

## Circuit Analysis Tools: Integrating Smartphone and Tablet Applications and Simulation Software into Circuit Analysis Instruction and Laboratories

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**Abstract:** The purpose of this practical action research design pilot study was to evaluate different technological applications and software available for use in circuit analysis to new electrical engineering and technology students and observe the use and response of students to these tools. The research design followed a four-step procedural framework called the Dialectic Action Research Spiral. This is a cyclical procedure where the teacher-researcher chooses an area of focus, determines data collection techniques, analyzes and interprets the data, and develops an action plan. The area of focus of this research was chosen during the first semester of instruction and observation in the Fall 2013 semester in ECET 10700. During the first semester through observations and interaction with students the researcher was able to find key elements relative to why students have trouble understanding concepts taught. In Spring of 2014, the same course was taught by the same instructor using interventions developed based on findings from 2013. The significance of this procedural framework is that it is recurrent and data is always being collected and evaluated against the focus to see if the process is working its way towards an actionable solution. Results, conclusions and recommendations are included in the study.

**Keywords:** engineering technology; circuit analysis courses; key learning concepts; multisim.

## Introduction

Electrical engineering technology students are fortunate to live in a world where they are able to utilize the laboratory to actually test through concepts and ideas and see real-world at work. They do not rely solely on theory or abstract thinking and then on “good faith” make assumptions when doing their work. Theories can actually be tested and verified in the laboratory in the world of engineering technology.

The use of the laboratory is a major component of engineering technology and can be argued is the most important portion of the engineering technology student’s college career for any core course. This is where students become masters of what they have learned in the classroom or in textbooks. It’s not unreasonable to suggest that graduates of engineering technology degree programs have a more versatile background than other engineering areas of study because of their ability to troubleshoot and verify what they have learned. Students can apply the same engineering problem solving method to solve every problem they encounter. This makes them valuable assets in any company as they are not limited to a single area of expertise. Laboratory experience will serve students in industry well. The knowledge they gain is applicable for whatever task given to them by referring back to the problem solving methods learned and utilized.

A key goal for any instructor is not simply to have students parrot back and memorize information they may never use again, but to facilitate concept retention and understanding. Each core course that engineering technology students take is a precursor to some greater theme or concept in their studies. A student must grasp all aspects of the knowledge they are acquiring to perform well in subsequent courses not simply remember formulas and equations. To effectively embrace this goal instructors should be open to new tools and make the effort to evaluate their effectiveness for possible use with their students.

In the digital age the increase of powerful software simulation has been the single biggest improvement in recent years for many fields of study. It allows a student to model whatever it is they are building or organize a problem they are trying to solve. It is much cheaper and quicker (and sometimes necessary) to try something in a computer program. Parameters can be easily adjusted and multiple plans of attack saved at the click of a button rather than having a team of students manually perform calculations and physically build a project from scratch.

The field of engineering technology is no exception and in some ways the practitioners are leaders in this foray because they can actually do some of the programming themselves. Currently there is somewhat of a race for programmers to find how best to use computers and now tablets and smartphones to perform these tasks because of the new business of downloadable applications. The advent of the tablet and smartphone and applications that can be installed on them have increased the pool of

programmers and therefore the range of problem-solving tools available to teachers and students.

Anyone with programming knowledge and the will to make a better application to solve a problem can create one of these applications in the comfort of their own home. No longer do students have to rely solely on a very expensive, all-inclusive program platform to complete work. They can simply open a tablet or smartphone and find a reasonably cheap or even free application that can aid them in whatever task they are performing. This is not to take anything away from well-established, engineering specific software that still continues to be relevant and necessary to perform higher level tasks. This is merely to suggest that the landscape of tools available is changing and as such, instructors have to be open to the change and embrace current pedagogy in instructional design for learning to take place.

### **Purpose Statement**

The purpose of this study was to evaluate different technological applications and software available for use in circuit analysis to new electrical engineering and technology students and observe the use and response of students to these tools. The intent of this study was to find how to improve students' understanding of circuit analysis using circuit simulation tools on computers, smartphones, and tablets. Since electrons propagating through a circuit are impossible to see with the naked eye, analysis becomes a rather unique concept and can be difficult for students to understand. Even those skilled at mathematics can sometimes do a lot of algebra or calculus in their circuit analysis and produce answers that mean nothing to them because they cannot see the results or understand what they've just evaluated.

In the Fall 2013 semester ECET 10700: Introductory Circuit Analysis course including basics of voltage and current and different analysis techniques was offered to engineering technology students at a large, Midwestern, urban university. It is important to understand the struggles when first learning the material and what techniques and aids are available to help student comprehension. Because smartphone and tablet circuit applications are so new, little research has been done on their effectiveness when used with standard circuit simulation software in the classroom. New electrical engineering technology students should be afforded every tool available to them to succeed not only in their immediate circuit courses but future courses and ultimately in their careers. In an introductory course like ECET 10700, where there is focus on building circuits in the laboratory along with manual analyzation by calculations, circuit simulation seems to be a logical aid to further improve understanding of fundamental concepts. By examining these tools, instructors of circuit analysis courses can use this information to better instruct their own students in this digital age of tablet applications and software simulation.

### **Literature Review**

As this is an action research study, it is important to understand the research that is relevant to the key elements of the study. This review of the literature germane to this study is divided into three areas: instructor bias; active learning in computer-aided learning environments; and the use of Multisim as a learning tool in circuit analysis courses.

### *Instructor Bias*

This study is different in that the instructor performing the research had never taught this course before. There must be an identification of the fact that in doing research on a course over two semesters that there may exist some bias between semesters strictly due to the instructor. Although bias is very difficult to eliminate in most studies and in the research process in general, awareness of what biases exist can aid in the reduction of the influence of that bias (Clark and Creswell, 2014; Malone et. al, 2014). One of the biases that can exist is that teaching a course for the first time is going to be different than teaching the same course again. Once it has been taught the instructor may develop a better understanding of his or her own teaching method and will use the improvements in the subsequent semesters. An awareness not to entirely change the same delivery of material presented should be present to establish a baseline.

Acknowledgement of the process of reflexivity is a common and encouraged aspect in research, especially in qualitative studies. Creswell (2007) believes "how we write is a reflection of our own interpretation based on the cultural, social, gender, class, and personal politics that we bring to research." However these should not unduly influence the objective eye of what a study should accomplish. As McCabe & Holmes (2009) attest "reflexivity is often thought of as a focused attention on one's own relative ability to be unbiased while also recognizing and considering the effect of one's existing biases on the research." In this study there was careful consideration to this and every decision was challenged by the researcher to ensure there was no baseline deviation in teaching methods from semester to semester. Johnson et. al (2013) indicates "experience is a demographic factor that could affect teaching performance." The bias that could occur from that would possibly skew the data and a better result or attitude in student behavior seen in the second semester could indicate something the instructor has consciously or subconsciously done to improve his or her method. Mantzoukas (2005) states "the aim is to extricate any biases from the research study so as to acquire the objective facts and thus to approximate the truth and reality of the phenomena as far as possible."

Careful attention was paid to teaching the course material the same way both semesters. Observations were made objectively without allowing how the material was taught to affect the interpretation of the data. On the subject of letting bias affect interpretation Walther et. al (2013) state "interpretation should emerge purposefully from the combination of data and interpretive view." This had to be the control mechanism that allowed the researcher to focus on the new tools available to students. A different method of teaching might also unduly influence the motivation of the students to use these new tools. When doing

research on students Prave & Baril (1993) state “to effectively control for initial student motivation that is not dependent on the instructor, researchers must ensure that this item measures only that interest directly related to course content.”

### *Active Learning in Computer-Enabled Learning Environments*

In the digital age, instructors have the advantage of using computers to aid in teaching and learning. The methods of how computers are being used has shifted. Phelps (2002) states “end-user training in the use of computer software and hardware has become a significant area of professional development in a range of educational, organizational, and community contexts.” Now computers are almost an essential part of everyday learning for students, and research shows that computer-enabled learning environments can increase aptitude and creativity. Researchers have discovered that computer materials attract student attention and cause them to spend more time on material, but that students with higher creativity levels will actually use the materials to generate some valuable information (Brand-Gruwel et al., 2014; Hannifin et al., 2014; Hsu et al., 2009) . This is encouraging news considering how much of a potentially negative impact the overuse of computers can have when students already are glued to them for social networking and entertainment purposes. Since most computing is done on the internet with access to these distractions, it is a possibility that these easily accessed distractions could stifle a student’s focus on the tasks they are being asked to accomplish. And so as to not single out students considered to have lower creativity, Hsu et al (2009) recommend utilizing reading comprehension training and group discussions to “persuade students to generate ideas and then increase their cognitive abilities” when using computer-related materials.

Computer-enabled learning environments are becoming even more prevalent due to the increasingly popular variety of online courses being offered. As Katuk (2012) states “the number of students who enroll in online courses has also been growing more rapidly than the overall higher education enrollment. But she also points out that the drop-out and attrition rates of e-learners are also increasing. So there must be care taken by the instructor in a computer learning environment to create an atmosphere where students still can be motivated to succeed and that the computer is an aid to the course work and doesn’t detract from it. Phelps (2002) reiterates this by stating “successful computer learning requires learning approaches closer to those implicit in the contemporary adult literature.” Just having access to a computer doesn’t mean a student will get out of a course what they need if their focus is more on learning the computer as opposed to using it as a learning tool.

There is one thing that a computer-learning environment does well and that is to get the student to become an active participant in what they are learning. This can be accomplished through discussion boards students have to be involved in, or group projects using computers where they can communicate and send materials to each other, or even being asked to complete assignments in a computer program. Lecturing is still an important tool that an instructor must

utilize, but there is evidence that active learning can be very effective. Freeman et. al (2014) completed just such a study that found that students in traditional lecture courses were 1.5 times as likely to fail as those in active learning courses. An encouraging feature of using active learning in a classroom is that the methods of what works in a particular course can be very diverse and instructors should constantly evaluate their own methods to see if they are producing better results.

#### *Using Multisim in Circuit Analysis*

Traditional circuit analysis done by manual calculation methods will always be important to a student's understanding of analysis techniques, but in the advent of the computer learning age the usage of simulation software can enhance that understanding. One circuit analysis simulation software program introduced to the electrical engineering and technology world is Multisim by National Instruments. The use of Multisim should not be used as a replacement for traditional circuit analysis lecturing, but rather as an addendum. Guo-hong et. al (2011) suggest to "introduce Multisim software to combine with traditional teaching ways as it has an abundant element library and powerful function of analyzing and simulating circuits. However it should not be entirely substituted for traditional teaching methods entirely or it will weaken the students operating ability." It affords a student the ability to improve their comprehension of circuit analysis.

The large library of Multisim and unlimited virtual instruments that can be employed allow a student to test through circuits and verify circuit analysis techniques. As Wei et. al (2008) state "it provides up to more than 10 virtual instruments, whose external form and operating methods are similar to actual instruments." So not only are they getting the benefit of verifying circuit element values by using the program they are by proxy learning how to use the actual instruments they will use in the analysis of circuits when physically built and tested.

There is also a cost benefit to using Multisim. Since it is a simulation software program the cost benefit of using Multisim lies in its ability to quickly change circuit parameters without having to actually own a box full of circuit components to test. This also means that more students can be involved in the actual measurement and verification of circuits without having to have a physical lab station for each student. As Mahata et. al (2010) state "laboratory resource sharing is becoming increasingly important to educational institutions as well as practicing engineers, mainly driven by the advancements in computer technology."

The use of Multisim is not limited to simple AC and DC circuit analysis. Topics like power electronics, digital electronics, controls and many others are included in this software package. Some of these fields are very expensive to test in industrial settings and the use of a simulation program like Multisim allows an engineering team the ability to test their expectations quickly before moving to hardware implementation. As Cheng (2011) describes it "provides a software

platform to allow users to observe and analyze before the realization of hardware.” This means more testing can be accomplished quickly which saves employers time and money. Kejie et. al (2009) expand on this for the academic world by stating “if we can provide a software simulation platform before the hardware experiment, the theory models and the circuit build models could be clearly shown to the students and they could adjust the parameters in the circuits arbitrarily in the simulation program to see the influence and response, which could reduce blindness to the experiment at a large scale.”

## Research Design

This study was a pilot study and utilized a practical action research design. As Creswell (2012) states “Practical action research involves a small-scale research project, narrowly focuses on a specific problem or issue, and is undertaken by individual teachers or teams within a school.” Mills (2014) adds that practical action research “assumes that teacher researchers are committed to continued professional development and school improvement and that teachers want to systematically reflect on their practices.” As this study meets all criteria from both Creswell and Mills, a practical action research design was employed.

This research was done by an individual instructor and not a group of instructors. Although the outcomes and suggestions of this pilot study can be used by other faculty to continue the research, it is important to know that because of the nature of the study, and because of the organizational complexity and uniqueness of each classroom, the results are not generalizable (Gay et al., 2011).

## Population and Sampling Frame

The population for this study consisted of all students who completed all coursework from the Fall 2013 semester and from the Spring 2014 semester of ECET 10700. Any student who did not attend class regularly or did not finish the class was excluded from the population. Since all students who completed the course participated in all tests, quizzes, homework assignments, and lab experiments, the entire population was included in the sampling frame. The population demographics for the Fall 2013 semester are shown in Table 1:

**Table 1 - Fall 2013 Demographics**

	Number of students
Total Population Size	21
Sampling Frame	21
Males	19
Females	2
Successfully Passed Course	19

Did Not Pass Course	2
Excluded from Population	9
Withdrew from course	9
Not Attending Class	
Regularly	0

The population demographics for the Spring 2014 semester are shown in Table 2:

**Table 2 - Spring 2014 Demographics**

	Number of students
Total Population Size	27
Sampling Frame	27
Males	22
Females	5
Successfully Passed Course	27
Did Not Pass Course	0
Excluded from Population	13
Withdrew from course	9
Not Attending Class	
Regularly	4

### Sample Size for Interviews

Since there was no quantitative data being analyzed in this study, the strategy for sampling was based on observations made by the researcher. As Creswell (2012) states “This is not a probability sample that will enable a researcher to determine statistical inferences to a population; rather, it is a purposeful sample that will intentionally sample a group of people that can best inform the researcher about the research problem under investigation.” To narrow down who would best inform the researcher on the research problem, criteria for students in the sampling frame for the Fall 2013 semester who were sampled included students who started to establish themselves as either performing well or were struggling but still passing the course through the first exam (test). “Performing well” was defined as having an overall course grade percentage of at least 90% after the first test was graded. “Struggling but still passing the course” was defined as having an overall course grade percentage between 72% and 60% after the first test was graded.

Once these two groups were established, 3 non-probabilistic convenience samples were obtained for each of the two groups of students totaling six in all for the fall semester. In the spring semester the same sampling criteria was used



and six more interviews were obtained. Cohen et. al (2007) state that convenience sampling “involves choosing the nearest individuals to serve as respondents and continuing that process until the required sample size has been obtained or those who happen to be available and accessible at the time.”

### **Data Collection Methods**

To help establish validity in this study, triangulation was instituted. Three methods of data collection were used. Data were collected via interviews with students and also from observations made from the researcher during lab periods and before and after lecture periods. Finally, data from student outcomes from the course were collected including GPA, performance on quizzes, tests and labs, attendance and other course assignments. Although the findings of this study may be reproduced elsewhere at other sites, there was no generalizability intended with this research.

### **Interview Protocol**

During the Fall 2013 and Spring 2014 semesters, interviews were conducted. Field notes were used to record these interviews. As described by Creswell (2012, 168) a researcher is enabled to “take notes during the interview about the responses of the interviewee. It also helps a researcher organize thoughts on items such as headings, information about stating the interview, concluding ideas, information on ending the interview, and thanking the respondent.” The format of structured formal interviews where the same set of questions was asked to each of the defined groups (Mills, 2014) was utilized.

There were two questions asked of the sampled students. For the students who were defined as “performing well” they were asked, “Aside from taking notes and paying attention in lectures and doing the required homework, why do you think you are doing well in this course?” The second question asked was “What is it about analyzing circuits and the coursework that seems to make sense to you?” The students defined as “struggling but passing the course” were asked two similar, open-ended questions.

So that they did not feel like the questions were intimidating or demeaning, the questions were prefaced by stating that this was an effort to try and make their learning experience better so that they could succeed and the questions asked were meant to help them. The first was “What do you think could be done to better help you understand the material being presented?” The second question was “What is it about analyzing circuits that doesn’t make sense or is confusing to you?”

### **Observational Protocol**

For this study the researcher was an active participant observer. Mills (2014) states “as researchers of our own teaching practices, active participant observation is likely to be the most common ‘experiencing’ data collection

technique that we use.” As with the interviews, records of these observations were written in field notes. Mills’ (2014) protocol to observe and record everything possible to attune the researcher what was most interesting was utilized. Mills elaborates that “during these observational periods you can start with a broad sweep of the classroom and gradually narrow your focus as you gain a clearer sense of what is most pressing (2014).” Both semesters during lab periods and before and after lectures observations were made. Student interactions and discussions before and after lecture and during labs were observed. Readiness for class and lab was observed. This entailed seeing if students were prepared with homework done and pre-labs completed prior to entering the classroom or were they trying to finish an assignment at the last minute. In the Spring 2014 semester along with the aforementioned observations, there was also a focus on observing use of the apps and Multisim.

Mills (2014) suggestion to look for bumps or paradoxes was also followed. He states “in this strategy, you consider the environment you are observing as if it were ‘flat’; nothing in particular stands out to you.” Unexpected responses from students to the action plan enacted or other anomalies from expectations were noted. To find what cellular devices were being used and who had smartphones or tablets, lab periods were used to make those observations. Students tend to leave their phones and tablets out during their lab work and since the researcher was interacting with every lab station during lab periods, it was easy to tally up what kinds of devices students were using. If a student didn’t leave their device out the researcher found opportunities to ask them about their devices as the opportunities presented themselves.

### **Methodological Framework**

The design followed a four-step procedural framework called the Dialectic Action Research Spiral. As described by Mills (2014) this is a cyclical procedure where the “teacher-researcher chooses an area of focus, determines data collection techniques, analyzes and interprets the data, and develops an action plan.” The area of focus of this research was chosen during the first semester of instruction and observation in the Fall 2013 semester in ECET 10700. During the first semester through observations and interaction with students the researcher was able to find missing links of why students have trouble understanding the key concepts taught. Essentially this can be thought of as the reconnaissance portion of the research to establish what the focus of the study should encompass (Creswell, 2012).

The significance of this procedural framework is that it is recurrent and data is always being collected and evaluated against the focus to see if the process is working its way towards an actionable solution. As Creswell (2012) states, “It is a ‘spiral’ because it includes four stages where investigators cycle back and forth between data collection and a focus, and data collection and analysis and interpretation.”

### **Analysis and Interpretation**

The Spring 2014 semester was devoted to the analysis and interpretation of the data along with a continuous evaluation against the intended focus of the study. Between the two semesters a temporary action plan of possible solutions was established and then analyzed for effectiveness and usefulness. The interpretation of the observed data in this study was important as there was only one researcher. Creswell (2012) describes interpretation as “extending the analysis by raising questions, connecting findings to personal experiences, seeking the advice of critical friends, and contextualizing the findings in literature and theory.”

Field notes were used and from those notes themes were sought from the interviews and observations. As Mills (2014) states “if data are to be thoroughly analyzed, they must be organized.” Although the process was not fully linear since this research was conducted over two semesters with different students, Mills’ organizational protocol to “become familiar with the data and identify potential themes, examine the data to provide detailed descriptions of settings, participants and activity, and categorize pieces of data and grouping them into themes (2014)” was still utilized. In the spiral framework this was done until all data were collected.

The data from the Fall 2013 semester was analyzed and interpreted to create an action plan to institute in the Spring 2014 semester. The observed data of students using the apps was then used to determine a finalized action plan. As Creswell (2012) describes, “The plan includes a summary of findings, recommended actions, and the identification of individuals responsible and those who need to be consulted or informed.”

## **Limitations**

One of the limitations of this study is that it was performed over the course of two semesters. To ensure that the action plan is ultimately successful the study would ideally be performed over a longer period of time so that the cyclical nature of the Dialectric Action Research Spiral could be allowed to unfold and recycle itself long enough to provide more data and interpretation.

Another is that the smartphone/tablet applications reviewed and proffered to the students were done solely on Android and iOS devices. Any student who had a smartphone or tablet operating on a Windows or Blackberry (RIM) OS might not have the same immediate access to these tools as a student who owns a device with the aforementioned operating systems. Time was devoted by the instructor to let those students who did not have Android and iOS devices to use these applications, but it should be noted that this is not equable to a student having access to them at any time if they owned them.

## **Results**

As success in this introductory circuit analysis course serves as a foundation to the students’ success in subsequent circuits courses, it was important to

understand the frustrations and hindrances of why students were not grasping the foundational concepts of circuit analysis and what tools could be afforded to them to alleviate these issues. This course is an introduction to both AC and DC circuit analysis. For the AC and DC circuit analysis the researcher focused on what could help the students understand the concept of current. For AC calculations the researcher focused on how students could easily use and compute complex numbers to perform their analysis using the same analysis techniques learned in the DC portion of the course. These seemed to be the two biggest impedances to student comprehension.

During interviews conducted comments about visualization and current like the following were common:

“I just can’t visualize what is going on with the current. I feel like I’m just putting numbers into formulas”

“I can visualize the electrons moving through the circuit. To me it’s like a physics problem.”

Clearly, visualization of the concepts was a major theme of the interviews conducted. Students who were performing well could visualize what was occurring in circuit. When concepts such as current and how it was simply electrons propagating through a circuit based on voltage and resistance were explained, they said that they could picture the electrons moving at a rate based on those other two parameters. In fact a majority said circuit analysis problems seemed to make sense if they thought of them in terms of physics because at the very foundation, circuit analysis deals with the physics concepts such as energy and velocity when talking about power and charge movement rate (current). It made sense then that when talking to the students who were performing poorly they said they could not visualize the concepts. Yes they were told that the rate which electrons moved through a circuit is the current and yes they could punch numbers in a calculator to obtain an answer using Ohm’s law, but it was meaningless to them because it was just a number they were told to find. Subsequent formulas for power and circuit analysis techniques such as mesh and nodal analysis only deepened their confusion. Add to that confusion the looming lessons on time dependent devices such as capacitors and inductors and a handful of students start to think about changing their major.

As evidenced by the interviews, visualization seemed to be the key that some were missing for circuit analysis. An effort was then made to find tools to further enhance their ability to visualize what is occurring in a circuit and hopefully give them the push over that hurdle on which they were stuck. Focus was turned to the burgeoning world of smartphone and tablet applications.

Examining the personal mobile devices of each of the students in the Fall 2013 semester found that of the 21 students who finished the course, although they all had a cellular device, only 2 did not have a smartphone or tablet, and 7 students had both a smartphone and a tablet. It was also found that of the 19 who did have a smartphone or tablet that 18 were either Android or iOS devices and one

being a Windows OS device. Having been involved in this department the last three years this data reinforced previous observations in other courses the instructor taught and assisted with that the overwhelming majority of engineering technology students carried either Android or iOS devices. The data for these observations can be found in Table 3:

**Table 3 – Fall 2013 Smartphone/Tablet Counts for Students**

Number of students completed course	21
Number of students with smartphone or tablet	19
Number of students with both smartphone and tablet	7
Number of students with Android or iOS device	18
Number of students with other smartphone or tablet	1

Armed with this knowledge the researcher downloaded, evaluated, and read the reviews for as many circuit analysis applications as could be found on both devices. It must be noted that the researcher owns both types of devices and has for many years. Being familiar with how each one works, the researcher felt comfortable making these evaluations without other input. It was found that for Android devices the best choice was an application called “EveryCircuit” and for iOS the best choice was “iCircuit”. Both apps are very similar in available features and in how they operate.

The key feature of both apps is an ability to construct any type of circuit the student might encounter and then simulate the program to watch how the charge moves through the circuit. Animated dots are displayed in the circuit to show students the direction the current is distributing charge and how it is being split amongst the branches. To visually indicate how strong a current is in any particular branch of a circuit, the moving dots are bigger and brighter and move faster where the current is stronger and are dimmer and move slower where the current is not as strong. In each app the student can click on a branch to get real-time values for voltage, current, and power for each component. As with any modeling software, values for circuit sources and components can be changed at any time with relative ease to see how different values will affect current and voltage values in the circuit.

In DC circuits students can follow the distribution of charge in one direction in a circuit as they are taught in the classroom and observe how that charge is split if it has any parallel branches. They can also see how in RC series circuits for instance the time constant works and that after five time constants the capacitor has the entire voltage of the source and there ceases to be any current flow, meaning the animated circuit current dots in the app become slower and less bright until they are not there anymore. They can see in RL series circuits how the circuit current builds over five time constants to where the inductor has an effective voltage of 0 V and acts like a short, meaning the circuit current dots in

the app start off very dim and slow and get brighter and move faster until the circuit reaches steady-state.

In AC circuits students can visually see the current switch directions based on the frequency and voltage of the source. They can see how increasing the frequency of the source affects the current frequency. Real-time graphs for voltage and current can be shown at the same time. In purely resistive circuits it can be seen how the voltage and current are in phase with one another, but when you add a capacitor or inductor (or both) you can observe how the current either lags or leads the voltage.

The helpfulness of these apps is in their relatively short learning curve for use, their portability and convenience, but most importantly, their ability to let students visualize exactly what it is they are studying. It brings another perspective to the table instead of just parroting an analysis technique and obtaining a result. It now makes that result meaningful because they can see what it is they are analyzing.

The other focus of this research was in the AC section of the course and the struggle of introducing complex numbers into circuit analysis. During observations and impromptu discussions with students in the fall semester, it was found that not everyone had the same skillset in mathematics. Although all students had taken and sufficiently passed the required college-level algebra and trigonometry prior to enrollment in ECET 10700, not all students excelled and retained the knowledge. It was found that they remembered the concept of an imaginary number, but not what that looked like as a vector on a graph with a real component. They also had trouble converting between polar and rectangular notation. It is crucial to be able to use these mathematical concepts to excel in AC analysis. The students who performed well said they were aided by the fact that they knew their scientific calculators forwards and backwards and that they used them extensively in their calculations of complex numbers and converting between the two notations.

This is not a mathematics course and there is no objective in the course outcomes that says they will relearn how to manually solve every complex equation and problem with proficiency. But since AC circuit analysis and the concept of impedance requires that a student be proficient enough in complex numbers to do simple functions like addition, subtraction, division, and multiplication, it seemed necessary that time was spent finding tools the students could use that did this easily and effectively. One solution could have been to find the exact model number of every single calculator the students were using, navigate to the respective manufacturers websites find the user manuals, and post the relevant section on complex numbers for each calculator. Instead drawing upon the data obtained that a majority of students were carrying a smartphone or tablet, it was decided once again to explore the app world for a solution.

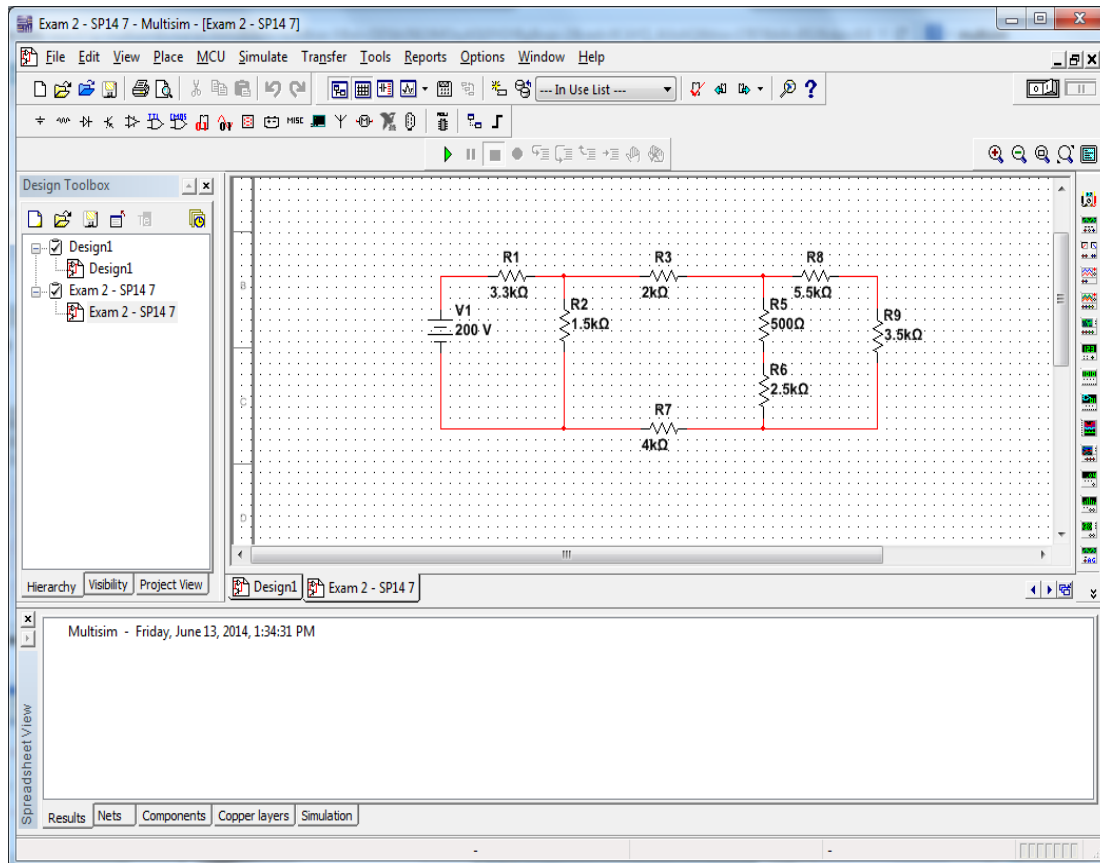
A search was again made in the respective Android and iOS app stores for apps that would focus solely on quick and easy complex number calculations. The

two essential requirements were that they had to be able to convert a number from polar to rectangular and vice versa and also be able to take any complex number (polar or rectangular) and add/subtract/multiply/divide any complex number (polar or rectangular). It was determined that for Android devices the best choice was an app called “Complex Calc” and for iOS devices the choice was an app called “Complex RPN Calculator”.

Both apps had a very clean interface and easy functionality. The Complex RPN Calculator app had a much steeper learning curve than the Complex Calc app, but the Complex RPN Calculator had a more than sufficient help menu to help lower that curve. Both performed the same functions and provided good answers, and they were quick and easy to use with a little practice. And the other good thing about each app is they are free to download.

Due to the cyclical nature of the Dialectic Action Research Model and the constant reevaluation of the data that was being obtained through observations, it was discovered that another key area to focus on was laboratory performance. Labs took entirely too long and students were not completing their pre-labs before lab. Some of this was due to poor time management but as some students pointed out they felt as if they had plenty of homework assigned dedicated to the manual calculations of circuit voltages and currents and time constants and things of that nature. Students felt that the pre-lab work where they obtain theoretical values which are later tested and verified through physical construction of circuits was excessive for this being a 100-level course. Instead of writing this off as students complaining and being lazy, this was treated as a way to introduce them to another circuit analysis tool. Typically in one of the later lab assignments of the semester they are introduced to a powerful and more costly PC-based software program called Multisim. To this point it has only been used once or twice in the later part of the semester. It was decided that introducing them to this program earlier on in the semester through newly created Multisim assignments would be a way to give them another tool and alleviate some of their concerns about the “excessive” (in their words) pre-lab work they were required to do.

Multisim is an all-inclusive circuit analysis program. It can be used for circuit modeling, for bigger projects involving groups of people, and has the ability to interface with the powerful and important LabVIEW program. It has a laundry list of features and applications, but the analysis will be narrowed to the relevant coursework for which it can be used. Unlike the smartphone and tablet apps reviewed, this program does not show animations of circuit current. However one can build any circuit, attach a limitless number of virtual measurement instruments in the circuit and obtain any current, voltage, and many other component and circuit values. An example of the interface for Multisim can be found in figure 1:



**Figure 1: Multisim Interface**

In laboratory, students are asked to build physical circuits and use measurement instruments to obtain values in the circuit. The compromise to them not having to do manual calculations for pre-labs was to build the circuits in Multisim prior to lab and use those values as their pre-lab values. This way they would have a better grasp on how to use the program and on top of that they have yet another tool they could use in their struggle to understand key concepts in the course. And if they had measured values that didn't match their theoretical values they could easily manipulate their program and do some troubleshooting to see whether they entered a component value wrong or they had a mistake in their physical circuit. As Heying et. al (2010) state "students can improve the performance of designs by taking advantage of powerful simulation to identify errors earlier in the design flow and reduce costly prototype iterations."

The three major changes instituted in the Spring 2014 semester based on the evidence and analysis of the Fall 2013 semester were to introduce the circuit analysis apps, the complex numbers apps, and introduce earlier on in the semester the all-inclusive software program Multisim. The students of the Spring 2014 semester were introduced to the software and applications to help them better understand the same material presented to students in the Fall 2013 semester who did not have access to the same tools.



It was found in the Spring 2014 semester, of the 27 students who completed the course and attended class regularly, 22 had smartphones or tablets and 10 had both a smartphone and tablet. Of those 22, 19 were either Android or iOS devices and there was one Blackberry and two Windows OS devices. Again, the overwhelming majority of students had either Android or iOS devices. The data can be found in Table 4:

Table 4 - Spring 2014 Smartphone/Tablet Counts for Students

<b>Spring 2014</b>	
Number of students completed course	27
Number of students with smartphone or tablet	22
Number of students with both smartphone and tablet	10
Number of students with Android or iOS device	19
Number of students with other smartphone or tablet	3

In the spring semester interviews were conducted and students were observed at different points in the semester to see if they had a positive effect in their comprehension of the key concepts. The extra assignments created to introduce the students to Multisim throughout the semester didn't seem to take much extra time outside of class to complete and the students responded well to the inclusion of the assignments. They liked being able to use Multisim on the pre-lab assignments as well. Pre-lab assignments were being done on time and students even used Multisim to double check their homework assignments. The biggest success was the introduction of the smartphone and tablet apps. In observing the use of these apps the most commonly heard exclamations upon learning how to use the circuit analysis apps and seeing the circuit current move were "Ah!" and "Oh!" and "Aha!" indicating that the concept clicked for them and it became clear what it was they were studying. Students downloaded these in the first few weeks of the course and used them extensively throughout the semester as an aid to finish homework, studying for tests, and answering extra even-numbered problems in the book. And because they are exciting and visual tools, students were observed using them when there wasn't even an assignment due. Some students would go to the instructor's office or while in the lab and show off to the instructor what new features they found and how interesting the work was due to the ability to "play" with their device and get something educational out of it in the process.

And there a positive unintended consequence of using these apps was found. Not only were they understanding the concepts better, but there was an enthusiasm and an intrigue into what they were studying. In other words, the course became something they wanted to learn more about.

Students were allowed to use the complex number apps on their quizzes and tests so more attention had to be paid during test time to make sure they weren't using their device to cheat. But it was found that the instructor repeated information less often during lectures and the only students who dropped the course either had medical issues or were absent from class an inordinate amount of time in the Spring 2014 semester, and the students who had dropped the class in the Fall 2013 semester due to poor performance all passed and most excelled in the Spring 2014 semester.

### **Conclusion, Discussion and Recommendations**

No other conclusion from this study can be drawn than to say that affording study participants the use of the circuit analysis and complex number apps and the early introduction of Multisim through extra assignments helped achieve positive course outcomes. Allowing study participants to use Multisim on pre-lab assignments also helped students achieve positive course outcomes. The goal of this study was to find solutions to some of the glaring problems that existed in student comprehension of crucial early circuit concepts. The hope is that more research can be done in this area to even better aid students in the future. As Cohen et al. (2007) state, "Action research starts small, by working through changes even a single person can try, and works towards extensive changes."

For future studies it would be wise to monitor the amount of other operating system devices such as Blackberrys and Windows being used by students and maybe seek out similar apps that are comparable. As of the date of this study the overwhelming majority of students not only own either Android or iOS devices, but they are fiercely loyal to their brand, indicating they don't plan on switching anytime soon. It is safe to say that there will be a need to focus on these operating systems for the foreseeable future but faculty must be aware of any changing trends to best aid the students. It is clear that additional quantitative, qualitative and mixed methods research should be designed and performed. Larger sample sizes could be used for quantitative studies designed to find out more about student perception regarding any number of issues germane to visualization, basic core concepts of circuits, and student access to various hardware and software. Additionally, more in depth qualitative research could be conducted including large-scale comparative case studies or smaller ethnographies that help researchers understand how and why certain students visualize and comprehend complex foundational concepts the way they do. Finally, a high quality mixed methods research design could focus on combining quantitative survey data and feelings and perceptions from qualitative data gathered during focus groups to determine a deep understanding of issues related to this study.

The following recommendations comprise the finalized action plan as an answer to the perceived deficits in student comprehension. Recommendations based on data gathering and analysis include:

1. Alert students prior to the semester that an Android or iOS smartphone or tablet would be beneficial to their success, just as you would suggest or require a good scientific calculator
2. For students using Android devices, let it be known your approval of and suggestion to download the circuit analysis app "EveryCircuit" and complex number calculator "Complex Calc".
3. For students using iOS devices, let it be known your approval of and suggestion to download the circuit analysis app "iCircuit" and complex number calculator "Complex RPN Calculator".
4. Let students use the circuit analysis apps for their homework and general understanding of circuit concepts and let them use the complex number apps on homework, quizzes, and tests.
5. Introduce the use of Multisim earlier in the semester with extra assignments and allow them to use Multisim on pre-labs instead of doing manual calculations.

In conclusion, it is important for all students to succeed early in their academic careers. Unfortunately, in engineering and engineering technology foundation level courses, it is often a short window for students to produce academically. If students cannot comprehend both the theoretical and applied nature of complex engineering concepts, they have little chance of graduating. It is imperative for engineering and engineering technology faculty to use every tool at their disposal in an effort to serve students. It appears that recent developments in terms of access to technology and new software programs can provide the necessary clarity for students to succeed.

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