An Intelligent Universal Virtual Laboratory (UVL)

Michael Duarte, Brian P. Butz, *Senior Member, IEEE,* Susan M. Miller, and Annapoorna Mahalingam

Abstract—The Universal Virtual Laboratory (UVL) is a realistic, real-time, electrical engineering virtual laboratory. The software developed targets individuals who do not have adequate mobility of their upper bodies to perform laboratory experiments. To provide a more realistic and enhanced learning experience, the users of the virtual laboratory are allowed the freedom to build and test a wide variety of realistic electrical circuits, and be able to perform curriculum-based experiments. Typically, this laboratory would accompany an introductory electrical circuits course sequence. The virtual laboratory also contains an intelligent lab assistant that can guide the student and answer student queries.

Index Terms—Adaptive technology, circuit topology, intelligent tutoring systems, interactive software, natural language interfaces, virtual laboratory.

I. INTRODUCTION

ACCORDING to the Center for Disease Control [1], 13.6 million individuals have limited hand use, and another 16.3 million have mobility limitations. In the field of science and engineering, approximately 109 700 persons with motor disabilities are employed in the United States [2]. Also, approximately 31 300 students with motor disabilities were registered in science and engineering programs in 1995 [3]. This project is intended to encourage and assist individuals with such mobility disabilities to enter the field of electrical and computer engineering. Presently, disabled individuals with motor disabilities have a difficult time with the laboratory portion of the curriculum. At most, individuals with limited or no use of their arms and hands could only watch their lab partners perform the laboratory experiments. Although better than nothing, observation may not be enough for a quality laboratory experience.

The goal of the Universal Virtual Laboratory (UVL) is to provide a student with motor disabilities a self-paced realistic laboratory experience that contains a solid, curriculum-based background in circuit experimentation and a virtual lab assistant to provide guidance and feedback. Typically, this laboratory would accompany an introductory electrical circuits course sequence. A secondary goal of the UVL is to provide all students a virtual experience. This option enables instructors to use the UVL as a pre-lab experience or as a component within a distance-learning

program. The laboratory has been developed to reinforce and to replicate the material covered in a typical introductory electrical circuits course sequence. Consequently, developed experiments include exercises involving dc, ac, and transient circuit analysis. The laboratory also allows students to create and analyze circuits of their own choosing.

Recent advances in computer technology and availability have allowed the computer industry to develop hardware and software applications that address the needs of the physically disabled. Circuit simulation software has existed for some time, with early simulators being DOS text-based programs such as *PSpice* [6]. With the introduction of operating systems with graphical user interfaces (GUI), better laboratory simulation software became available, such as *Electronics Workbench* [4]. However, these programs contain an interface with features, such as small buttons and an unfriendly breadboard, that are difficult for the physically disabled to use. Because the instruments and components do not look realistic, students who use these programs may not get the feel of an authentic laboratory experience.

This project attempts to provide the user with a familiar and realistic environment, using several existing Microsoft Windows applications. The goal is to create an environment similar to a real electrical engineering laboratory, and to offer the user a way to learn the different aspects of instrumentation and circuitry. Furthermore, the laboratory can be run from either a CD-ROM or from a Website for distance learning engineering courses.

II. IMPLEMENTATION

This section describes the basic elements of the UVL. The *User Interface*, Section A, describes and provides the rationale for the user interface. Section B, the *System Architecture*, gives an overall view of the components. Specifics of the system architecture are discussed in Section C, *The Design Process*. The mechanism facilitating communication among the UVL's application programs is described in Section D. Finally, Section E is an overview of the intelligent laboratory assistant.

A. User Interface

The user interface was created to meet two goals: 1) to present a user with a realistic environment and 2) to provide an environment that a disabled user could manipulate without difficulty. To achieve these goals, the laboratory was designed to allow many different types of adaptive technology to work with the software. Adaptive technologies such as switches, large keyboards, and voice recognition, enable individuals with disabilities the opportunity to manipulate a computer. The UVL can also accept traditional mouse and keyboard manipulation. To make the user interface friendly to voice recognition manipulation, a design scheme was selected so that simple voice commands would

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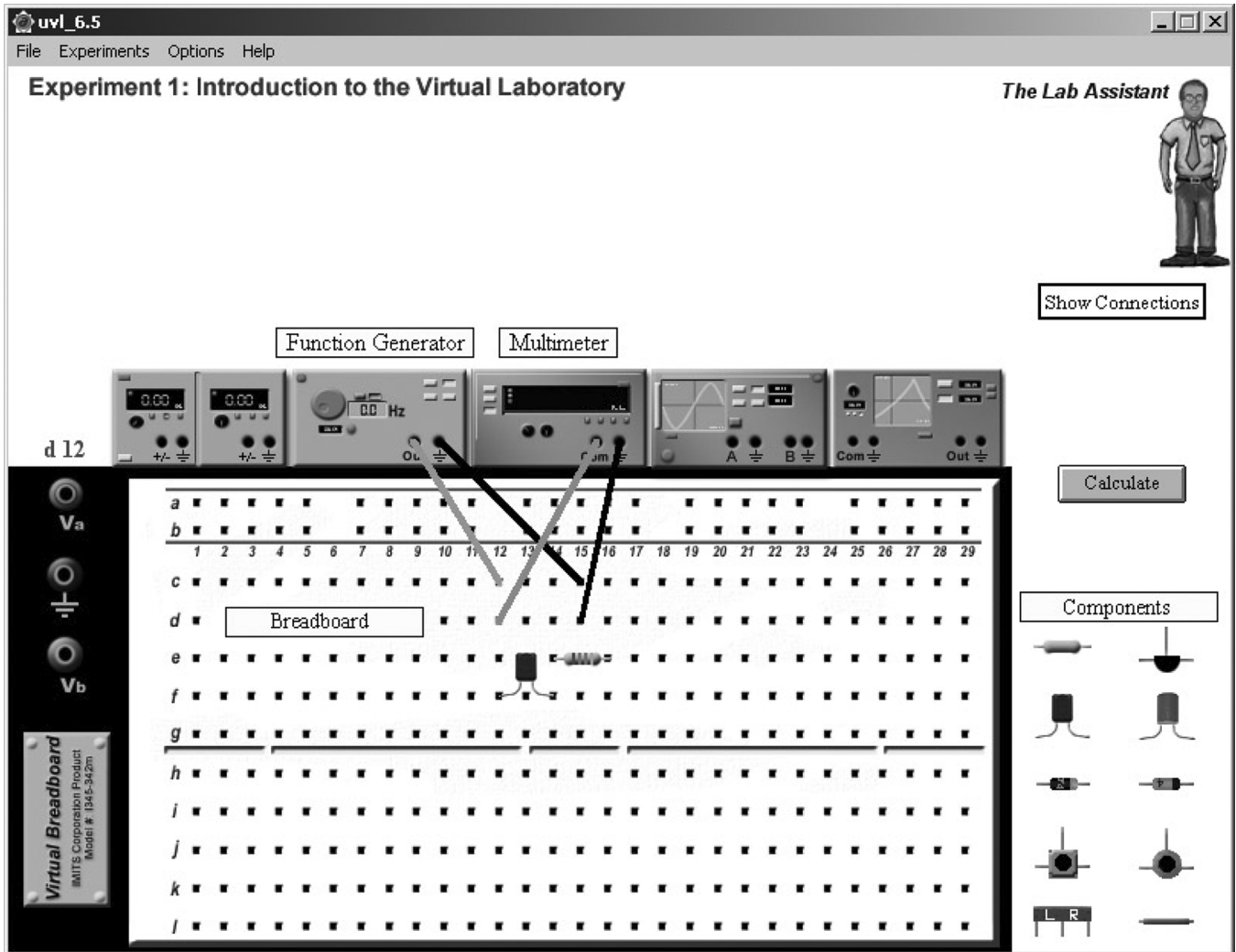

Fig. 1.   User workspace with a circuit on the breadboard.

perform major laboratory functions. Fortunately, with minor alterations, these simple voice commands could also be performed with the other adaptive technology devices.

The user interface consists of a breadboard with miniature instruments and a variety of electrical components (Fig. 1). The components available are resistors, capacitors, inductors, diodes, zener diodes, potentiometers, variable capacitors, transistors, and jumper wires. At this work station, the user has the freedom to build any type of circuit configuration possible. Typically, the student is given an experiment to complete, which includes circuit schematics to build and test circuit theory. The instruments available to the user are two dc power-supplies, a function generator, an oscilloscope, a spectrum analyzer, and a digital multimeter.

The instruments are connected to the holes on the breadboard when the user selects the instrument of his/her choice and enters the coordinate of the hole in which the user wishes to place a cable. The components connect to the breadboard in a similar way. The coordinates are the letters and numbers seen on the breadboard (Fig. 1). An example of the interaction with the voice recognition device might be: "Move mouse right," "Click," "C, 2, 2000." This would move the cursor to the right

over a particular component, and place it on coordinate "C 2" with a value of 2000 ohms for a resistor.

Each instrument in the work station has a corresponding larger version that is used to change the parameters of that instrument. With the two input instruments (dc power-supply and function generator), the user can change the settings and control the type of signal being put through the circuit. The output instruments (multimeter and oscilloscope) can be used to measure the voltage and current of particular parts of the circuit. The user can manipulate the settings on these instruments to view the signal similar to actual instruments. Fig. 2 shows the larger version of the function generator and the oscilloscope, respectively.

The specific instruments that were modeled are fully adjustable to a range of values found on the equipment in an ordinary electrical engineering laboratory. The digital multimeter is able to measure the current and voltage of a dc circuit as well as measure the rms value of the current and voltage of an ac circuit. The two-channel oscilloscope is able to display a current or voltage signal of both a dc and ac circuit. The oscilloscope also has the proper buttons and knobs that control the x–y displacement and the x–y ranges.

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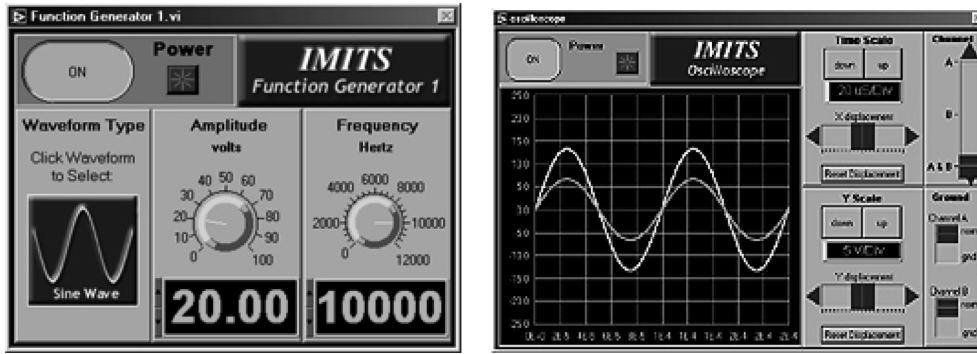DUARTE *et al.*: INTELLIGENT UNIVERSAL VIRTUAL LABORATORY (UVL)

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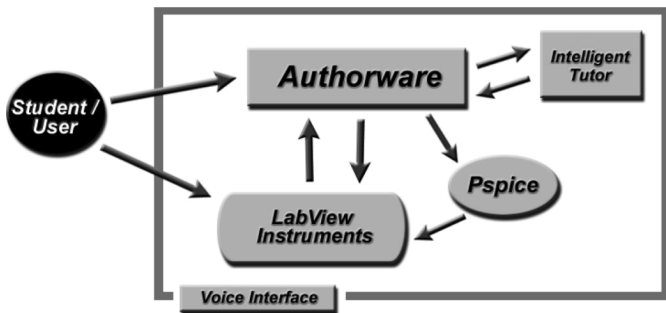Fig. 2.   Function generator and oscilloscope.

Fig. 3.   UVL system architecture.

The function generator and the dc power supply can be used as inputs to the circuit. The function generator supplies a sinusoid or square wave signal, and has an adjustable amplitude and frequency setting. The dc power-supply, supplies either a positive or a negative voltage to the circuit.

Finally, the spectrum analyzer in actuality has two main functions. It serves as both a frequency sweep generator and spectrum analyzer. The user can use the frequency sweep generator portion of the instrument to apply a frequency sweep to a circuit and measure the output of the circuit with the analyzer portion.

As can be seen from Fig. 2, the buttons, knobs, and displays are large so that a user with disabilities could more easily manipulate the instruments. For example, if a student uses the cursor with voice recognition software, he or she can more readily navigate the cursor over the large buttons and displays.

B. The System Architecture

Fig. 3 shows the system architecture of the UVL. In one configuration, this architecture uses the voice recognition device as the interface to the laboratory. The user, via the voice interface *Dragon Dictate*,[1] interacts with a packaged *Authorware*[2] executable. *Dragon Dictate* is an off-the-shelf software package that allows users to manipulate the Windows environment, via voice recognition. This program recognizes all keyboard and mouse commands and is used by individuals with little or no use of their hands, yet who still have clear speaking voices. The use of the voice recognition software was assessed by an adaptive technology specialist who found no issues for accessing and

utilizing the UVL software with this device. The specialist also found that the ability to create custom macros with this software improved the usability of the UVL software.

The user controls the instruments that are packaged as separate executables similar to the *Authorware* package. The user cannot change or manipulate the code developed in *Authorware* or *LabView*.[3] Instead, these packaged versions only run in the *Windows* environment, and allow the user to control only what is displayed to them. *PSpice*,[4] which is used to calculate all the necessary information of the circuit the user builds runs autonomously and hidden from the user. At no point does the user interact with *PSpice* in any way.

The intelligent laboratory assistant is a C++ natural language interface, developed specifically for this project. It accepts questions or comments posed by the user and determines what information the user is requesting. The intelligent laboratory assistant can also determine if a circuit the user has built on the breadboard is the same as the circuit they are required to build (discussed further in Section E). This C++ executable runs hidden from the user and seems, to the user, a natural part of the user work space.

C. The Design Process

In the process of designing the UVL, the major issue encountered was what software applications can be used that will make the system run and perform like a real laboratory. The laboratory had to give the user a way to produce a virtual layout of a circuit configuration. When this layout was completed, it had to be analyzed to extract certain information about the circuit. Finally, this information had to be displayed on instruments that look and function like real instruments found in a real laboratory.

Macromedia's *Authorware* was chosen to give the user a way to lay out a circuit or build a circuit on a breadboard. *Authorware* is an interactive multimedia development package that has been used as an authoring tool for computer-based training because it easily handles a wide variety of media and precisely tracks and responds to users' actions. It can display images and text, track and store user movements, and communicate with other packages. Since users of the UVL need to move components to create a circuit that seems real, a package that could not only

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[1]Dragon Dictate is a software product owned and licensed by ScanSoft, Inc.

[2]Authorware is a software product owned and licensed by Macromedia, Inc.

[3]LabView is a software product owned and licensed by National Instruments, Inc.

[4]PSpice is a software product owned and licensed by Orcad, Inc.

make interaction simple, but also record the interactions was needed.

Authorware is designed so that a developer can easily add graphics and mobility to a screen. Innate to *Authorware* is the user tracking mechanism. This mechanism is the most important key to the UVL, because of the need to "know" what the user is moving, connecting, or changing on the screen.

When a user builds a circuit, *Authorware* records the interactions and with a programmed algorithm, develops a description of the circuit. For example, if an image of a resistor is on the screen, the user could move the resistor to a particular part of another image, say the breadboard. Once the user has moved the image of the resistor to his/her desired location, *Authorware* stores a numeric location of this image. This numeric location can then be used later to perform an analysis of the circuit.

Although *Authorware* can be programmed to do many different calculations and even execute C-based code, it cannot easily analyze a circuit. Thus, the problem is how a circuit built in *Authorware* can be analyzed to extract the appropriate information that the user needs to see.

PSpice is a popular circuit analysis program used by many electrical engineers as a tool to analyze and test circuitry [6]. To use *PSpice* to analyze a circuit, one has to generate a text version of the circuit in a text file. This "text circuit" is called a "netlist," which is essentially a component-by-component "text" diagram of the circuit written in a specific format for *PSpice*. Knowing that *PSpice* needs this netlist file, *Authorware* had to generate a text file with the netlist of the circuit built by the user. Using *Authorware's* ability to track movements of images by the users, a translation of where the user puts an image of a component to a node location was plausible. Therefore, with *PSpice's* ability to analyze the circuit and store the analyzed data in another text file, the next issue was how to display this information.

National Instruments' *LabView* is a well-known package that is used in industry for instrumentation analysis [5]. This program seemed ideal because of its ability to be customized through its native graphical code (G-code) language. Instruments created in *LabView* needed the ability to process information coming out of the *PSpice* output file. Because *LabView* can send information to other programs and analyze data from real instruments or from other programs, the output from *PSpice* was used as a data stream continuously sent to *LabView*. This stream would then be parsed for the appropriate information using a search algorithm.

D. The Communications Channel

In order for the UVL to function as closely as possible to real-time, the architecture discussed previously needed to work quickly, efficiently, and transparently. Through extensive testing of *Authorware, LabView*, and *PSpice's* input and output capabilities, using text files is found to be a reliable method to create a constant communications channel. Although using text files is not the quickest way for *Authorware* and *LabView* to communicate, it was adequate to communicate among all the software packages. This communications channel allows the virtual instruments to update in a minimal amount of time. Consequently, the input instruments (function generator, dc power supply, and sweep generator) send *Authorware* the settings the user has set

through a text file. *Authorware* then takes these settings and the netlist it has created from the virtual breadboard and sends it to *PSpice*. *PSpice* then creates an output file with all the mathematical information of the circuit and sends it to the output instruments (oscilloscope, multimeter, and spectrum analyzer) for display. The creation and exchanging of files, as well as the *PSpice* calculation, is completely hidden from the user.

E. The Intelligent Laboratory Assistant

The intelligent laboratory assistant found in UVL consists of two parts: a natural language parser and an intelligent circuit comparer or circuit recognizer (CR). The natural language parser portion of the assistant is used to answer questions that the user might pose during a laboratory session. When the user of the laboratory wishes to post a question or comment to the intelligent assistant, he/she calls the assistant by clicking the assistant icon. Once the assistant is activated, the user can either type or dictate his or her question or comment. This question is stored to another text file and the C++ executable containing the natural language parser loads this file and makes the necessary assessment of what the user wants to know. An example of a user query could be: "How do I measure the voltage across the resistor?"

With this information, the assistant parses the sentence and identifies the key words to make an assessment of what the user wants to know. The key words in the previous example are: "How," "measure," "voltage," and "resistor." These words are used to search the assistant's knowledge base and make a decision on what the user should see, which could be a simple tutorial on how to connect the digital multimeter across a resistor to measure its voltage. A detailed description of how the natural language parser performs is given in [7].

The CR is an intelligent circuit analysis module incorporated in UVL to examine and analyze a student's work, identify errors, and provide explanations and suggestions to guide the user to the right answers. The UVL provides the user with a set of experiments and instructions on how to build and simulate circuits provided in each experiment. The user is given the freedom to build the circuit in any way, adhering however, to the essence of the schematic. Therefore, when a student builds a circuit on the breadboard, the circuit may be connected in a manner physically different from the connections shown in the circuit schematic; yet the circuits might be equivalent. In a real laboratory setting, if a student has a problem with an experiment/circuit he/she would approach the laboratory teaching assistant (TA). Typically, the TA would 1) examine the student's circuit keeping in mind the objective of the experiment, 2) check to see if the circuit contained all required components, and 3) examine to determine that the required components were properly connected as illustrated in the experimental schematic. Using these observations, the TA would draw a conclusion about the causes and nature of the problem. The CR provides this functionality in the UVL.

The CR is a program developed for UVL that has knowledge of circuit topology and is capable of using this knowledge to assess student work. The objective of the CR is to verify that the circuit created by the student is a valid representation of the laboratory manual schematic. The student activates the CR

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by selecting the "check my circuit" button provided near the breadboard. The CR compares the student's circuit to the appropriate laboratory manual schematic. The result of the analysis is recorded in a text file and displayed to the user through *Authorware*. A detailed description of how the CR performs is given in [8].

This intelligent lab assistant makes the UVL unique when compared to other laboratory/electronics simulators. Integrating the ability to perform laboratory experiments independent of real laboratory equipment and components, and in conjunction with an intelligent lab assistant, a user of the UVL possesses a complete laboratory experience within a single software package.

III. EVALUATION AND TESTING OF THE UVL

The UVL was tested in two ways: 1) in sections of physically able undergraduates to determine its usability and effectiveness and 2) by an adaptive technology specialist to determine its appropriateness for use with individuals who do not have adequate mobility of their upper bodies to perform laboratory experiments.

A. Methodology Used Within the Classroom

1) Sample: The sample consisted of undergraduate electrical engineering students ($N = 114$) who used the UVL as part of studies conducted at different time intervals. A small group of students ($n = 27$) from several institutions beta-tested the UVL as part of their use of the Interactive Multimedia Intelligent System (IMITS)[5] during spring 2002. During fall 2002, students at two institutions ($n = 71$) and during fall 2003 students at one institution ($n = 16$) used the UVL when they used IMITS as part of a quasi-experimental study.

Most students in the sample were male ($n = 92; 81\%$) and between 17 to 20 years old ($n = 80; 70\%$). Sixty-two students (54%) were white; 24 students were African American ($n = 24\%$); 9 (8%) were Asian American; 3 were Hispanic (3%); 1 was Pacific Islander (1%); and 14 rated themselves as Other (12%).

2) Procedures: In collaboration with the researchers, each on-site instructor set expectations for use of the software. Thus, the manner in which the software was integrated into class activities was unique to each site. This variability was deliberate; the goal was to reflect the manner in which the software might be used by an instructor in any classroom. Instructors varied in how they used the software. For example, one instructor incorporated IMITS and UVL as part of weekly lab activities. Another instructor provided the software to students to use as a tutor and only minimally integrated the software in regular teaching activities.

Except for spring 2002 cohort, which included distant sites, research staff visited each site, presented a description of the study, and obtained written consent from those students who agreed to participate in collection of student data. Students completed a demographic form and instruments to measure learning

[5]IMITS is an interactive intelligent tutoring system developed by the Intelligent Systems Application Center at Temple University. IMITS tutors students in Electrical Engineering Circuit Theory and Design. For more information visit: http://www.temple.edu/IMITS

TABLE I
MEAN AND STANDARD DEVIATIONS ON UVL QUESTIONS
WITH POST HOC COMPARISONS

Survey Questions about the UVL	Semester of Participation			
	Spr 2002	Fall 2002	Fall 2003	Combined
	Mean	Mean	Mean	Mean
	(*SD*)	(*SD*)	(*SD*)	(*SD*)
	n = 27	n = 71	n = 16	N = 114
I was comfortable using the virtual lab	3.41	2.99	3.44	3.15
	(1.0)	(1.1)	(.81)	(1.07)
The lab seemed or "felt" like a real lab.	3.37_a	2.77_{ab}	3.63_b	3.04
	(1.2)	(1.0)	(1.2)	(1.14)
The virtual lab helped me verify results.	3.41_a	2.89_{ab}	3.50_b	3.10
	(.88)	(.94)	(.89)	(.96)

and cognitive styles. Students were provided the software and directions on how to use the software as part of class activities. At the conclusion of the course, students completed a *Usability Questionnaire*. All data were coded to ensure confidentiality. One should note that students who volunteered to beta-test the software (spring 2002) did so under conditions that were very different from those in the other two cohorts.

B. Data Analyses and Results From Classroom Use

1) Quantitative Survey Items: Usability data provide information on a program's functional effectiveness, ease of use, motivational influence, and quality assurance [13]. Students who used the software were asked to complete a *Usability Questionnaire* in which the format of most items was a 5-point Likert-type scale (where $1 = \text{strongly disagree}, 5 = \text{strongly agree}$). Students were asked how comfortable they were using the lab, the degree to which the lab was authentic, and the lab's usefulness in verifying results of projects and assignments that they completed while using IMITS. Overall, students' responses were slightly positive toward the UVL. The combined means are presented in the right column in Table I. There was consistency among students' responses to these three questions; all correlations were found to be positively correlated at a statistically significant level.

To determine whether students in each cohort perceived the UVL similarly, a multiple analysis of variance was conducted on survey responses. Groups were statistically significant different on two survey items: 1) "The lab seemed like a real lab" (i.e., authenticity): $F(2, 113) = 5.54, p = 0.005$, and 2) "The virtual lab helped me verify results" (i.e., usefulness for learning): $F(2, 113) = 4.83, p = 0.01$. A *Tukey's Honestly Significant Differences* (HSDs) multiple comparison test was conducted post hoc to determine which groups were statistically significant different from each other. Means for each sample are shown in Table I. Means in the same row with the same subscripts differ significantly at $p < 0.01$ in the Tukey's HSD comparison. For both survey items, students in spring 2002 and fall 2003, cohorts responded more favorably than did students in fall 2002 cohort.

This response pattern was similar for the third item, (comfortableness using the lab), but this difference did not reach a statistically significant level.

Students were also asked, "Would it be helpful to include specific lab exercises with the UVL?" A statistically significant negative correlation existed between responses to this item and each of the aforementioned survey questions. Students who were comfortable using the UVL did not see a need for specific lab exercises, and students who were not comfortable using the lab thought it would be helpful to include lab exercises. This finding suggests that some students may require specific directions to get value from the UVL. Although the UVL was available to all students as they solved complex design problems across various IMITS scenarios, only some students took advantage of the opportunity to test their answers or to explore other engineering problems. Those students who did not use the UVL may need more explicit directives on how to use the UVL to solve problems.

2) Individual Differences in Using the UVL: Analyses were conducted to determine individual differences in students' perception of the UVL. As part of the protocol, 72 students completed the Learning Styles Inventory [14], which classifies a student's learning style along four continua: Verbal-Visual, Intuitive-Sensing, Active-Passive, and Sequential-Global. Not unexpectedly, a statistically significant positive correlation existed between scores on the Visual scale and favorable responses to the question concerning student comfortableness using the lab, $r = .227, p = .019$ and a statistically significant negative correlation between scores on the Verbal scale and the same item, $r = -.331, p = .008$. That is, students who stated a preference for learning through visual strategies were more likely to be comfortable using the UVL, and students who stated a preference for auditory learning (i.e., verbal) were more likely to be uncomfortable using the UVL. Global learners were also likely to be less comfortable using the UVL; a statistically significant negative correlation existed between scores on the Global scale and responses to the same item $(r = -.257, p = .029)$.

On the *Demographics Form*, students provided information about mathematics courses they had completed. The only statistically significant positive correlation was between enrollment in differential equations and comfortableness using the UVL (point biserial $r = .246, p = .032$). Students also self-rated their algebra skills. Statistically significant negative correlations existed between skills in algebra and each of the three UVL survey items. Students who rated themselves low in algebra skills rated using the UVL positively (and, of course, the converse was true).

3) Qualitative Responses: Students were asked to describe their use of the UVL. Seventy-six students provided written answers to this question. Of those reporting, 45% $(n = 34)$ provided positive responses regarding use of the virtual lab; 42% $(n = 32)$ stated that they did not use the lab; and 13% $(n = 10)$ reported finding it difficult to use.

Of those using the lab, most students indicated that they used the lab to verify test answers to IMITS problems. One student stated, "To test a circuit before I entered my answer." Another noted, "I used the virtual lab to confirm my answers." "Test answers where possible. Did trial and error solving for

one problem so I would know what value I was supposed to be getting."

Students used the UVL to aid understanding of specific problems in IMITS. One student stated he used the UVL for, "Understanding frequency concepts. Calculating small problems." Another responded, "Help with node voltage and mesh current problems."

A few students used the UVL for more than verifying answers. One student noted, "I used the virtual lab to confirm a few questions asked. I also built various circuits just for interest's sake. Overall, I felt the laboratory was a very instructive and engaging component of the software." Another stated, "For the first project, I didn't need the virtual lab, but I used it just to build my own circuit and see if I could get some correct values. I built a small circuit taken from my textbook and it gave me correct values."

One student viewed the lab as having practical value, "It helped me apply circuit theory and practical application." Another student noted, "I used it to build a circuit, and I gained experience similar to a real lab."

C. Evaluation by the Adaptive Technology Specialist.

The individual testing the UVL software has more than twelve years experience working with alternative computer technology and physically/mentally challenged individuals. As an Adaptive Technology Specialist she assesses the physical abilities of individuals and determines which alternative input device/devices will be needed for computer access. She has successfully instructed more than 500 disabled individuals to access a computer for their personal preferences, i.e., educational pursuits via the Internet, empowerment, communication, mental and physical stimulation, etc. Three alternative means of input were used to access the UVL program; voice recognition software, a special keyboard, and an adaptive switch. These alternative devices were chosen because of their diverse computer applicability. The adaptive Intellikeys keyboard is hardware; the voice recognition program, Dragon Dictate, is software; and the Discover Switch is a combination of hardware and software. All three of these devices have been very successfully used in the computer laboratory of a long-term care facility for adults who have a wide variety of physical limitations.

The Intellikeys keyboard/mouse is a large keyboard that allows the user to access all key characters and mouse functions and requires no software installation to use. Rather than keys, this keyboard has a touch-sensitive base requiring very little hand strength and also has a clear acrylic keyguard that snaps over the keyboard to prevent accidental keystroke. It also allows the users to rest their hands on the keyguard without interfering with intended keystrokes. The UVL software was completely accessible using this device, and no problems were noted.

The *Dragon Dictate* Classic Edition voice recognition software allows the user to speak into a microphone and control the computer. This program recognizes all keyboard and mouse commands. It is used by individuals with little or no use of their hands, yet who still possess a clear speaking voice. No issues for accessing and utilizing the UVL software were found with this device. The ability to create custom macros with this software improves the usability of the UVL software.

The Discover Switch software and hardware combination enables a nonverbal, minimal movement individual to control all computer functions by depressing a small switch. Virtual access boards appear on the monitor, and an automatic scanning process allows the user to click a small switch to make the desired choices on the monitor. This device was initially slow and extremely time consuming because the pre-created virtual control boards that are part of the switch software made it necessary to frequently shift between three or more virtual boards to work on one experiment. With the creation of customized virtual control boards, the UVL program was accessed in a more timely and productive manner.

The adaptive technology specialist concludes that the UVL software allows current users of an electronics lab to access realistically simulated electronics equipment although they are not in the lab. The UVL software opens the world of electronics to the physically challenged individual who was previously not able to access the electronic equipment of the electronics lab. This level of accessibility of software is key in enabling the disabled youth of today and people who have encountered disabling life changes to pursue rewarding careers.

IV. Conclusion

The UVL has been developed to simulate a basic electrical engineering laboratory that accommodates experiments to reinforce theory learned in initial electric circuits courses. It has been developed especially for students who have limited or no use of their hands and arms. The laboratory does offer a realistic representation of an introductory circuits laboratory and has been tested successfully with a number of physically able students. The results show that the laboratory is user-friendly and does provide an excellent pre-laboratory exercise. The UVL has not yet been tested with physically disabled students but has been designed in cooperation with an adaptive technology specialist who works daily with physically disabled individuals.

The virtual lab assistant provides any student using the UVL with advice, with the ability to have their circuit configuration checked, and with personal tutorials on how to use the various pieces of laboratory equipment.

The initial evaluation of the UVL involved students enrolled in circuit courses. Overall, students had positive perceptions of the UVL, although differences in perceptions were found based on user differences in learning style, prior knowledge, and skills. Visual learners were more comfortable using the UVL; verbal learners were less comfortable. These relationships are reasonable since the UVL is an image-based environment. In addition, the more Global the learning style, the less likely students felt comfortable using the UVL. This finding is understandable, since designing circuits involves analytical and sequential activities. In addition, no differences in students' perceptions of the UVL were based on their academic performance as measured by GPA.

Students' responses suggest two types of users: Confident users who independently used the UVL to explore circuitry and to test their work and timid users who wanted direct instruction and specific exercises before they would venture into the virtual lab. This dichotomy in student usage is not unique to the UVL.

When confronted with novel learning situations, some students "jump in" and experiment; others wait for directions.

The goal of this initial study was not to identify connections between instructors' incorporation of the UVL and students' perceptions. Some instructor's included the UVL as part of the regular class expectations; other instructors provided the UVL as an "add on." Given that students value what teachers endorse, further study is needed to delineate the relationship between instructors' endorsement and use of the UVL and students' perceptions.

For more information on the UVL, please visit http://www.temple.edu/IMITS.

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Michael Duarte received the B.S.E. and M.S.E. and degrees from the Electrical and Computer Engineering Department, Temple University, Philadelphia, PA.

He is a Software Engineer with the Intelligent Systems Application Center (ISAC), Temple University. Since fall 1997, he has been one of the major contributors to the Interactive Multimedia Intelligent Tutoring System (IMITS) and the Universal Virtual Laboratory (UVL). He has published several papers about the Universal Virtual Laboratory.

Mr. Duarte is a member of the Golden Key National Honor Society and Eta Kappa Nu. He received the Connelly Foundation Scholarship, the Junior Achievement Scholarship, and a Presidential Fellowship. He is listed in *Who's Who Among Colleges and Universities*.

Brian P. Butz (S'69–M'71–SM'94) received the Ph.D. degree in electrical engineering from Drexel University, Philadelphia, PA.

In 1987, he founded the Intelligent Systems Application Laboratory (ISAL) at Temple University, Philadelphia, PA. This Laboratory provided a focal point within Temple University, concentrating on research in intelligent systems. From 1989 to 1996, he was Chairman of the Electrical and Computer Engineering Department, Temple University, where he is currently a Professor of Electrical and Computer Engineering.

Dr. Butz is a member of the American Society for Engineering Education (ASEE) and the Association for the Advancement of Computing in Education. He has been a member of the Executive Committee of the Philadelphia Section of IEEE and was its Chair in 2000. He has received ASEE's Centennial Certificate, IEEE's Third Millennium Medal, and the IEEE Philadelphia Section Award. He received the Christian R. and Mary F. Lindback Award for Distinguished Teaching at Temple University in 1984. In April 1999, he received the Innovative Excellence in Teaching, Learning and Technology Award at the Tenth International Conference on College Teaching and Learning. He received the Distinguished Alumnus Award from the Electrical and Computer Engineering Department, Drexel University, and the Temple University Great Teacher Award in 2000.

Susan M. Miller received the B.A. degree in psychology from the University of Chicago, Chicago, IL, and the M.S. degree in instructional design and Ph.D. degree in educational psychology from Purdue University, West Lafayette, IN.

She is an Assistant Professor in educational psychology at Temple University, Philadelphia, PA, and Director of a Master's degree program in instructional and learning technology. In her role as Educational Psychologist and Program Evaluator, she has been affiliated with the Intelligent Systems Application Center for several years. Her professional interests include the application of theory and consideration of individual differences in technology-rich environments and evaluation of intelligent agents. She has conducted research in the area of multicultural education and coauthored the "Survey of Cultural Attitudes and Behaviors" designed to assess cultural bias and discrimination in educational settings. She has published in these areas, as well as made numerous regional, national, and international professional presentations.

Dr. Miller is a member of the American Educational Research Association and the American Psychology Association.

Annapoorna Mahalingam received the M.S. degree in electrical and computer engineering from Temple University, Philadelphia, PA.

She is an Application Support Engineer at The MathWorks, Natick, MA. From 2002 to 2004, she was a Research Assistant at the Intelligent Systems Application Center (ISAC) at Temple University, where she incorporated an intelligent circuit recognition mechanism into the Universal Virtual Laboratory (UVL). She has published several papers about the subject.