What Happens When Computer Software is Used to Monitor Students' Conceptualization, Construction, and Analysis of Actual Electronic Circuits

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May 8, 2001

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Abstract

Of primary concern is the ability of students high school age to be able to conceptualize what actually goes on in electronic circuitry in order for them to be able to build and troubleshoot with precision skill. The Fault Assisted Circuit Electronic Trainer (FACET) was used on three students to determine if this electronic computer-aided instruction would be beneficial in helping students understand and conceptualize this complicated circuitry. This was a qualitative study where after each exercise on the FACET System, the students were interviewed to determine what was difficult to understand, easy to understand, where they struggled, and what was beneficial about this type of learning. This study took place in an Electrical Technology class at a three-year half-time Career and Technical Center.

PROBLEM STATEMENT

At the end of the three-year tenure that the majority of technical education students spend in their course of study, they are required to take a National Occupational Competency Testing Institute (NOCTI) exam that consists of a 180 question written component and a three hour practical assessment. It is through the results of this evaluation that many technical educators determine where weaknesses lie in the curriculum, students' conceptualizations, and instructor's approach and delivery methods in presenting the material. These students are compared to other students across the nation in the same program of study and can receive a national certification if their scores fall within the national standards. The areas of testing are broken down into various categories and we have found that in the written portion of the electrical/electronic NOCTI exam, the lowest scores occurred in the analysis of AC and DC circuitry.

This component of the test is associated with values of resistance, current, voltage, and power in series, parallel, and combination circuits. The issues of concern lie in the mathematical computation of the values of these components and the use of instrumentation to measure and verify those calculated values. It is in this area that students experience conceptualization difficulty and where extra focus and guidance is essential, not only to pass the NOCTI exam but to fulfill the students' knowledge requirements that will help satisfy business and industry's needs. The basic fundamental-DC-circuit construction and analysis provides an important foundation for further studies in advanced electrical concepts. Without mastering these basic fundamentals, it is difficult for students to move on to analyze and construct higher-level AC and DC circuits.

A primary concern is the students' ability to maintain interest in the material being presented. The presentation of the information to this point has been performed in the more traditional manner with the use of lecture, blackboard, overhead, and demonstrations. Dialogue occurs primarily between a few students in the class who are able to comprehend the information, and me, using these traditional delivery systems. If the students fail to follow and keep up with instruction, they are apt to lose interest and become bored. Information given in the form of rules and laws of various circuits is vital, sequential, and builds upon previous knowledge. Once a critical concept is missed or misunderstood, there is little hope of attaining the skills and tools needed to advance to higher level circuit construction and analysis. Obviously, motivation and attitudes need to be substantially improved and the students need to be more excited about what they are learning.

Another concern about learning circuitry concepts is the ability to apply what they have learned to actual hard-wired electrical and electronic systems. Most students can absorb mathematical formulas and memorize laws pertaining to circuits and some can even synthesize and analyze a drawing using these tools. The difficulty, however, lies in the application of these formulas and laws into an actual electrical circuit. There seems to be difficulty in transferring this information from schematic diagrams to an actual circuit. For instance, a student may be able to calculate a value of resistance in a series circuit but may have difficulty setting the function and range of a multimeter and placing it across the component in the manner which will yield the correct reading. A multitude of events must occur here. The students must remove all power from the circuit. They then must set the meter's function to read resistance. The meter's range must be set to attain the most accurate reading possible and finally, the meter leads must be placed across the component they wish to read in accordance with the schematic. After they accomplished this, they can then compare the meter reading with the mathematical calculations established in circuit analysis. The weakness lies within the relationships between schematic reading, the mathematical calculations, and the application and measurement of the actual circuit.

Another major concern is the student's retention rate. During the course of the three year program, there is review and application but for various reasons, when the student is ready to take the NOCTI, enter further schooling, or enter the work force, the information learned eludes them. Why can't some of the students recall the simplest of formulas or remember how to place a meter into the circuit appropriately? Is it because they were simply learning to pass tests? Is it a use it or lose it scenario? Is it simply that they dislike math and theory, and therefore feel it is unimportant (i.e. academic in nature and unrelated to wiring an electrical circuit)? For whatever reason, the retention rate is low as evidenced in the NOCTI exam and we need to look at other methods of delivery to improve retention levels.

Another issue lies with the current method of delivery. Are there enough thought-provoking questions? Are students provided with the guidance to develop a self-inquiry approach in their learning (Avots, 1993; Newmann & Wehlage, 1993)? I may not be giving the students the latitude at this point to develop their own thought-provoking questions using the traditional delivery methods. If the students feel liberated and comfortable enough in their learning environment to experiment and take risks, then it is possible that their learning experience will be richer. Different methods of independent learning may accommodate this type of learning environment. New learning methods and delivery systems may also serve those who are not auditory learners and those with special learning needs.

It is for the above reasons that I wish to explore what happens when computer software is used to guide and monitor students' conceptualization, construction, and analysis of actual electronic circuits. The computer aided learning component that I will use consists of the computer and monitor, an interface that allows communication between the computer and the many different types of breadboard modules that include DC fundamentals, AC fundamentals, and various solid state modules. An AC and DC generating station and a metering system used to measure voltage, current, and resistance are also included. This unit comes with its own software that guides the students throughout the lessons and monitors their results. There are tests at the end of each unit and the students can check their score results immediately. Throughout the lessons the computer prompts the student to connect certain circuits, calculate and measure required values, checks the answers, and provides feedback immediately following the insertion of the answers. The student may review and re-take the final unit exam up to three times.

In my research I hope to see how students use this software and ascertain whether and how it aids in the development of students' conceptualization of DC and AC circuitry by answering the following questions. Will this type of learning environment serve to foster more interest in this area of study? Will the students be able to apply what they learn in this software and hardware based instruction to realistic discrete hardwired components? Will this type of delivery system help students to retain the information longer? Will this learning method foster and provide thought-provoking questions, and will it provide the students with the guidance and comfort level to develop a self-inquiry approach? Will this technique help students that are not auditory learners or who are special needs learners attain a level of competency in fundamental circuitry?

REVIEW OF THE LITERATURE

Although in the literature the acronym CAI (computer-assisted instruction) is used primarily to describe drill and practice and tutorial type software, I will use this term also to define any use of the computer that facilitates interaction of the computer and software with students in an educational learning environment. CAI allows students to study and practice procedures as long as necessary to achieve certain objectives. This helps to level the playing field where students bring diverse backgrounds to the class or laboratory. This review will support the premise that those students with a willingness to learn electrical or electronic concepts can succeed in spite of limited educational backgrounds when given the right learning tools and support.

Immediate feedback, one of the best characteristics of CAI, saves time and prevents the student from learning the incorrect concepts and techniques. In a homework assignment, a student can repeatedly do problems incorrectly. In a traditional classroom, the student will not receive feedback until the next class period. With CAI, students can ascertain their own weaknesses and focus on those areas in which they need the most concentrated effort. Often, in conventional classrooms, students may move on to advanced topics while holding misconceptions about fundamental ideas. This may lead to frustration and they may feel that electrical circuits are more complicated than they really are. Many students may drop a program because of explanations not made clear either by drilling or virtual visual demonstrations. Good CAI rewards students immediately for correct responses and this encourages students to continue on with more complex circuitry. They may stay on a task longer until they master what they need to understand in order to continue.

This type of instruction should leave more time for the teacher to work with students on an individual basis and spend less time correcting papers and projects. We should keep in mind that CAI does not replace teacher interaction but rather enhances student learning. Computers are merely instruments of learning. Effectiveness depends upon the skill of the lesson, the author, and the design of the delivery system. The teachers and CAI must work in concert to increase effectiveness of learning (Doyle, 1993).

CAI in various forms can be used to enhance student learning. Those forms include tutorials, drill and practice, simulation (simulation of electrical circuitry in our case), and commercial training systems. Tutorials are self-instructed programs that present lessons on the screen with text, graphics, or both. Evaluators of such software should not be misguided by pretty colors and fancy graphics and should not assume that this type of software will provide maximum interaction with students. Students will become bored with this type of display and will not benefit from the program. Podany (1990) evaluates ten physics software packages that include electricity and magnetism at the middle school level. These ten software packages appearing in this report were chosen because they were judged to be exemplary. Podany's study estimates that there are hundreds of software packages in the middle school science area, specifically on the topics of electricity, magnetism, and heat energy. Evaluators in this study felt that science is a high interest topic now and that it will be in the future. They also felt that nothing replaces actual hands-on activities and experiments and that is why my research focuses on a software package that utilizes both virtual and actual electronic circuit activities.

Drill-and-practice CAI software can help with applied mathematics in the electrical discipline by aiding in circuit analysis. There are certain concepts that this type of practice is best suited for such as multiplication tables, etc. The immediate feedback keeps the student motivated. This is similar to the programmed learning instruction packets used by the military that would explain a concept, pose a question, then direct you to a page and number according to your response. They would let you know if you were correct or not, and if you were not correct, explain your mistake. Drill and practice software can do this more effectively posing questions and providing answers and explanations until the student has succeeded.

Simulation - CAI programs that simulate complex circuits can be very powerful tools for learning. It may take some time to learn to operate this software, sometimes using a tutorial. Doyle Hasty (1993) did research with Motlow State Community College using CAI in the areas of direct current, alternating current, and digital concepts. Student satisfaction according to Hasty, was near 100% because of the effect of simulation. They also used a textbook for assignments along with lecture to accompany the software use. It may be helpful to the instruction process for the teacher to lecture to the group, stepping the students through the simulation process to minimize time spent on learning mechanics of the simulation software.

The studies that I looked at are diversified. One was with CAI applied to a science program at a middle school, one was with CAD (computer aided design) specific to electrical and electronic design, another with CAI used in a community college, again with electrical and electronic focus, and an intriguing one with the University of Illinois at Urbana-Champaign. Illinois used a somewhat different approach (Burks,1995). They used the network to implement CAI and they called it ALN (Asynchronous Learning Networks).

All lessons, quizzes, tests, and communications were done via network, with minimal group meetings. I will take an in-depth look at all of these studies and try to show similarities and differences along with results that reflect both teachers' and students' impressions. I will also examine how the relationship of these results will effect and impact my research.

The basic purpose of the study done at the University of Illinois (Oakley, 1995) was to develop new pedagogy for teaching engineering students electronic circuit analysis. The designers of the study were hoping for a significant improvement over traditional methods and for an increase in faculty productivity. They used the Asynchronous Learning Network (ALN) method, which means the students could access the learning environment at any time from home or school. All tests, quizzes, and assignments were given on the network. There were many advantages to this structure. The feedback for tests and quizzes was almost immediate. Students' work could be accessed by the professor at any time without paper. Students could use email to ask questions which could be answered in an electronic forum where all could participate.

The Department of Education engaged in a project (RP453) that summarized the feasibility of incorporating computer-aided design (CAD) in electrical and electronic courses (Roach and Medhat, 1990). CAD software is the industry standard in architecture and mechanical drafting. Recent versions incorporated design of electrical and electronic systems so that they can be added to structural drawings for bidding purposes. In industry, a fifty percent lead time has been recorded for those industries that have used CAD over those that have not (Roach and Medhat, 1990). The advantages according to this study are quick alterations to circuits, one design cycle to get the design right the first time, and better documentation which means an earlier start to production or construction. The aim of this project was to investigate the application of CAD to electrical and electronic systems in education, the extent to which education can approximate industry, the curricular changes necessary to implement software, and staff development implications. They applied CAD to digital and analog electronics, microprocessors, telecommunications, and control systems to name a few. Through surveys and meetings with colleges and professionals, they were able to draw some conclusions about the usefulness and effectiveness of CAD.

The study done at Motlow State Community College (Hasty, 1993) had a different focus. Their enrollment statistics showed that seventy-one percent of freshmen entering the college were not properly prepared for college level courses and some level of remediation was necessary. Given this type of population, the community college felt that by using CAI, students could progress through electronic and electrical courses at their learning styles. According to Hasty,improvements in advanced computer technology promoted innovations in CAI lessons making CAI a more feasible format for providing individualized training. Recent software programs have improved graphics, animation, feedback, fault insertion techniques, tests, quizzes, and other interactive features. Students in this institution's electronics classes were a heterogeneous group. These students progressed at very different rates. The study's authors hoped this type of software would be useful in this environment.

Hasty identifies the characteristics of a good CAI program.. A CAI program should have branching capabilities, where students can take different tracks based on responses to inquiries. It should have remediation where additional study of certain areas are available for practice. The software should have flexibility so the instructor can choose from a broad range of exercises. It also should be self-paced with good audio and graphical representations to help students learn abstract concepts. One of the most important approaches, simulation, should be available so the students can interact, control, or become part of synthesizing and analyzing circuitry. Good CAI software should have clear concise objectives and a properly organized sequence of lessons from simple to the most complex. The software should have manageable steps so students can master each step before moving on to the next with instructional background materials such as definitions and procedures. Another important ingredient is the necessary feedback process which addresses the student's responses in a positive way and ensures that students grasp fundamentals before moving on to more advanced concepts. The program should promote interest and motivation where the students have a desire to continue using this type of tool and the instruction materials should be well written with clarity and correct grammar to set a good writing example for the learners. These are high standards. Software with these characteristics should enable a variety of students to be successful at any rate of speed within reason.

These three studies found that CAI showed improvements in student learning and all agree that CAI had a positive impact. In the University of Illinois study, they compared students who used the ALN method to students who learned by traditional methods and those using ALN scored much better (better grades) than those who did not. Also, in subsequent courses, students showed more retention of the fundamentals introduced in the basic skill sets and there were fewer students who dropped the course. On the faculty benefit side, there was less test preparation and grading, which left more time for instructional purposes. There were also fewer office hours because questions and responses were addressed on a bulletin board so that all could examine responses at the same time. Once again, the student-faculty ratio was increased without negative impact on student learning.

In the Motlow Community College study, Hasty says that student satisfaction, as well as student success, approached the one hundred percent mark. Their test-taking skills improved because there were frequent tests with immediate feedback. There was also an appreciable improvement in reading ability because unlike text reading, this type of reading was attention getting and applicable. They also noticed that students were more motivated and learned without difficulty to participate in independent learning.

The results of the CAD study (Roach and Medhat, 1990), although done with a different strategy than the previously mentioned studies, led to a recommendation that electronic and electrical analysis courses at the college level include CAD as part of their curricula. Circuit theory is traditionally regarded as rather a dry subject with low student interest, thus student performance is poor relative to other subjects (Sanderson and Roinson,1992). In an attempt to rectify this, CAD software was used instead of traditional laboratories. Students were able to build and experiment with circuits after a relatively short familiarization period. It was felt that student motivation and interest was certainly enhanced and a greater depth of understanding resulted (Roach and Medhat, 1990).

The following recommendations were made by the investigative committee: CAD techniques should be adopted in relevant courses as soon as possible, CAD should be used as a vehicle for integrative assignments, and time must be made for staff development and training/updating. There are some common denominators throughout the research. The results seem to indicate that a good CAI package positively affects student achievement. The quality of software, the way it is imparted, and the attitude of the instructor all play an important role in how a course would be received, and the degree of its effectiveness. Will an actual circuit design and analysis program be similarly successful with students in this study? Will the mechanics of the software program itself serve to frustrate the lower functioning students or will it draw them into the mainstream? Would this just be another complicated tool that they have to learn how to use or will it be a tool that will help them use other tools more efficiently and expertly? Will the more advanced students learn independently so that the instructor's time can be used to facilitate those who need more attention?

This study will describe what happens when CAI software is integrated into the electrical and electronics curriculum.

RESEARCH DESIGN

The focus of this design may help to answer how computer assisted learning affect student comprehension of design, construction, and analysis of electrical and electronic circuits. My method of research will establish if conceptual change takes place and perhaps to what extent. Although conceptual change is what I am looking for, there may be other effects that the study may have on both the students and myself that may emerge as the research progresses. At the very least, I would expect some change no matter how small and insignificant even if it's only a familiarization with another type of teaching and learning technique.

The software and hardware vehicle we will use to help facilitate this research is the Fault Assisted Circuit Electronic Trainer (FACET). This trainer is manufactured by Lab Volt Incorporated, is a company that specializes in electrical and electronic equipment designed to aid secondary and post-secondary technical curriculums. I will refer to this vehicle as the system or the hardware and software system throughout the remainder of this research paper.

Our computer lab is the venue for such a study. We have, along with our laboratory, a classroom that includes lab equipment and seven computers (Windows NT networked with online access). There is an acoustical ceiling and vinyl floor, originally installed for sound-absorbing purposes, which serve to make the environment comfortable and user-friendly. The noise level is at a minimum so that discussion, tape recording, and video taping can take place with little interruption. There are many text references on hand throughout the classroom so the students can cross-reference any materials such as drawings and definitions. The computer tables are laid out along the perimeter of the lab so that I may circulate around the classroom and view each screen over the shoulders of the students. The students may sit side-by-side to share a computer or students can work on their own units. The interface board along with the power supply and meter station are to their left. My computer faces all of the students so they can watch demonstrations. There is a white board and a flip chart handy for lectures and schematic drawing examples. The classroom area also has lab equipment around the perimeter so that I may do demonstrations with actual components and wiring. The software can be used to support the lab equipment and the lab equipment can be used to support the software concepts. The room is conducive to focus groups and individual interviews. The students' ages range from 15 to 19 and will be all males. Some of the students are very extroverted and there will be no problem getting input from them while I may have to pry information from others because they often answer in one word or phrase responses.

Our school is a vocational technical high school with five sending districts. Most parents expect their children to attend college, so it is rare that I would have students with above average intelligence. In rare situations, I have had students who were planning on becoming electrical engineers that used our course for some practical hands-on experience to enrich their academic studies. For the most part, my students will enter the work force after high school, attend a post-secondary technical school, go on to junior or community college, or enter the armed forces.

I worked with four students that were made up of a primarily homogenous group. Some of the students will have some sort of learning problem, particularly a low level reading and/or math level. It is unlikely that these students will be going on to further education immediately except as adult evening students learning particular advanced skills in their craft. Most students have some experience with the computer and possess the necessary focus to maneuver in the Window's environment. We did however have to spend some time introducing the FACET software and the nuances of maneuvering within its environment.

I exercised the role of participant observer. My data collection methods included in-depth interview sessions and document analysis from a research journal that I kept. There was also some video recording of lab experiments and theory dialogue. I also developed a survey or questionnaire so that I may employ triangulated data analysis. Some of the factors that I observed were: student interest, ease of use of software, willingness of students to make corrections, points of enlightenment, attendance changes, overall attitude changes, student collaboration, dialogue with the instructor and each other, improvement in abilities, motivation, and self-inquiry, along with other emerging processes.

The software and hardware system that the students used is a self-directed system in which the software guides and monitors students' activities in connecting actual electronic circuits. Each student logs on for privacy and the students begin reading information on the computer screen. The software is broken down into major categories such as DC fundamentals, AC fundamentals, and solid state circuitry. Each of these categories resembles a textbook where they are divided into units, with unit tests at the end. Each unit begins with an objective, followed by exercises and review before the final unit test. Throughout the unit, students are asked to build and analyze circuits and circuit components. They are prompted for responses in mathematical calculations as well as measurement with instrumentation. If the response is correct, a green correct flag appears. If the response is incorrect, a red flag appears and the students need to go back and correct their mistakes. They can either use the mouse or function keys to get around the keyboard. At the end of their lesson period, the students exit the lab exercises in a manner that will save all of their information to that point so that the next time they log on, they can resume where they previously left off. There is also a help menu where the students can access a calculator, the Ohm's law formula chart, and a resistor color-code chart.

The hardware consists of an interface unit that houses the DC, AC, and semiconductor fundamentals boards, an RS232 cable that connects the interface board to the computer, a + and -15 volt power supply, and a built in digital multimeter to measure voltage, current, and resistance when prompted.

This approach to learning was well received by both the students and myself. They struggled in the beginning when they were learning the software and they had to discipline themselves to refer back to the computer program instructions. In the beginning they had some difficulty in associating the virtual circuit and hard component wiring, but eventually made those associations. They had very little difficulty with changing components since that could be done with relative ease. Since many prompts and questions stem from the same circuit, the students only had to construct an actual circuit once for each exercise.

I used the constant comparative method of data analysis by analyzing recurring phenomena such as language, circuit building success or failure, attendance improvement, grade improvement, attitude improvement, and points of enlightenment.

This study described how students use this software to build and analyze actual electronic circuits. The intent of the study was to demonstrate whether and how students of this age group and ability level grasped circuitry concepts that have been historically difficult to master.

FINDINGS

Student interviews, video analysis, student surveys, and field notes were utilized in describing and analyzing what happens when computer software is used to guide and monitor students' conceptualization, construction, and analysis of actual electronic circuits. These methods of collecting data were analyzed for important patterns of information and many unexpected and pleasant revelations occurred.

It was obvious at the initial stages that there would be much confusion and many obstacles that the students would have to overcome in order to be proficient enough to engage in their educational journey using this new learning enhancement tool. One student actually thought that he had completed a unit but when he visited the unit summary report he was surprised to see that the histogram chart only reported thirty percent completion. The unit report at the end of the unit gives scores of all the unit exams taken and shows the percentage of unit completed. This provides evidence to an instructor that the student went through each step in the unit before attempting to test out. If a student did not do well in a test, the report may show that the student attempted to take the exam without going through the whole unit. Somehow, and unintentionally, this student ended up at the end of the unit without studying each section. Typical units are usually broken down into four sections consisting of objective, informational texts, lab experiments, and summation.

There was also the issue of parts and circuit board identification and familiarization. This was the purpose of Unit 1, to introduce and orient the student in all aspects of the trainer. This could not be done without guidance and direction from me. Ervis asked if what he had in his hand was a two-post connector and even though he felt that he had the right component, I think he needed the reassurance to move ahead. Their confidence would build as the weeks passed and we both found that they did not need my reinforcement as much. Another student even found himself on unit three when he was looking for the conclusion of unit one. It was really quite evident that the students needed to slow down and analyze the introductory information to include the table of contents, unit objectives, and the correct key or mouse applications that would lead to a systematic and sequential approach to successfully completing each unit. After completing the first unit Josh was confused as to how to check his performance on the unit test. "It doesn't show me what I got on the test, only that I completed it". There is a unit summary menu that gives the students four alternatives in assessing and evaluating their results. One is seeing the results of the unit test. This is where the students would see the histogram representation of their scores. Another alternative shows how much of the unit that was completed with a pie chart and simply states that the unit-test was completed. Another choice lets the students go through each question to see which ones were right or wrong. This provides a golden opportunity for review and shows which concepts the students need to strengthen. The final alternative is a unit test retake that will register up to three retakes. Once the students digested the end of the unit menu concepts, they felt less confused and more confident with the self-evaluation of strengths and weaknesses.

They were also confused with the actual circuit board layout. One student stated that he was confused as to what they were expected to do in order to complete circuits to begin analyzing and trouble shooting. He thought that he had to actually add components. In reality, all they really needed to do was to insert two-post connectors in order to connect components that were already installed in the circuit board. Dashed lines represented the destination of these two post connectors and the students had to insert them according to what the instructions wanted them to measure or what type of circuit they wanted them to connect. There was also confusion about the purposes of some of the components. Josh was prompted by a unit exercise to explain what the purpose of an arrow protruding through a battery indicates. I think he knew this but seeing this in a different environment confused him. He first thought that this arrow indicates the direction of current flow. I explained to him that the way the battery symbol is drawn already provides an indication of current flow. The small line on one side and the larger line on the other indicate the positive and negative terminals and in our industry we assume that electrons flow from positive to negative. So I asked again in light of this review, what he thought an arrow going through a component would signify and he was able to recall that it meant that this was a component whose value could be varied. I encouraged all not to abandon what they already knew. This is simply another tool and approach to learning and that they should see some very familiar components and concepts just in a different venue.

At this point I also questioned the quality of information dispersed by the software system. Are the questions concise, clear, and written in an appropriate level for my students to understand? Did the students simply not understand what they were asking? Did the students not retain what they have learned in the past? In unit one, the dashed line and the arrow going through the power supply symbol were the two most commonly misunderstood concepts. After the students reviewed the unit, they did find that this information was there. This information may have been blurbs that the students overlooked or didn't take too seriously but they did discover that the information was given. I reiterated that in a software package such as this that memory and space is at a premium so that every graphic and every piece of text is crucial and should be internalized. During one of our interviews, when I asked if everyone understood what the purpose of the interface board was, Matt responded with, "That has all of the circuit blocks on it to work with." Josh then stated that he did not understand what the picture on the computer screen wanted him to do. As we were conversing Josh was fingering through the keyboard and came across an example of what he was failing to understand. "See, here it is Mr. V, they show the circuit here on the computer but I'm not sure what they want us to do." I explained that they must also read the accompanying text and it said with the two-post connector removed, measure the voltage value of V1. Josh then connected the meter into the circuit but had both leads on the same side of the power supply. I coached him on how to read the circuit diagram and how and where it showed to insert the meter leads. Later on in his studies Josh became pretty proficient with the various meters and schematic interpretation.

After a few days of practice and lab exercises, the students were no longer confused by the mechanics of the system and were able to navigate around the software and hardware well enough now to use it to cultivate learning. We were in the business now of deciphering the relationships of voltage, current, and resistance using the applied math and measuring equipment, which is actually the heart of this research. The relationship is expressed as a simple equation, $E = IR$, where E is the electromagnetic force expresses in volts, I is the intensity of electron flow expressed in amps, and R is the resistance opposition to current flow measured in ohms. This equation provides an immense challenge to many students and although the math may be simple, the concept of the relationship is not. We brainstormed one day about why a concept with such an easy math application is so difficult for high school students to grasp. One of the explanations was that it might be hard to understand something that you really cannot see. You can see a wire but you can't actually see the current flowing inside of it. You can see a power supply but you cannot see that it is packed with an electrical pressure. I asked about the light bulb and if when lit there was visible enough evidence of electrical work being done. We all agreed that this was the result of the relationships of current, voltage, and resistance, not the actual properties of these components. When I asked Matt what the actual relationship between voltage and current was he stated that they were opposite or indirectly proportional, (i.e.) when one went up, the other went down. Josh on the other hand disagreed and testified that when one went up, the other went up, that they were directly related. Ervis agreed and stated that I showed them this concept during a previous lecture session. Devon made an excellent analogy. He stated that in a right triangle that contained a 30-degree angle, the hypotenuse would always be twice as long as the opposite side regardless of the length of the sides. I found this to be a profound analogy and evidence of critical thinking. He was looking for a way to define what proportional was and I think it helped the other students, at least the ones that understood basic geometry and trigonometry.

As the students went further into the lessons it became more difficult to determine from where the confusion was originating. First of all, students need to set up the actual circuits on the interface board as prescribed by the schematic on the computer screen. If an error occurred in their analysis we needed to make sure that this was set up correctly. If a measurement was required, the students needed to set the function and range of the meter to adequately read associated values of current, resistance, and voltage. They would also need to place the meter probes into the correct locations for appropriate values, and would need to interpret values on the digital scale in the correct denomination, (i.e.) amps, milli-amps. volts, milli-volts, ohms and kilo-ohms. Usually, if the numbers were right but the decimal place was wrong, the computer would prompt the students that they may be out of range by some power of ten.) Sometimes the students would insert answers in one denomination and the computer required it in another. In other words, if the computer wanted the answer to be 10 milli-amp, it would not except .01 amps, when in actuality, they are the same value. This, on one hand, is evidence of one of the weaknesses of the software program and on the other hand beneficial to the students because it regularly forces them to convert values by some power of ten.

Another source of confusion may have been the ability to compute the math part of the total analysis procedure. In some cases the measurement was correct but the math computations were wrong and vice-versa. It is often necessary in electronic circuit analysis that the measurements coincide with the mathematical computations for verification and provisions for alternate methods of problem solving. And if all this were not enough, there were software glitches that added to the confusion. Either because of wear or manufacturing defects, there were times that we determined, usually as a team, that that part of the circuit had some sort of component failure whether it be that it was destroyed or not calibrated appropriately. In any case, after checking all of the previously mentioned issues that were sources for confusion, there was also this to contend with.

This provided some frustration, however it also added tremendously to the learning experience of the students. They were actually troubleshooting at the component level and were not aware of it. When Matt was working with additive and subtractive power supplies, we did everything possible to check and re-check the circuit configuration, the math, and the measurement methods, but could not resolve the correct answer. Even though I did not encourage this, he finally kept on entering values that mathematically made sense and finally entered the right one. From knowing the answer we determined one of two things. The software was either asking the wrong question, or there was a defective battery power supply within the unit. When we tried another circuit board, and copied the same procedure, the correct answer appeared and it was evident that there was a bad component. I felt that Matt understood this segment of his studies despite the glitch and I also think it made him exercise problem solving skills that exists outside the realm of the learning material.

Sometimes when students were initially confused and we began dialoguing about the matter a light bulb came on and they resolved their own misunderstandings. A case in point, Matt states, "Mr. V, something is not right here. They are telling me to turn on switch three after I put in the two-post connector and only one light lights. Isn't this a three-way switch? Oh wait, I see. This light is connected to one of the switch legs of the three-way switch so only one light will light." I informed Matt that he was perfectly right but that they wanted him to connect two two-post connectors so that both lights would light alternatively. Matt has mastered three-way switch concepts for a while now and he was thrilled that he was able to associate what he knows into the lab exercises. I don't think he learned anything new here but some reinforcement was taking place. His source of confusion here was not reading the instructions accurately. He mistook a plural noun for a singular noun that would be inconsistent with what the software was prompting. It seemed really easy for the students to make these types of errors because the text is short, and in their attempt to be expedient, they misinterpreted the information. I again reiterated to Matt that because the information is so brief, every word is important. I also pointed out that they were beginning to see different forms of electrical component symbols but the function is the same. What seems to be emerging at this point is evidence that this software program can be useful to enhance and support the students' ability to apply electrical theory and concepts.

The ability of the software to accept an estimated answer to within a reasonable tolerance is phenomenal. If they were asking for a value of a current, the software would accept a reasonable range. We found however that it was beneficial for the students to be as accurate as possible (to the hundredths when dealing with amps). Even though it would accept an answer, when plugged into a formula to find another value, the original value could throw off the final result by too much. Matt found this out when he rounded off a measured value to two milli-amps and the computer accepted his response. He then needed to divide the amperage (.002A) into the ten volts that was supplying the circuit to determine the total resistance. (R = E/I, Ohm's law formula). His answer was 5000 ohms and the computer rejected his value. This served to confuse Matt because the computer accepted the 2 milli-amps. We went back and re-measured the amperage and found it to be precisely 2.67 milli-amps. We divided 10 by .00267 and the result was 3745 amps, quite a difference from the original 5000. The 5000 ohms result was far too different from the correct answer for the computer to accept. This frustrated Matt but I reassured him that if he took all amperage values out to the nearest hundredth it would be within the software's tolerance level. Matt stated that he didn't know how he attained the two milli-amp answer. He said that if he had read the 2.67 milli-amp value he would not have drastically reduced it to 2, but would have used the 2.67 value. I determined that the voltage must not have been adjusted to the necessary 10-volt value and he agreed. This again is evidence of all of the variables the students need to consider in circuit analysis and trouble shooting. This is a lot to think about and technicians need to approach this analysis in a systematic step-by-step and thorough deliberate manner.

Devon was confused at one point by a meter reading he was getting. He stated that the meter was now not working and perhaps I should take a look at it. He was trying to read a switch in the open and closed position. This is simply a continuity check on the switch where, when closed, there would be no resistance, and when open, an infinite amount of resistance existed. This was a prime opportunity for Devon to learn about a different type of meter reading. To this point, the meters we use in the laboratory for continuity checks contain a beeper that would sound when there is continuity in a circuit and silence when there is not. They did not have to read a value but simply listen for the beeper. This is reminiscent of the old dry cell and battery used in junior high science classes. The digital meter that is used with this system does not have this feature and many meters in use in industry do not either. It is, however, important that the students know how to use the many types that are out there. I explained to Devon and the others that the meter is fine. When the leads are in place and you read a series of zeros, it means that there is zero resistance in the circuit. If the meter digital readout doesn't change from when the leads are off the circuit to when the leads are on, that means the circuit is open or has an infinite amount of resistance. To compare the uses, I had Devon retrieve one of our standard meters from the lab and make the comparisons. I don't believe I taught this method to my students so this was definitely something new that I would not probably touch on. This software and hardware system seems to be filling in some voids of the curriculum that I do not teach. This to me is a very positive aspect of this system and lends itself as an enhancement tool to a degree more than I originally expected.

Josh had a little difficulty with some of the vocabulary that led him to insert the incorrect response a number of times. In one case the computer asked for nominal values of resistance and Josh used the meter to determine the answer. A measurement with a meter incurs too many variables such as the calibration of the meter and the manufacturing tolerances of the resistors. I explained that when they ask for a nominal value, they don't want the actual value of the component, but the manufacturer's value in name only. Most resistors are manufactured with a five-percent tolerance but in circuit design, nominal values are used to construct and analyze circuit behavior. The software program does not define any term that is not strictly limited to electronic concepts so it is the responsibility of the students to ascertain their meanings in order to understand what they are asking.

Devon had an issue with the message that the computer lost communication with the base unit. He was showing some frustration when this occurred because it was a temporary loss of power that interrupted his lesson. The software gives this message for a number of reasons. If for some reason power is inadvertently removed from the unit there will be a loss of communication. The most frequent cause of this disconnection occurs when students place the meter leads into the circuit improperly. This occurs most often when the students are trying to read a value of current, and they place the meter across a component instead of in series with it.

The frustration levels were relatively low throughout the research. There were occasions that students would sign off and walk away from the unit and even though I sensed the frustration, they did so in a calm manner. Another event that would cause a certain level of frustration is entering a response that causes a red flag to appear indicating a wrong answer. If this occurred once or twice there was usually no evidence of frustration. The frustration level, however, seemed to rise proportionately with the number of times that the feedback was negative. They all handled it in different ways but for the most part stuck with the problem solving until resolved, with or without my assistance. They usually did not call upon my assistance until they took the problem as far as they possibly could on their own. Often they would even ask another student who previously completed the exercise before they would involve me. When they drew me into the problem they still were not beyond a reasonable frustration level and I attribute this to many things. One, I felt that they considered me a major player in this learning role and that I was another resource and means for getting to a solution. I did not volunteer answers but provided avenues to get to the correct answer. I think they liked the idea that I could give them a different angle or slant on the analysis and would often stop me and say when they felt that they had enough information to further pursue the problem on their own. Two, I felt that the students were comfortable enough with me to feel that they could include me whenever they felt it was necessary. Three, since the system is somewhat new to me as well, they may have considered me a partner in learning. When they or I made some discoveries along the way, I showed the same enthusiasm, surprise, and delight as they had. They knew that they were not alone in this process and that provided some comfort and reassurance.

Another small source of frustration was the circuit modification capability of the system. After the students would analyze and resolve a circuit, the software would modify that same circuit by changing the value of one component. This in turn would change the values of the total measurements of the circuit. Their charge, by using mathematics and the measuring instrument, was to determine which component was changed and to what value. Where to begin probably caused the most confusion. Sometimes it required that the students think backwards and forsake the usual step-by-step sequential steps they would use to solve for unknown values. In order to do this they had to take measurements of components that were possible to measure and use the math to solve the modified value. This frustrated Matt a little because he stated that he became so comfortable in solving circuits a certain way. He stated that with a step-by-step process he could refer to his notes and just follow the sequential steps. They are to draw the circuit, place all of the known values to their corresponding components, convert numerical systems if necessary, figure out what the unknown is, choose the correct formula, plug in values, and solve. By altering a component with the circuit modification feature, they could not necessarily use these steps in the prescribed order. The circuit modification feature perpetuated critical thinking and they sometimes had to think outside the box.

In the beginning of the research when I first introduced the students to the computer aided instructional unit that they were going to be working with I noticed some pretty interesting reactions. One of my students reacted with the statement "this could be fun".

I could have interpreted this statement in many ways. For instance, did he mean that learning by using software in this manner could be enjoyable? Perhaps he meant that doing something different from the traditional lab assignments and being away from the other students would be fun. Did he take this as being a time to sit down and relax? Knowing this student I tend to interpret this statement in the most positive light. I think he was looking at this experience initially as an opportunity to enhance his knowledge of electrical circuitry and was looking forward to an alternative way to accomplish this.

I handed out a questionnaire that included some points of interest, application, retention, and self-inquiry. (See attached questionnaire) Each question contained the same four alternatives which were strongly agree, somewhat agree, somewhat disagree, and strongly disagree. They ranged in numbers respectively from four through one. The students were to put the number after the question that applied to their thoughts and feelings. There were seventeen questions pertaining to interest and for the most part the results were threes and fours. The questions were written such that a four (strongly agree) represented feelings of interest and enthusiasm. Most of the lower numbers were reflected in the beginning questions as they represented how the students felt at the beginning of the research. A combination of apprehension and a slight fear of the unknown may account for these initial low scores. As the students became more comfortable with the unit it seems as though the interest level rose. One of the students stated that he initially did not perform well on the prompts as he was going through the reading of the objectives because, "I don't like learning from words on the computer."

The first impression of the system stems from the preliminary information in each unit that is necessary to set the students up with objectives, conditions, and criteria for what they will learn. There are no real hands on activities until they arrive at the lab exercises. After learning the systematic approach of these lessons, the student's interest, even in the most mundane parts of the exercises, seems to have escalated to a reasonable level. There is evidence in the video that the students were interested in staying with thought-provoking problems until they were solved. There were signs of frustration but not to the point that proved detrimental to their interest. One peculiar feature was that all four students preferred to work independently rather that with a partner. Responses to questions on the survey reflect this. All students put a four when asked if working independently was of interest to them. When the question was addressed about working with another student there were a mix of two's and three's. When I approached the students with this they stated that sometimes others would cloud their thinking and that it was difficult to learn at their own rate when placed with someone with different learning styles or needs. Their lack of interest in working in pairs however didn't seem apparent in the video. The students seemed to be working in concert and sharing the responsibilities equally, and seemed to be grateful that there was someone with whom they could problem solve. We also tried two students working in the same lab with two separate units and even then there was dialogue when one of the students was experiencing difficulty.

All four of the students stated that the immediate feedback capabilities of this unit made this type of learning more interesting. I think that the strongest evidence pointing to this phenomena was not the strongly agree alternative on the questionnaire but the reactions of the students when the green flag (correct answer) appeared both during observation and in the video processes. They all seemed to have their own way of celebrating when they discovered that they had the correct answer. Josh would always rub his hands together and sit back in his chair. Ervis was usually more verbal with an alleluia or another demonstrative term. Devon would simply and calmly say "Yes, that's right," and Matt always reacted with a nice smile. You could also sense the disappointment when they discovered their responses were incorrect, but they always stuck with the problem until they arrived at a correct solution.

The students also all agreed that working on this system at their convenience was intriguing. They thought that it was beneficial especially during those down times between tasks when there really wasn't enough time to begin a new task. Another good time was first thing during class period when there was no general lecture type theory or the theory time was short. It is not extremely time consuming to log on to the system and the students could be up and running in no time. All materials needed are self-contained in the unit and the only other items needed were a notebook and pencil. They could also work right up to the end of the class period because they could log off and clean up in a relatively short time as well. There were also times when a student was injured or ill and could not perform in the lab and they took those opportunities to work on the software system. I never had to remind the students that this opportunity was available. Whenever they experienced a lull in other activities, they logged onto the system. Even when they did not have much free time and were away from the unit for a while they made sure that they incorporated this learning activity into their schedule so they wouldn't get too far behind. Behind for them is measured by how far behind they were in relationship to the other students taking part in the research. There wasn't a competition so to speak but they were always aware of where they were relative to their fellow participants. The students felt more comfortable if they were ahead of other students. This was reflected in dialogue just about every time students logged onto the system. If another student was behind, the student that was ahead was quite content with letting the other student log onto the system while he tended his normal duties. There seemed to be an uneasy feeling either way, if a student were far ahead as well as far behind. They always seemed to want to be within a reasonable distance of each other academically speaking.

When inquiring about the level of interest in having the Ohm's Law Chart, color code resistor chart, and a calculator in the help menu, 100% of the students responded with a four, the highest rating. They stated in interview sessions that this feature had many benefits. It brought mathematical formulas right to their fingertips. When prompted by the software to calculate certain values of resistance, voltage, or current, they found comfort in knowing that all they had to do was to go to the help menu, access the formula chart, and plug in known values. When the variables were substituted with values, they could then access the calculator from the help menu and calculate the answers. They stated that this took some pressure away because even though they had to make sure that the corresponding values were linked with the correct variables, they didn't have to labor over which formula to use, nor did they have to worry about memorizing the color code resistor chart values. They felt that they could focus more on the problem-solving skills and methods and less on memorization. One student also advocated that one needed to bring minimal reference material and tools to the work- station and this yielded faster and more efficient start up and cleanup times. If a student forgot a calculator or reference chart they were not discouraged from entering the system. During observation I found that the students were accessing and utilizing these features on a regular basis as if it were second nature.

When students were asked if they would like to work on advanced concepts using this system they overwhelmingly agreed that it would be of interest. There are associated interface modules in alternating current, solid state, and digital fundamentals that are all theoretical requirements of our course. In interview sessions, all agreed that the software would serve as a tool to enhance current learning methods. They also stated that the system alone would not prove to be beneficial as these advanced concepts are more difficult and would require a little more in depth instructor intervention.

Another point of high interest was the system's ability to allow for unit test retakes. This feature fit into our methods of evaluation quite well since our lab structure is set up for competency based instruction and learning where students do not move onto the next project without mastering the previous one. One student stated that this feature lets you go back and see what you misunderstood or didn't get. He said it sort of removed some anxieties about taking the unit tests because the only one that counts is the last one that you take. The software system does however keep track of all test scores and allows the instructor to examine student progress throughout the test-taking experiences. The students found the histogram representations of their progress interesting to view.

The majority of the students only somewhat agreed that the environment in which they were working added interest to their lessons. Some students mentioned, and it was evidenced in the video, that the interruptions from other students passing through the learning area were sometimes disruptive. The physical layout of the classroom and lab do not render total privacy all of the time, but for the most part other students respected the need for privacy and were very accommodating.

It is very crucial that the students are able to apply what they have learned in mathematics, fundamental laws, and measurements to actual electrical circuits as opposed to virtual circuits as shown on a computer screen. The idea of transference of information to realistic work applications is the true purpose and goal of our program. It was inspiring to know that this educational software system could contribute to the application process. All four students strongly agreed that they could apply the mathematics of Ohm's Law to real circuits. (I explained on the questionnaire that real circuits refer to actual circuits outside the realm of this software program that they would construct or troubleshoot). Therein lies the beauty of this software program. It sets up the circuit virtually on the screen and prompts the students to construct, troubleshoot, and analyze the actual circuit on the interface board. As a participant observer, I noticed that initially the students were having difficulty correlating the diagram on the monitor with the actual circuit block on the board. Once they established this connection, they had little difficulty applying the laws and rules of the various circuits. In one point of enlightenment, Ervis stated, "Now I see how series aiding and series opposing power supplies work in series and parallel. In parallel, the current adds up but the voltage stays the same. In series the voltage adds up and the current stays the same." In order for Ervis to comprehend this, it was necessary for him to transfer the necessary concepts to the actual electronic circuit connected on the interface board. He had to connect the power supplies according to the diagram on the screen, and use the meter to read the values in the various power-supply checkpoints, and either add or subtract various values of current and voltage to prove the laws of parallel and series power supply connections. There was evidence here that conceptualization and association was beginning to emerge and that this vehicle of learning was responsible for this enlightenment.

All four of the students strongly agreed that they could apply measurements of resistance, current, and voltage to real circuits using the multimeter. Josh stated, "When I read across the two resistors I don't get anything but when I read across each one I get what they are supposed to read." I was actually pleased with what Josh was stating. The knowledge necessary to use a meter is intense because there is so much to consider. The function has to be set as to whether you are measuring current, voltage, or resistance. The range needs to be adjusted so that you are reading within the parameters of the required measurement. The technician has to determine if the power should be on or off when taking the reading, and finally they need to determine exactly where the leads should be placed into the circuit. Josh had all of these concepts in place. What he didn't do was place the two-pin jumper in between the components to tie them together. It was an oversight rather than a misconception. When he placed the jumper in the correct position all measurements made sense. During my observations and in the video, I noticed the students using the meter on a regular basis with little difficulty as if it was another tool. It is critical that this occurs for safety reasons when the students begin to apply these techniques to circuits with higher values of voltage and current.

All of the students strongly agreed according to the questionnaire that they could construct simple DC circuits from schematics in real circuit applications.

As I observed, the students were able to construct simple DC circuits with little difficulty by using the schematic as a guide. In the beginning the software was very specific by showing students how to connect the circuit using text and diagrams. As the students progressed through the units, the direction was less descriptive and eventually weaned the students from too much information. In one of their lessons Josh was having difficulty deciphering what it was they wanted him to construct. The dialogue went as follows:

Mr. V: "I don't see a two post connector in the dashed line of the connecting block".

Josh: "But it didn't tell me to put it in".

Mr. V: "Can you see it in the circuit diagram"?

Josh: "But where does it say to do that"?

Mr. V: "I think the software is going to be less explicit from now on.

This will teach you to read the circuit diagrams better".

From this point on Josh, as well as the other students, paid closer attention to circuit diagrams and became quite proficient at interpreting these drawings. The cognitive process here requires that the students interpret the schematic and transfer that knowledge into a practical working circuit. The software at this point is fostering transference, application, critical thinking, comprehension, and a bit of self-inquiry.

The students all somewhat agreed that they feel relatively comfortable applying all that they have learned to real circuit applications. Why not strongly agree? It could be that all of these concepts together are a bit overwhelming and some of the students may feel that they would still need some guidance depending on the difficulty level of the circuit.

Retention is the crème de la crème of this research and it is where I had hoped to see the most improvement. This is what the students take with them to participate in industry standard certification exams, the work world, and further education. The higher the percentage of what they learn that stays with them, the more successful they will be. According to the questionnaire the four students strongly agreed that they were able to retain most of what they learned about Ohm's law and the associated math. This was also evident in other ways. I gave them written unit tests, different from the test that they took on the computer at the end of the unit, and about a week after they had finished the unit and were on to the next one. They all performed equally well on the written test a week later. (See enclosed example) In interview sessions, the students were able to explain the relationships of voltage, current, and resistance. This relationship is the foundation of Ohm's Law. This is a concept that has been very difficult for the students to comprehend after traditional teaching and learning approaches using blackboard, overhead, and demonstrations. Voltage, resistance, and current are effects of power sources, conductors, and loads and these effects are invisible. The results can be seen such as bulbs lighting or motors turning, but what actually happens inside the conductors, loads, and power supplies cannot. It is extremely difficult for students to conceptualize phenomenon that they cannot experience with their senses. Circuit theory is traditionally regarded as rather a dry subject with low student interest. Thus student performance is poor relative to other subjects (Roach and Medhat, 1990). It has been my experience that math in itself is a dry subject without application, and when applied to invisible electrical concepts, it serves to foil student interest. This is why I feel that it is necessary to make every effort to involve students in correlating math with measurement. Devon states, "When I do the math, I kind of understand the values of the components, but when I actually construct the circuit and make some measurements with the meter, it makes more sense." They are taking transparent concepts and ideas and turning them into realistic and concrete perceptions.

All of the students strongly agreed that they retained most of what they learned about the laws of series and parallel circuits. Although these are easier concepts then the applied math, there is much that can be misconceived in these areas. How components are connected in relationship with each other directly affects the total circuit values. Memorization skills play a large role in the success of learning and applying these laws. The students need to examine the circuit components and determine how they are interconnected before they can begin to construct and analyze them. Understanding the difference is also crucial to where and how the students place the meter into the circuit. For example, Josh, when analyzing a parallel circuit, had difficulty in determining where to place the meter leads when asked to measure total resistance. First of all, I explained to him that it is necessary to be able to identify a parallel circuit. This is a circuit connected in such a manner that the current flowing into it may divide and flow into more than one path (Forster, Schultz, Singer, 2000). It also states that all components are connected across the power supply. Therefore, with the power supply removed, Josh was able to obtain the correct measurements and move on.

As the students became more comfortable with the capabilities of the trainer, it seemed that they were willing to take more risks. I attribute this to two reasons. One, they realized that with the low voltage and current capacities of the unit, risk of personal injury was non-existent. Current and voltage act the same in series and parallel configurations regardless of their values and the students can learn circuit behavior without fear of bodily harm. This is another great feature of this training equipment in that it is perfectly safe. Two, damage to equipment was virtually non-existing because of the built-in circuit protection which yielded a loss of communication error flag and a shut down of the power. The students realized that this would be the worst that can happen and became confident that they couldn't damage any equipment. This set the stage for a totally risk free learning environment and once the students learned how to reset the system after shut down, they proceeded with relative confidence. This enhanced risk taking capability allowed by the system freed the students to pursue their problem solving and circuit analysis without worry of personal injury and equipment damage. What may concern me is how they will approach circuits containing higher voltages and currents. I tried to impress upon them to treat the system as if it did contain higher voltages and currents so that they get into the habit of exercising safety precautions.

There was evidence that relationships were developed and improved over this process. Students became somewhat dependent upon each other and myself whether working alone or with each other. This dependency created dialogue that in turn established some forced conversation with others that they really didn't know well. It gave them some common ground in which to establish and foster a relationship that may have ordinarily not occurred. The benefits of this interaction also teach the students the value of communication and team approach in problem solving that are qualities that business and industry desire in their employees. Given these unexpected benefits, the Lab Volt System not only satisfies the content requirements of our curriculum but also contributes to the students' overall professional development process. The FACET system tends to perpetuate and encourage students to be able to use technology to solve problems, work in concert with others, ask for help, become involved with the communication process, and to make a conscious effort to keep up with others participating in the same project. It is my assessment that this system, along with other methods of delivery, will positively contribute to the students' pursuit of knowledge of electrical and electronic circuitry development, construction, and analysis.

Name____________________

QUESTONNAIRE

Write the number after each statement that reflects your level of agreement.

4 – strongly agree   3 – somewhat agree   2 – somewhat disagree   1 – strongly disagree

INTEREST

1. The computer-assisted instruction was intriguing to me at first.
2. I was excited about this type of learning.
3. I looked forward to the opportunity to work on these lessons.
4. It added a new level of interest for me.
5. I look forward to working on the advanced modules with this type of learning.
6. The independent learning aspect really interested me.
7. The immediate feedback aspect really interested me.
8. Reading the information on the computer screen really interested me.
9. Building the circuits from the instructions on the screen really interested me.
10. The features of the system such as the Ohm's law chart and the calculator really interested me.
11. The schematics really interested me.
12. The ability to take the unit exam more than once was interesting and helpful to me.
13. The introductory objectives were interesting to me.
14. The fact that I could work on this system at my convenience was beneficial and interesting to me.
15. The environment in which I was working added to the interest of the lessons
16. Working with another student provided interest for me.
17. Working by myself on the unit was more interesting for me.

APPLICATION

(The phrase *real circuits* in the next set of questions refer to circuits outside the realm of the computer software system that you or someone else has constructed)

4 – strongly agree 3 – somewhat agree 2 – somewhat disagree 1 – strongly disagree

1. I feel that I can apply the mathematics of Ohm's law to real circuits.
2. I feel that I can apply the laws of series circuits to real circuits.
3. I feel that I can apply the laws of parallel circuits to real circuits.
4. I feel that I can apply the laws of combination circuits to real circuits.
5. I feel that I can apply measurement of resistance to real circuits using a meter.
6. I feel that I can apply measurement of current in real circuits using a meter.
7. I feel that I can apply measurement of voltage in real circuits using a meter.
8. I feel that I can construct simple DC circuits from schematics in real circuit application.
9. I feel that I can analyze simple DC circuits in real circuit applications.
10. I feel generally comfortable with applying all that I have learned to real circuit applications.

RETENTION

(Retention refers to the ability to retain or remember the information learned using this system)

4 – strongly agree 3 – somewhat agree 2 – somewhat disagree 1 – strongly disagree

1. I remember most of what I learned about Ohm's law.
2. I remember most of what I learned about series circuits.
3. I remember most of what I learned about parallel circuits.
4. I remember most of what I learned about combination circuits.
5. I remember most of what I learned about symbols and their representation.
6. I remember most of what I learned about schematics and diagrams.
7. I remember most of what I learned to take resistance readings with a meter.
8. I remember most of what I learned to take current readings.
9. I remember most of what I learned to take voltage readings.
10. I remember most of what I learned about switching.
11. I remember most of what I learned about battery power supplies.
12. I remember most of what I learned about polarity.
13. I remember most of what I learned about how electricity flows.
14. I remember most of what I learned about the definitions of voltage, current, and resistance.

THOUGHT PROVOKING QUESTIONS AND SELF-INQUIRY

(Self-inquiry refers to your comfort level in asking yourself questions and feeling confident enough to explore solutions.)

4 – strongly agree 3 – somewhat agree 2 – somewhat disagree 1 – strongly disagree

1. The questions posed by the software were challenging but I was able to answer them after in depth thought.
2. The questions were relatively easy.
3. The questions were too difficult and I could not answer most of them.
4. I could construct most of the circuits they asked me to with some struggle.
5. I could construct most of the circuits they asked me to with relative ease.
6. I could construct very few of the circuits.
7. I could analyze most of the circuits they asked me to after in depth thought.
8. I could analyze any circuit they asked me to with relative ease.
9. I could not analyze most of the circuits.
10. I felt that I had the liberty to ask some what if questions and pursue the answers.
11. I actually asked myself some what if questions and was able to answer them.
12. I asked myself some what if questions and was not able to answer them.
13. I did not feel that I had the liberty to pursue questions and answers that were not part of the system.
14. I felt that I had the liberty to ask myself questions but did not feel comfortable in doing so.

Matt B.

100

UNIT TEST 1

1. The F.A.C.E.T. base unit provides for protection against

   a. overvoltage and power connection.
   b. overvoltage, overcurrent, and reverse power connection.
   c. overcurrent and reverse power connection.
   d. overcurrent and power connection.

2. A student can alter the configuration of circuit blocks by

   a. using the fault switches on the base unit.
   b. adjusting the variable power source.
   c. using the circuit modification switches on the base unit.
   d. inserting loose components into circuits at designated test points.

3. The DC FUNDAMENTALS circuit board is properly connected to the base unit when the

   a. ZIF connector knob is rotated in a CCW direction.
   b. ZIF connector knob is rotated in a CW direction.
   c. ±15 Vdc power source is connected to the base unit.
   d. power supply LEDs are illuminated.

4. The multimeter dc voltage function is selected by the

   a. range switch.
   b. automatic voltage selection circuit.
   c. VOLTMETER circuit block on the DC FUNDAMENTALS circuit board.
   d. person using the multimeter.

5. The variable power source in the OHM'S LAW circuit block on the DC FUNDAMENTALS circuit board is adjusted by the

   a. positive supply control on the base unit.
   b. negative supply control on the base unit.
   c. −15 Vdc control on the power supply.
   d. +15 Vdc control on the power supply.

6. On the DC FUNDAMENTALS circuit board, test points separated by dashed lines can be used to
   a. measure voltage.
   b. indicate faulty connections.
   c. energize the associated circuit.
   d. measure the resistance of the circuit.

(continued on next page)

7. When measuring circuit current, connect the ammeter

   a. across the component.
   b. to read a portion of the current.
   c. so all circuit current flows through the ammeter.
   d. parallel to the circuit to read all the circuit current.

8. An arrow through a battery symbol indicates

   a. the direction of current flow.
   b. the positive terminal.
   c. the negative terminal.
   d. a variable source output.

9.  is the symbol for a

   a. zener diode.
   b. light-emitting diode.
   c. DIAC.
   d. solar cell.

10. The term milliampere is abbreviated

   a. mA.
   b. MA.
   c. Ma.
   d. mil.

CONCLUSION

On our way to exploring what happens when computer software is used to guide and monitor students' conceptualization, construction, and analysis of actual electronic circuits, we experienced confusion, frustration, disappointment, misunderstanding, and some apprehension. On the positive side, we were able to exercise some problem solving and critical thinking skills, experience some conceptualization, comprehension, points of enlightenment, and develop a degree of circuit analysis skills. Generally speaking, the hurdles experienced in the beginning were those of software, hardware, system, and vocabulary familiarization. Later on, it was the circuit analysis, conceptualization, and other subject-related material that were the source of bewilderment. There is an indeterminate learning curve that must take place before the students can even begin to involve themselves in circuit conceptualization and analysis, and the amount of time it takes is dependent upon the students' ability to comprehend the prescribed information. The students are given every opportunity to master these initial concepts and in a variety of ways. There are written materials in addition to laboratory exercises that guide them through this initial familiarization process as well as the guidance from the instructor. It is a competency-based, independent, and self-paced tutorial approach that lends itself to many different learning styles. I was involved far more at the beginning stages and my involvement tapered off as time went on. I have made the determination that this system can be a valuable enhancement tool. I don't believe that using this as a sole teaching mechanism for this age group would be appropriate. I say this because it has been my experience that adults bring a whole new dimension of patience, experience, selfdiscipline, and perseverance to the classroom. It would be interesting to have done this study simultaneously with adults to see the differences.

The students all felt that they would like to see this system incorporated into the curriculum. They felt that there would be less lecture time and more lab type involvement on an independent basis. They felt if I could lecture on a particular unit that they were involved in prior to their getting started, it could provide relevance. The only issue with this is the competency-based approach that we use puts different students on different units at any given time. I could lecture at a moderate pace and be a little behind those that are advanced and a little ahead of the slower paced students. It is then a matter of giving everyone their own floppy disk and assigning log on times for all students. A major advantage of having gone through this research is that I now have four students that are proficient at the system and we can incorporate the students-helping-students initiative further into our methodology of teaching and learning approaches. Another positive aspect of this concept is that our facility just upgraded to Windows NT 2000 and the software can be networked to provide this software on more stations. We would just have to procure a few more stations. Given this study and the numerous programs that can benefit from this system we would have little difficulty in providing rationale for the purchase of additional units. There is an A+ computer certification class that would benefit from this. There is also a telecommunications program where basic electronic concepts are part of the curriculum. Our Automotive Technology Program now incorporates an electrical/electronic component because of the sophisticated electronic systems installed in vehicles today and this training unit would be a great asset to their program.

We learned that students will initially experience some confusion and frustration as they are introduced to this system and will have to persist to overcome these obstacles. The source of the confusion came in many forms. The students' interpretations of what was asked and expected proved to be one of the obstacles. Unit one, trainer familiarization, served to help the students get around the hardware and software and introduce new terms and nomenclature to help aid in interpretation of prompts, directives, and questions. All of this familiarization of course is necessary before students begin to construct and analyze circuitry and helps to set up a foundation to build upon further study. As a result, there is a substantial learning curve that all students must go through and the amount of time it takes will rely on many variables, none the least of which is student ability to digest and apply the information. There are many software nuances to learn as with any software based learning system not to mention all of the hardware components, both unfamiliar and familiar in an unfamiliar environment.

It was necessary for students to interpret information from limited written stimuli. In order to conserve memory, instructions and prompts are written in concise and short statements and questions that I had to translate for the students many times. This re-enforces the need for a facilitator. It was my experience with electronic terminology that allowed me to understand the statements and broaden their conceptual meaning. If I were learning for the first time I may have had difficulty myself interpreting the information.

I am confident that after sufficient time spent on familiarization of hardware and software, the students are less confused with the mechanics of the system and are more able to focus on construction and diagnostics of electronic circuits.

We can expect low to moderate frustration levels in both unit familiarization and the process of learning electronic circuit fundamentals. I think that what soothed frustration levels the most was the fact that I was considered a partner in learning. Often I showed signs of bewilderment and perplexity in the students' presence, especially when there was equipment failures, and I think that they found comfort in the fact that I was confounded about some of this material as well. It was as though we were banding together to dissect this new phenomenon and trying to set a standard and foundation for future users of this system and all had an equally important role. I think by the end of my research that this is where our relationship has taken us. It seemed more that we were working on a project with a common goal where everyone's input was valuable and crucial. We shared the glory of the success as well as the disappointments and the frustrations, and celebrated when we felt that we cleared difficult hurdles.

We also found that having the freedom and capability of logging onto the system pretty much at will was invaluable. There are often times when students are ready to begin a new task but there may not be enough time left in the period to begin engaging themselves in a lengthy project. This turns out to be a great time to log on. In a shared-time learning where where we have four sending school districts that do not have a common calendar, we find ourselves with limited attendance sometimes due to in-service days or parent conference days. This is a great time for students to participate in this activity because there is no major lecture and theory for the class as a whole. The traditional theory time could be used as independent study time on the FACET unit. Students could proceed to tasks after this traditional theory time in a normal fashion as if it were a typical day. In rare instances, when students may feel ill or may be injured and they do not feel up to the demand of physical tasks they can sit and participate in the interactive computer environment which requires less physical stamina. Having this system available removes the down time in learning because there is always something to do.

This system fosters an "all will be successful philosophy" that fits right into our competency based curriculum. Students participate at their own pace, get as much help as is needed, and can re-test as many as three times per unit. All students receive a quality and equal education regardless of ability, speed, and learning style and learning is not compromised or watered down.

The students become more familiar and proficient with schematic interpretation and become less dependent upon text and teacher explanation. This is the point where this system can foster and encourage transference, application, critical thinking, comprehension, and self-inquiry.

The students will retain more information in terms of vocabulary, component identification, applied mathematical formulas, and laws of various circuit configurations. This is evident in the dialogue during lecture and discussion sessions, test scores, and how they apply what they have learned in their daily projects. They will retain applied mathematical concepts better because they are able to calculate results and compare them with actual measurements through the use of instrumentation.

Students will be more open to risk taking. With the low voltage and current operations of the system units, there is very little possibility of personal injury or equipment damage.

Relationships between students and between students and teacher will be effected a great deal. There is more dialogue and there seems to be a bonding process that takes place when students band together to solve or troubleshoot a circuit. Students learn to depend on each other and on the teacher and this helps to create a cooperative learning environment that will transfer someday to a cooperative working environment.

There are six key principles that increase learning (DeBruyn, 2001). The first key principle is that learning is social. We teach content, but learning occurs best when students are able to interact with each other and their teachers. The FACET System provides these opportunities. Secondly, learning requires an appropriate physical environment. We tried to do this by creating an area dedicated to the quality interactive computer learning experience that we wanted to foster. Thirdly, self-directed learning is the most motivational type of learning for individual learners. The more that students are involved in the control of their own learning, the more ownership they can claim to what they have learned. In working with the FACET System, the students were able to control when they participated, for how long, and how fast they wanted to progress through the system. The fourth key that was pointed out by DeBruyn is that learning is increased by application. Applying what we have learned stays with us longer than memorizing. The FACET System gives the students every opportunity to apply the information they have been given consistently. The fifth key to remember is that when a student fails to learn, it is usually the fault of the learning and teaching approach, not the student. If a learning situation doesn't work for a student, it is our responsibility to provide a learning situation that will foster success. The FACET System is another delivery system that could be used to set up a learning environment more suitable to some learners. Finally, we may need to help students unlearn some of their outdated learning habits and attitudes. We need to be particularly observant when students are engaged in learning and guide them toward new and innovative approaches that will help them learn even better. The FACET System helps promote new types of learning approaches, both intrinsic and extrinsic in nature. An example would be for a student to limit memorization approaches and rely on application skills to reinforce their learning.

By applying these six key principles through the aid of a vehicle such as FACET, I believe it is almost guaranteed that learning will increase and we will be able reach more students with more information at a high rate of success.

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