students' Learning in a Technology-based Course. Two focus groups (FG-1 and FG-2) and one follow up interview were conducted. The first focus group FG-1 had six members and the second focus group FG-2 had four members. An orientation session was held to explain the both the research methodology employed and the voluntary nature of participation. The initial group consisted of 24 students, of whom 10 volunteered to participate in the study. These ten students were assigned into two groups having six and four members each based on their availability. The focus group was conducted at the end of the semester after participants completed their final exam. This schedule allowed the researcher to acquire a holistic picture of students' perceptions toward both simulation program and hands-on activity regarding circuit construction. The first focus interview was conducted with the focus group FG-1, and a week later second focus interview was conducted with the second focus group, FG-2. Participants' feedback was recorded using a digital voice recorder and a tape recorder. In the focus interviews, the participants were asked specific questions.

The qualitative analysis involved student interviews in form of focus groups and individual interviews of faculty. First, all students taking ECET-110 (DC Circuit Analysis) were informed about the purpose of the comparative case study. They were also informed that design methods include cognitive apprenticeship domains of modeling, scaffolding, articulation and exploration. All students were given an introduction letter and a consent form. Ten out of 24 students volunteered to participate in the study. Ten student volunteers were randomly divided into two groups. The first focus group (FG-1) had 6 members and the second focus group (FG-2) had 4 members. The first focus group was interviewed and responses were transcribed using MS-Word and also voice recorded using an audio voice recorder and a digital voice recorder. After one week, the second focus group was interviewed in a similar manner. Questioning was proceeded by a follow up meeting with the participants to seek additional feedback. Group members (from both groups) were males with diverse backgrounds, some of whom who had exposure to the electronic/information technology field, while others did not. All participants were from the same original group. The participants' mean age was 18.5 years.

To analyze the student response data the qualitative analysis software NVivo-8 and Microsoft Word were employed. The open coding results are displayed in Figure 1.

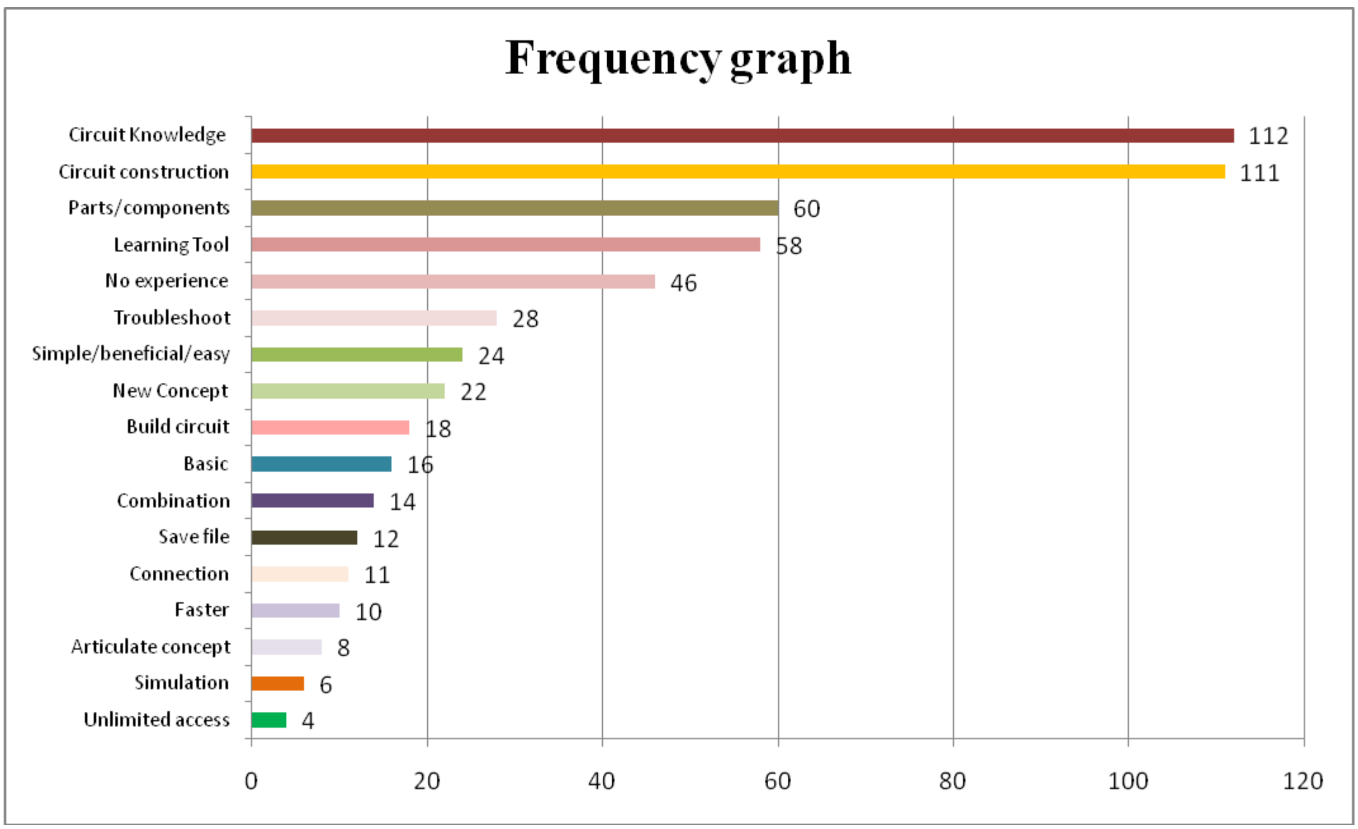

Figure 1: Frequency count of open coding process.

The open code frequency count analysis revealed that participants' most frequently used words or phrases were (frequency of 40+) were: "Circuit knowledge" (112) and "Circuit construction" (111), followed by "selection of parts/components" (60), "good learning tool" (58), and "no prior experience" (46). In the second phase of qualitative analysis, axial coding was used, and in the third and final phase selective coding was employed. Figure 2 shows the graphical summary of selective coding domains.

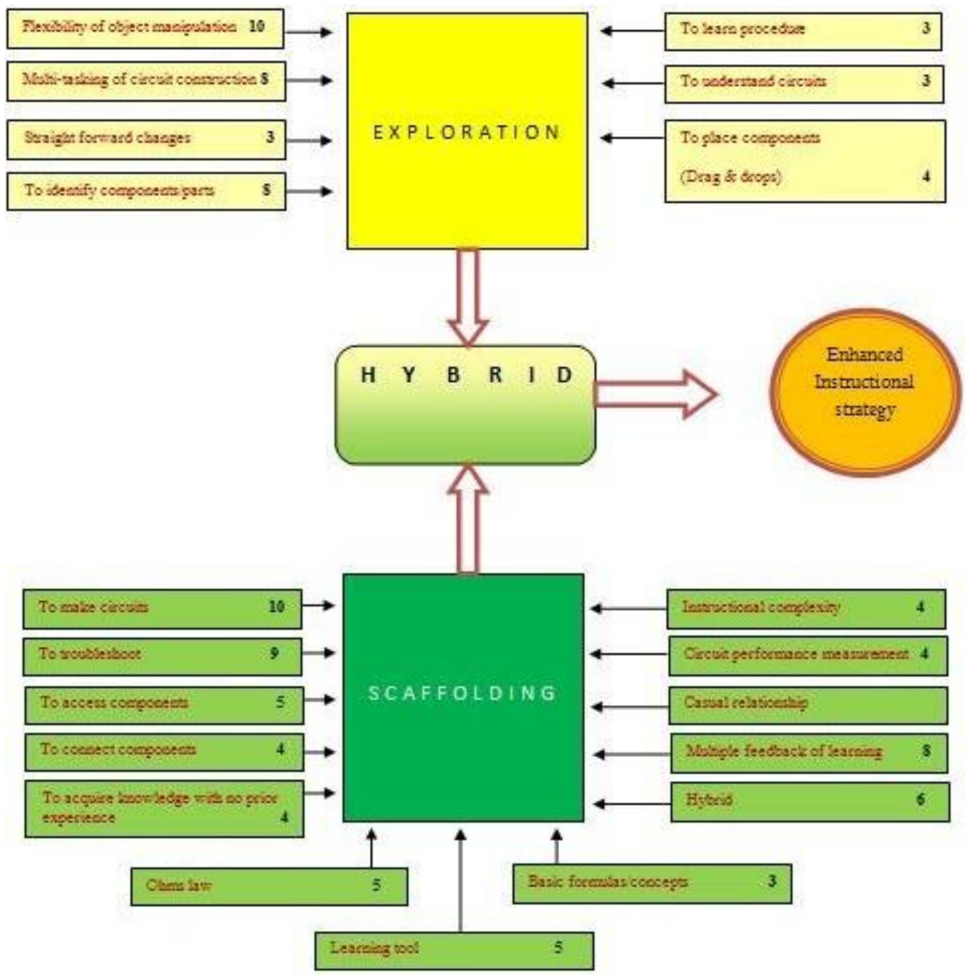

Figure 2: A Graphical Summary of Selective coding domains

The selective code revealed three domains of cognitive apprenticeship: exploration (hands-on or breadboard), scaffolding (simulation or Multisim-8), and articulation (hybrid or combination of hands-on and simulation). Figure 3 illustrates the frequency of positive and negative response of three domains of cognitive apprenticeship [Hands-on or breadboard (BB) Simulation or Multisim-8 (MS), and hybrid or combination of hands-on and simulation (HYB)]. Based on frequency of the codes it is evident that the scaffolding (simulation) method is more effective as compared to exploration or articulation, as illustrated in the radar display of Figure 4.

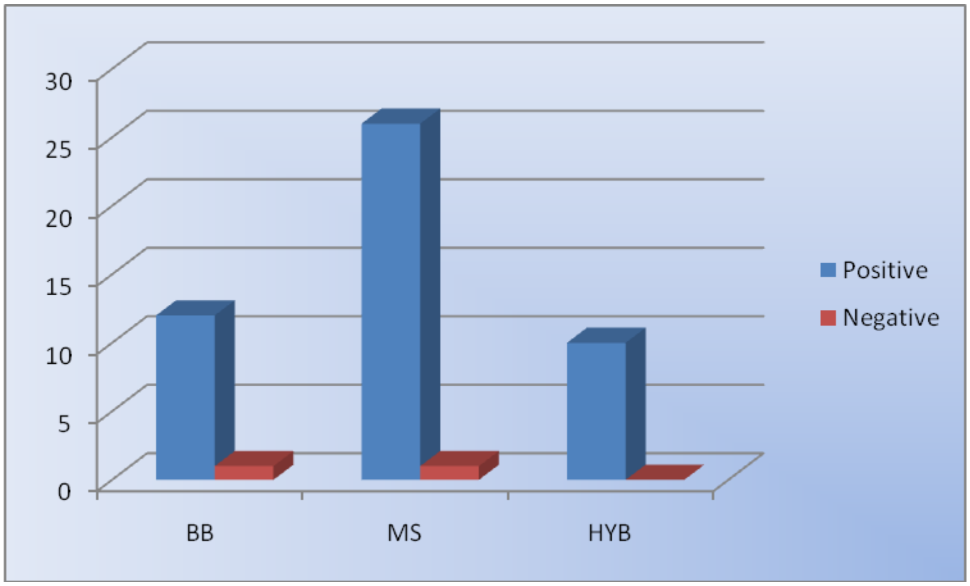

Figure 3: Participants response frequency for three instructional methods: Hands-on or breadboard (BB) Simulation or Multisim-8 (MS), and hybrid or combination of hands-on and simulation (HYB).

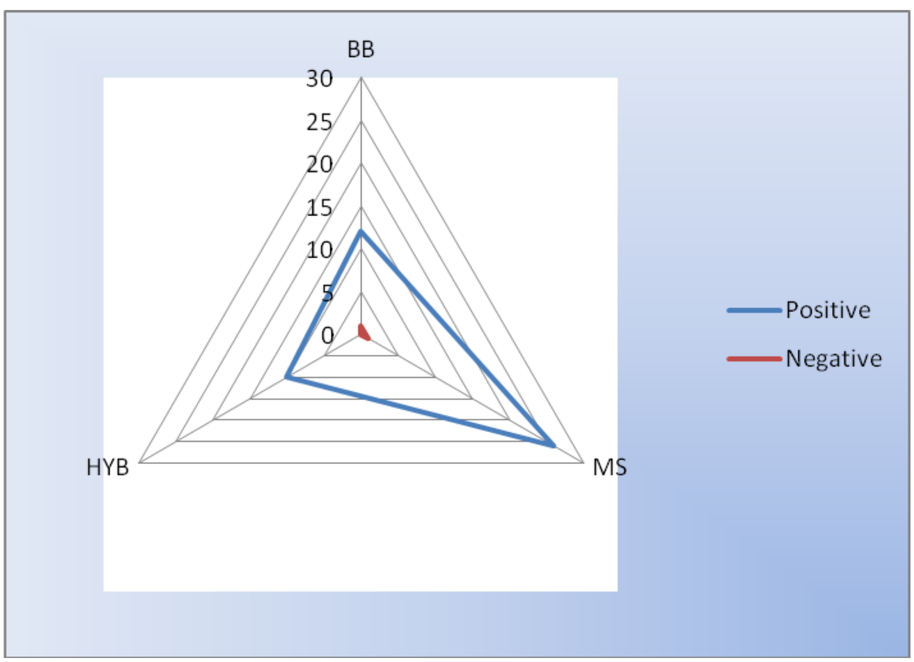

Figure 4: Radar plot illustrating the three instructional strategies Exploration (Breadboard) Scaffolding (Simulation) and Articulation (Hybrid).

Figure 5 illustrates the frequency of selective coding of the exploration theme. The negative phrases are “confusing,” “broken wires,” and “troubleshooting.” In the second theme of scaffolding, 63 responses are positive and 9 negative. The positive traits of the technique are “easy for beginners,” “with no experience,” “fast understanding of circuits,” “easy to build and monitor,” “simple to drag components and interconnect them,” “good database of components and equipments,” “easy to troubleshoot,” and “easy to save files.” Figure 6 illustrates the frequency of selective coding of scaffolding theme. The negative words/phrases are “boring,” and “hard to fix errors.” In the third theme of articulation, there are six positive responses and only one negative response. The positive characteristics of the method are “good learning tool,” “efficient combination,” and “related to real workplace.” This combination points to enhanced instructional strategy.

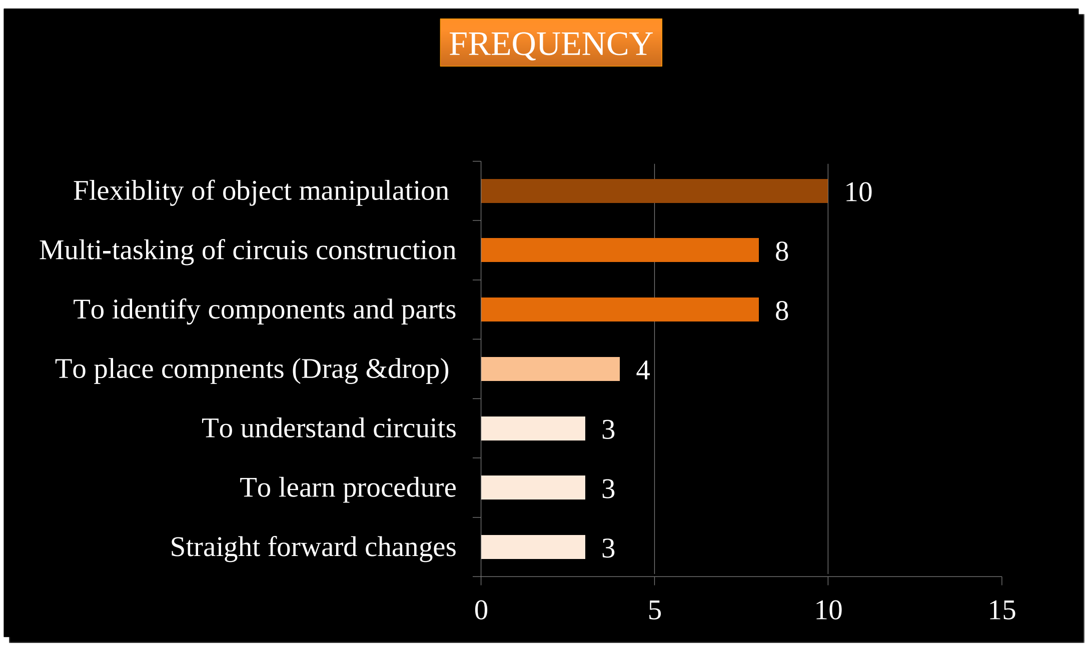

Figure 5: Frequency count of selective coding - Exploration

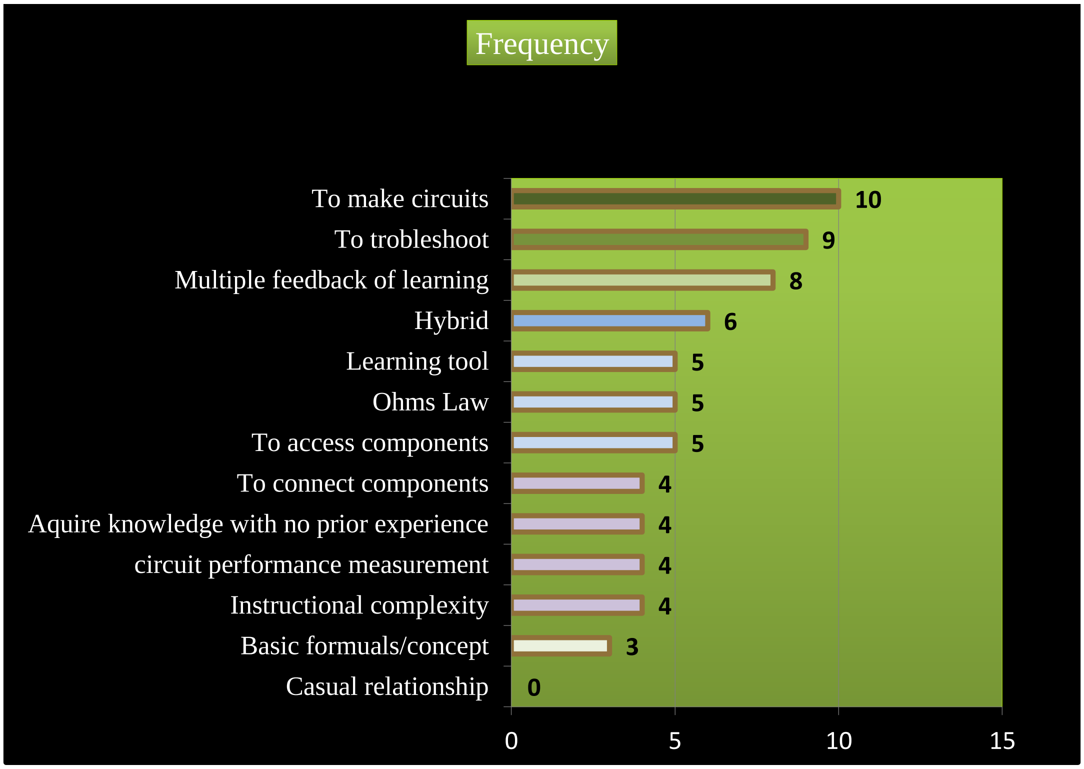

Figure 6: Frequency count of selective coding - Scaffolding

The themes and relative narrative provided the data necessary to address the research questions. A content expert, was also employed to code a 500-word section of the qualitative data to check for coding reliability with the help of coding software NVivo-8. The coding comparison resulted in a Cohen's Kappa of 0.63 showing an acceptable level of inter-rater agreement.

Summary of Data Analyses

In order to enhance the credibility and validity of the findings, the process of triangulation was employed. Cohen and Manion (1986) define triangulation as an "attempt to map out, or explain more fully, the richness and complexity of human behavior by studying it from more than one standpoint" (p. 254). The findings of quantitative analysis were compared with the findings of qualitative analyses. Furthermore quantitative and qualitative findings were scrutinized in light of the expert opinion.[16]

The quantitative analysis revealed that a marginally significant difference between simulation & hands-on group (Hybrid) and hands-on only group. The simulation & hand-on group (Hybrid) group showed higher mid-term scores compared to hands-on group. The effect size was moderate.

Moreover, for same group analysis i.e. for simulation & hands-on (hybrid) group, the quiz scores for simulation method taught first and quiz scores for hands-on method taught later, showed no significant differences. The effect size was moderate. The insignificant nature of results may be due to sampling error.

Furthermore, to explore the relationship between the method of instruction and the change in the test score, a mixed design ANOVA was conducted using the midterm and final exam test score of Instructor A's students who were taught simulation method followed by hands-on method with the scores of Instructor B's students who were taught with only hands-on method. The findings reveal that two groups performed similarly across the time with respect to their score. The effect size was small.

This case study was designed to assess the potential impact of the use of computer simulation-based instructional strategies on student learning viz a viz their circuit knowledge and problem solving skills. A mixed method research design was used in which quantitative data was collected to identify the presence or absence of learning patterns.

The quantitative data analyses revealed that in the initial phase of course delivery, a simulation based instructional strategy had a marginal effect on student learning compared to a hands-on teaching strategy. In the second phase of course delivery, data analyses revealed that the instructional strategy based on a combination of simulation and hands-on had had a marginal significant effect on student learning compared to a hands-on only instructional strategy. Since the two strategies complement each other they enable students to enhance their understanding of the basics of circuit design and application.

The qualitative data analyses revealed that students perceive that simulation scaffolds the learning process. They also perceived that simulation promotes articulation (i.e., the. ability to construct circuits) in incremental phases. However, students also perceived that simulation fails to replicate the real world scenarios and applications. A majority of students perceived that a hybrid approach (i.e., a combination of hand-on and simulation) is the best instructional strategy for learning circuit design and applications.

Discussion of Findings

As mentioned earlier, the present case study was designed to analyze the potential impact that the use of computer simulation based instructional strategies has upon students' learning and problem solving skills in a technology-based course. Therefore, this study essentially proceeded with two qualitative research questions and one research question using the combination of qualitative and quantitative approaches. The first research question explored the relationship between use of simulation and learning outcomes. The question was addressed to both students and faculty, whereas the other two research questions were addressed to students only, exploring the students' perceptions of the instructional design features of the simulation program Multisim-8.

The results regarding the impact of modeling element of simulation program on students learning reveal that the majority of students believe that modeling is faster, simpler and easier because it allows quick changes for circuit modification, which is beneficial in case of design of complex circuits. Students also believe that they can see the operation of the circuit with the help of meters in a very short time. However, a few students believe that they still prefer to work with real components on a breadboard because it is better to work with them. This is in line with the results reported by Banky (2007).[17]

The results regarding the effect of the support of simulation program on learner's articulation of new concept of the circuits suggest that student responses are mixed. Some students believe that simulation program is great because it promotes articulation since it allows circuit to be built in an incremental order, save it and reuse it later. However, other students believe that in real world application hands-on is very important; the repetitive nature of simulation circuit building is advantageous but can become a boring activity. The finding is similar to results reported by Banky (2008).

The findings in regards to the role of authentication of the simulation program for acquiring knowledge for real world situation reveal that the majority of students believes that simulation program by itself is not conducive for real world situations and applications. They believe that simulation does not reflect real world issues because all the pictures, symbols, icons of components do not emulate the real components and system in their true behavior. The finding is in line with the results obtained by Banky (2008). Furthermore students believe that a mix of both hands-on and simulation is the best strategy for optimization of learning and gaining insight into circuit design, operation and troubleshooting, and for providing them with a knowledge-base skill set for dealing with the real world situations. The finding is supported by results reported by Campbell et al (2004) regarding the effectiveness of combined approach.[18]

The findings based on the qualitative analyses reveal that students perceive that simulation scaffolds the learning process. However, students also perceive that simulation fails to replicate the real world scenarios and applications. The majority of students perceive that a hybrid approach, i.e. a combination of hand-on and simulation is the best instructional strategy for learning circuit design and applications.

Conclusion

In retrospect, a comparative case study was conducted to explore the impact of the use of computer simulation design methods on students' problem-solving skills for circuit construction in an undergraduate engineering technology course. The hypothesis was tested by investigating the following key questions: 1) Does the use of simulation improve students' learning outcomes? 2). How do faculty members perceive the use and effectiveness of simulation in the delivery of technical course content? 3). How do students perceive the instructional design features embedded in the simulation program such as exploration and scaffolding support in learning new concepts? The study employed qualitative and quantitative modes of data evaluation viz a viz cognitive apprenticeship instructional methodology. The study used a sample consisting of the 24 freshman enrolled in an 8-week technical course at a leading private university. Two groups were used; one was taught using simulation and hands-on instructional strategy and the other was exposed to hands-on instruction only. The findings reveal that simulation by itself is not very effective in promoting student learning. However, simulation becomes effective in promoting student learning when used in conjunction with hands-on approach i.e. hybrid or combinational instructional strategy. The findings of current study are affected and limited by its: smaller sample size, shorter student soak-in time (8-weeks), limited interactivity and capabilities of simulation software. Based on findings it is suggested that first students be exposed to theoretical knowledge in traditional lecture mode followed by simulation-based lab activities, and finally required to do hands-on lab experiments. It is recommended that future studies be conducted to validate the findings of the current study by incorporating: a larger sample size, a diversified ethnic group, a longer soak-in period (15 weeks), and other forms of instructional strategies.

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