

Effectiveness of Virtual Teaching Assistant Software for Circuits Open Laboratory

Firdous Saleheen, *Member, IEEE*, Brian P. Butz, *x, x*, Joseph Picone, *Senior Member, IEEE*,
and Chang-Hee Won, *Senior Member, IEEE*

Abstract—We develop a Virtual Open Laboratory Teaching Assistant (VOLTA), which provides the students a self-paced open laboratory environment with virtual teaching assistance in undergraduate circuits laboratory. This web-based software assists the students to perform the circuits laboratory at students' convenience even when the teaching assistant is not around. This way the VOLTA increases the laboratory guidance for the students, while reduces the workload of human teaching assistants. The VOLTA features a circuit recognition algorithm that helps the students verifying the simulation circuit. This algorithm uses image processing to recognize the simulated circuit. Primary results show that the circuit recognizer module can identify simple RC, RL, and RLC circuits. The advantages of this approach include individual self-paced learning, 24/7 accessibility, personalized instructions for shy students, increasing level of engagement, and efficient use of limited resources (i.e. space, lab equipments, teaching assistant etc.). In this study, we compared the effectiveness of VOLTA compared to traditional laboratory for an undergraduate circuit course. The results show that: 1) the students found VOLTA to be satisfactory, and 2) the students participating in VOLTA performed better on the quizzes. We performed an ANOVA test on pre-test/post-test gain score of traditional and VOLTA students. We found the p -value to be 3.54×10^{-7} , which indicates the VOLTA significantly improved students' performance. This study suggests that VOLTA can be used as effective teaching tool in circuits laboratories.

Index Terms—Electrical engineering education, virtual laboratory, open laboratory.

I. INTRODUCTION

Laboratories are quintessential part of the engineering education to deliver the hands-on experience of engineering concepts to students. Traditional on-site experiment-based laboratories have several drawbacks, such as expensive resources, limited space, schedule conflicts and short term exposure. Over the past decades, educators have been exploring virtual laboratories to mitigate these issues [1], [2]. Different approaches have been attempted in different branches of engineering such as controls [3], process engineering [4], nanotechnology [5], and chemical engineering [6], robotics [7], virtual laboratories [8], and remote laboratories [9]. These methods, however, do not replace the traditional hardware based laboratories.

F. Saleheen is with the Department of Electrical and Computer Engineering, Temple University, Philadelphia, PA 19122 USA. e-mail: f.saleheen@temple.edu

B.P. Butz is with the Department of Electrical and Computer Engineering, Temple University, Philadelphia, PA 19122 USA.

J. Picone is with the Department of Electrical and Computer Engineering, Temple University, Philadelphia, PA 19122 USA.

C.-H. Won is with the Department of Electrical and Computer Engineering, Temple University, Philadelphia, PA 19122 USA.

In a traditional “closed laboratory” environment, students perform the assignments following a ‘cook-book’ lab manual and submit a written report drafted after the laboratory has been completed. It is argued that this is the not format most conducive to learning [10]. Space constraints are mitigated by dividing the students into multiple sections. In each section, the students are grouped in a team because of equipment shortages. Sometimes, scheduling constraints force a lab to be performed out of sequence with the lecture. Because of time constraints, students receive a less-than-ideal exposure to the concepts and the associated instrumentation.

Open laboratory is one of the new, promising approaches in engineering education. An open laboratory is where the students can return to repeat and refine their experiments. Palais and Javurek defined the open laboratory as “a single large room containing equipment for performing experiments associated with all the electrical engineering undergraduate laboratories” [11]. The motivation of the open laboratory lies in its ability to maximize resource utilization. Lab scheduling becomes more flexible, teaming is enhanced, and equipment is more effectively utilized [12], [13]. However, this requires self-paced labs that can be completed without direct supervision.

In a traditional laboratory approach, teaching assistants help the students with assembly and debugging. Students can also receive individual instruction from graduate student teaching assistants (TAs) during office hours. It is very difficult to deliver on-demand, asynchronous help for large populations of students with a limited number of TAs.

Our goal is to transform traditional laboratories to open laboratories for basic electrical engineering courses such as circuits. By “open laboratory” we mean a physical laboratory where students can perform their laboratory assignments at their own convenience. In order to mitigate the availability issue of teaching staff, we proposed a framework that can provide “virtual teaching assistance” to the students. This framework is called the “Virtual Open Laboratory Teaching Assistant (VOLTA)”. Equipped with pre-lab testing and instruction, engineering design exercises, short topic explanation videos, instrumentation instruction (including safety), and a corresponding post-lab test module, VOLTA is able to provide asynchronous, on demand, and smart assistance to the students. In the preliminary study, we observe that the students participating in VOLTA performed slightly better compared to traditional laboratory students [14]. We performed the effectiveness analysis of VOLTA in Fall 2014 which was published in [14]. In that experiment, we observed the VOLTA students did as well compared to the traditional students with a p -value of

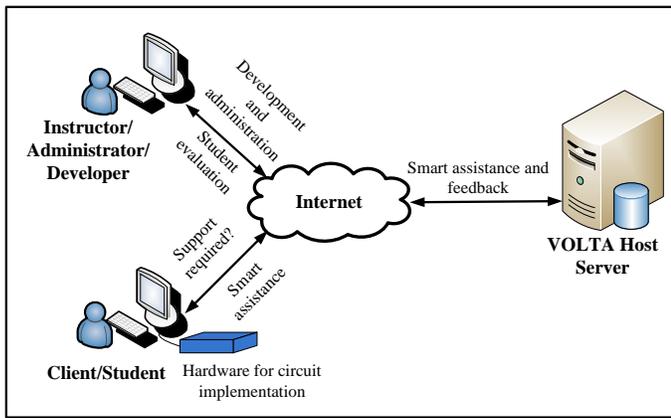


Fig. 1: Physical architecture of VOLTA.

0.117. Also, we observe that the announcement of considering pre- and post-test score in final grades improved the student performance. Therefore, in Spring 2015, we announced for both traditional and VOLTA students that their scores would be considered for the final grade. Besides, we added a feature of “Hardware help” for the students to troubleshoot their circuits, which enhanced the user experience. In this paper, we present the VOLTA framework, VOLTA’s adaptation in a circuit course, and an assessment of its application to an entry-level circuit course. We show that VOLTA significantly increases learning.

The rest of the paper is organized as follows: Section II and III describes the overview of VOLTA design and implementation. Section IV discusses the evaluation methods used to assess the effectiveness of VOLTA. Results are presented in Section V. Finally, we present discussion and conclusions.

II. VOLTA DESIGN

In this section, we describe the physical architecture and discuss different modules in VOLTA framework. The detail description can be found in [14].

A. System Architecture

The Virtual Open Lab Teaching Assistant (VOLTA) is a system which can guide a student to perform hardware electrical engineering circuits laboratory 24hours/7days without any human teaching assistant. Fig. 1 shows the physical architecture of VOLTA. The different modules of VOLTA, hosted in a server, are accessible via internet for the instructors, developers, and students. The students have a portable and compact hardware for circuit implementation. VOLTA is preloaded with instructional videos, definitions, and explanations. It supports on-demand learning and provides immediate feedback on laboratory exercises and exams. For instructors, it provides an administration panel that supports management of the laboratory content.

B. Software Modules

The VOLTA software consists of five modules and a database. The modules are (1) Instructor module, (2) Student module, (3) Help module, (4) Circuit recognizer module, and (5) Speech module.

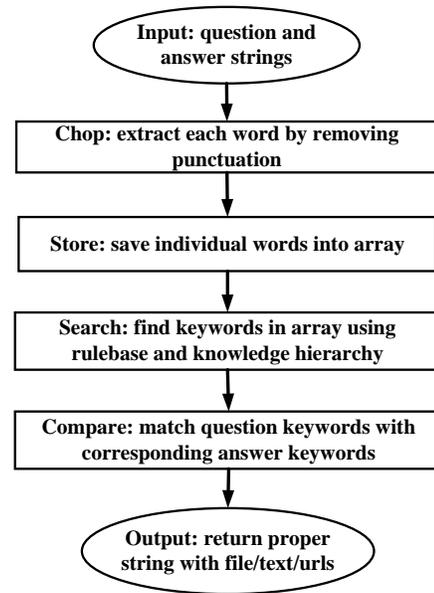


Fig. 3: Question and answer search module flowchart.

1) *Instructor Module*: The instructor module provides a flexible environment for an instructor or teaching assistant to perform his/her tasks. It authorizes the students for access into VOLTA through the student module. The instructor can update the lab contents via an administration panel. It also helps upload the supporting materials into database for the Help module.

2) *Student Module*: The student module is the part of VOLTA that interacts with the students. It guides the students step-by-step for completing an experiment. It helps the student to understand the subject clearly through tests. It evaluates the student before and after the lab-work. It fetches ‘smart’ assistance from VOLTA Help module.

3) *Help Module*: The Help module is one of the most important parts of VOLTA. This module provides the students with a teaching-assistance-like-service in virtual formats. The students can seek help from this module at any point of VOLTA session. This module provides multiple sub-modules consisting of definitions of circuit terminology, questions and answers about basic circuit and the related lab. We employed a search algorithm in VOLTA for finding the appropriate answers to the students’ query. The flowchart is shown in Fig. 3. There are also safety video tutorials, basic instrument use video tutorials, forum for discussing the problems, and how-to-use VOLTA video tutorial. These sub-modules are pre-loaded with the necessary materials by the instructor. It works in conjunction with a circuit recognizer module and a speech module. The circuit recognizer helps the students verify and debug their circuits.

4) *Circuit Recognizer Module*: The circuit recognizer module is one of the salient features of VOLTA. It helps the students verify their simulated circuits and debug their hardware circuits. This module contains an image processing algorithm for automatic recognition of the circuit schematics. Figure 7 shows the flowchart for the circuit recognition process. The students upload their schematic for simulation in VOLTA. The schematic serves as the input to the module. The image

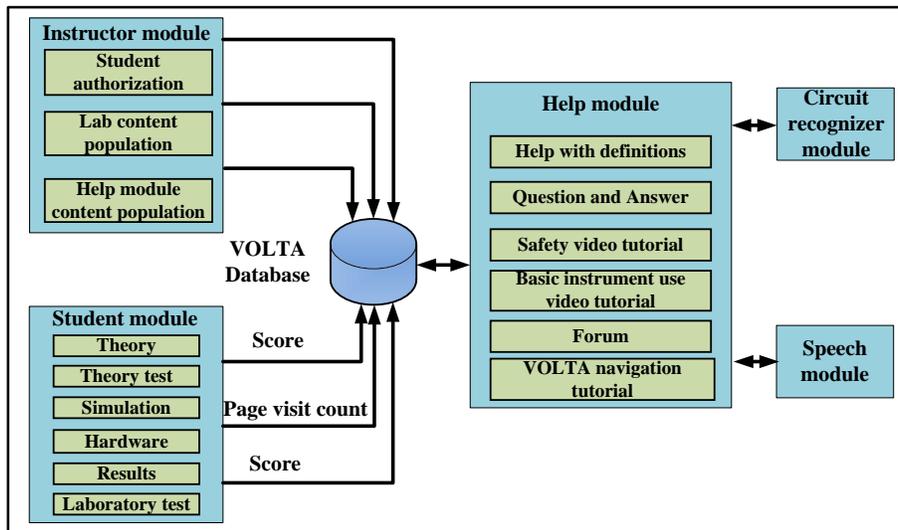


Fig. 2: VOLTA software modules.

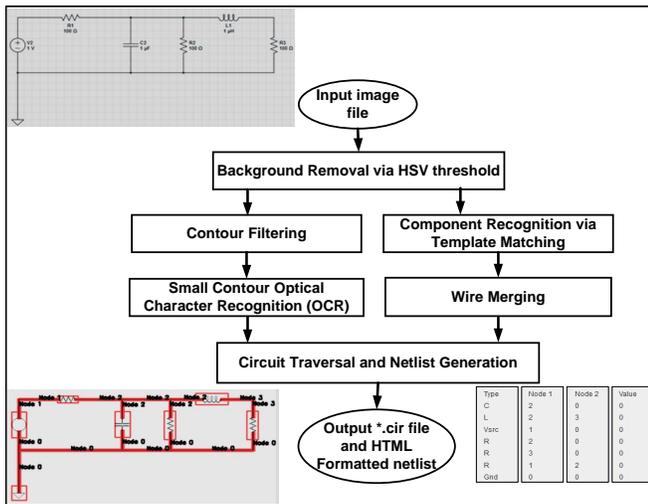


Fig. 4: Flowchart of Circuit Recognition Algorithm.

processing performs background removal, contour filtering, and component recognition via template matching [15], [16]. Finally, the module outputs a schematic with labeled nodes, components with values, and a HTML formatted netlist (word description of the circuit). This module also helps debugging a hardware circuit by providing troubleshooting steps. A hardware circuit may not work properly for a few reasons, such as bad connections, bad components, incorrect wiring, bad instrument setting, and power problems. With hardware help, VOLTA can help students like a teaching assistant.

5) *Speech Module*: This module is intended for the future works. The speech module provides a more flexible means for assisting the student. This module can offer help by detecting emotional state of the student. The input to the speech module is the speech signal generated from the student's voice. This speech signal will be analyzed for emotional state detection and will be used for offering help from VOLTA.

Site administration	
Auth	
Groups	Add Change
Users	Add Change
Student	
Course permissions	Add Change
Lab progress	Add Change
Simulation question responses	Add Change
User profiles	Add Change
Tracking	
Pageviews	Add Change
Visitors	Add Change
Tutor	
Answer elements	Add Change
Answer keywords	Add Change
Answer topics	Add Change
Answer with questions	Add Change
Nodes	Add Change
Rulebases	Add Change
Synonyms	Add Change
Vocab domains	Add Change
Vocab topics	Add Change

Fig. 5: VOLTA administration panel for instructors.

III. VOLTA IMPLEMENTATION

The VOLTA software is implemented using Python (version 2.7.1) and Django (version 1.6.5). Django is a high-level Python web framework for rapid and scalable web development [17]. Django framework is divided into three layers: model layer, view layer, and template layer. The model layer is an abstraction layer provided by Django for structuring and manipulating the data of the web application. For VOLTA, we used SQLite database engine. The views layer is used to encapsulate the logic responsible for processing a user's request and for returning the response. In other words, it determines the URLs (Universal Resource Locator) and returns the user with the response. The template layer offers a syntax for rendering the information to be presented to the user. This means that the designer can create certain HTML (HyperText Markup Language) templates with static part and syntax facilitating the dynamic content insertion. In this way, for each user a dynamic HTML page is generated.

Fig. 5 shows the administration panel of VOLTA. Through

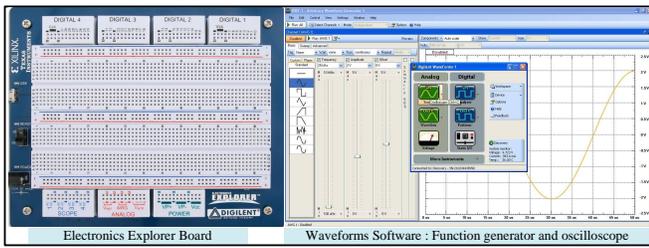


Fig. 7: Electronic explorer board from Digilent and the waveforms software.

this administration panel, the metadata of the model can be read and the content can be added. The database of VOLTA can be loaded with contents in two ways: via python scripts and via admin panel. Practically, before making the website live, it is convenient to load the content using scripts. After making the website live, for adding contents admin panel is used. In this way, overwriting the current user information can be avoided. From Fig. 5, we see the options for creating and authorizing users, adding different lab elements, and monitoring the lab progress of the student.

VOLTA user interface guides students through an experiment step-by-step. The students take part in pre-tests and post-tests that consist of multiple choice questions. The same set of questions are asked in pre- and post-tests. In post-tests, the multiple choice options are not in the same order as in pre-tests. After the pre-test, the students are directed to the simulation section. In this section, the students are instructed to simulate their circuits before constructing a hardware implementation. The hardware section provides instructions for building circuit in the breadboard.

The student uses Digilent EE (Electronics Explorer) board (Digilent Inc., Pullman, Washington, USA) for hardware implementation [18]. The EE board is built around a solderless breadboard, which also includes oscilloscopes, waveform generators, power supplies, voltmeters, reference voltage generators, and thirty-two digital signals that can be configured as a logic analyzer, pattern generator, or any one of several static digital I/O devices (Fig. 7). All of these instruments can be connected to circuits built on the solderless breadboards using simple jumper wires. For data acquisition and analysis, PC-based software named “WaveForms” is used. A high-speed USB 2.0 connection ensures near real time data acquisition.

In the hardware section, VOLTA provides assistance for tracing circuit connections. We call it circuit tracer. The troubleshooting guide starts with the component integrity test. A video instruction is provided to check whether the components are damaged. Secondly, another video instruction shows how to do the continuity test to check whether there is any loose connection. A brief description of circuit node and component connectivity is given for the desired circuit. This description is generated from a previously-loaded Multisim netlist of the circuit. Fig. 8 shows the hardware help interface. The Results section contains the guideline for the contents of report. At the end of the lab, the students take a laboratory which is a post-test in the form of multiple-choice based on the lab.

Fig. 9 shows the help page of VOLTA. The students can look for the questions, answers, and definitions. This page

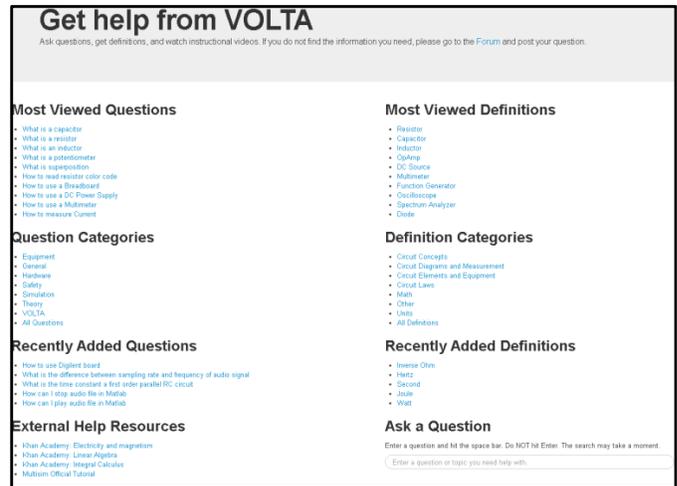


Fig. 9: Help module implementation.

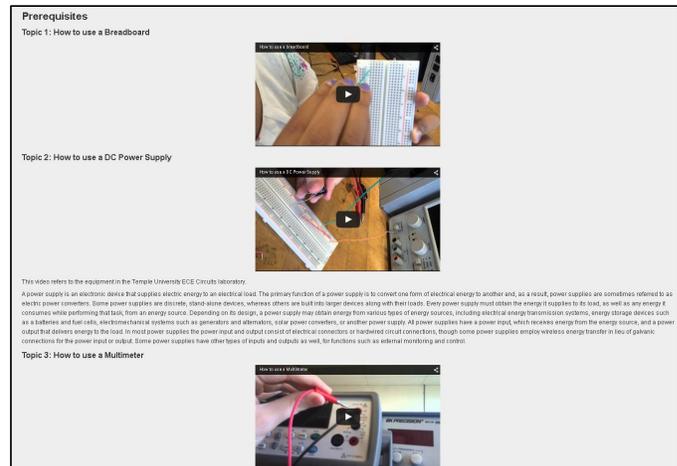


Fig. 10: Instructional videos in help module.

gives a summary list of most viewed questions and definitions. Also, there are video tutorials for performing basic circuit laboratory work. Fig. 10 shows the pre-requisite page with video instructions for doing lab-work.

IV. EVALUATION OF VOLTA

The VOLTA was evaluated from two perspectives: usability and effectiveness. Usability evaluation data provides knowledge about a program’s functional effectiveness, efficiency, ease of learning, ease of use, motivational influence, and quality assurance. On the other hand, the effectiveness study of VOLTA provides insights about its usefulness compared to traditionally taught classes. We obtained IRB approval from Temple University (Protocol number is 22447).

A. Usability Evaluation

The survey includes 20 questions using a 5-point Likert scale (where 1 = strongly disagree, 2 = disagree, 3 = no opinion, 4 = agree and 5 = strongly agree) and 3 open-ended questions. Twenty questions were asked covering seven broad categories:

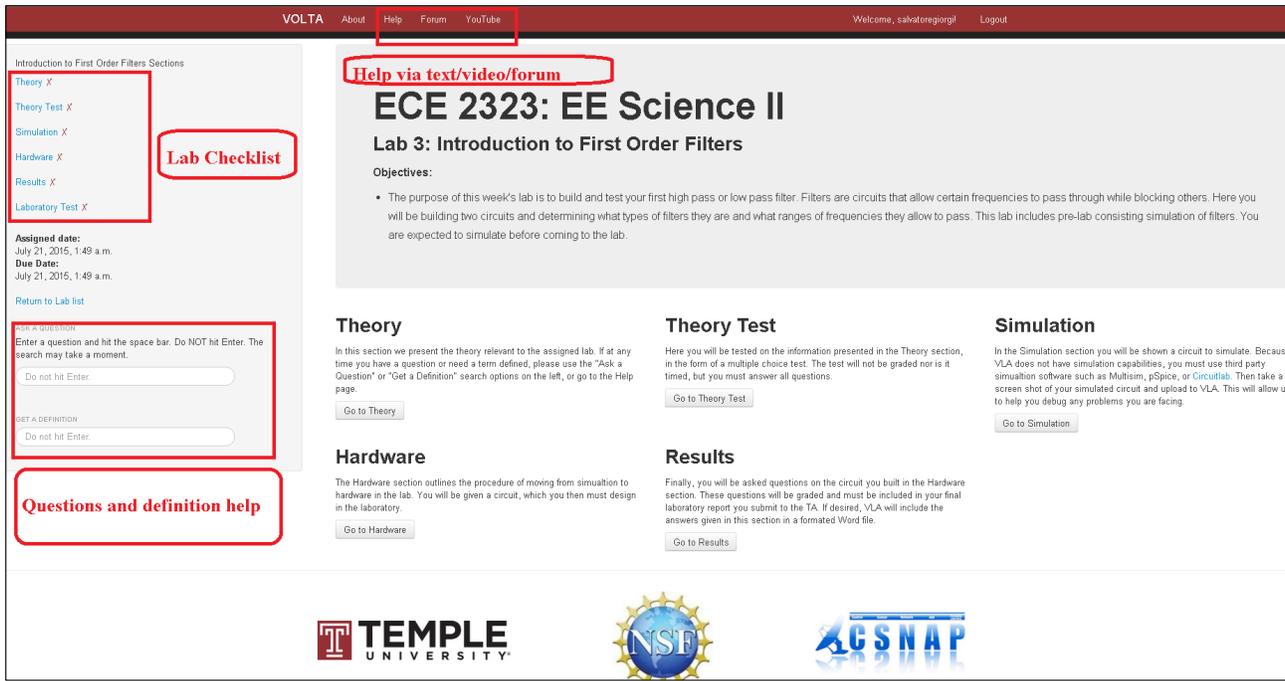


Fig. 6: User interface for the students.

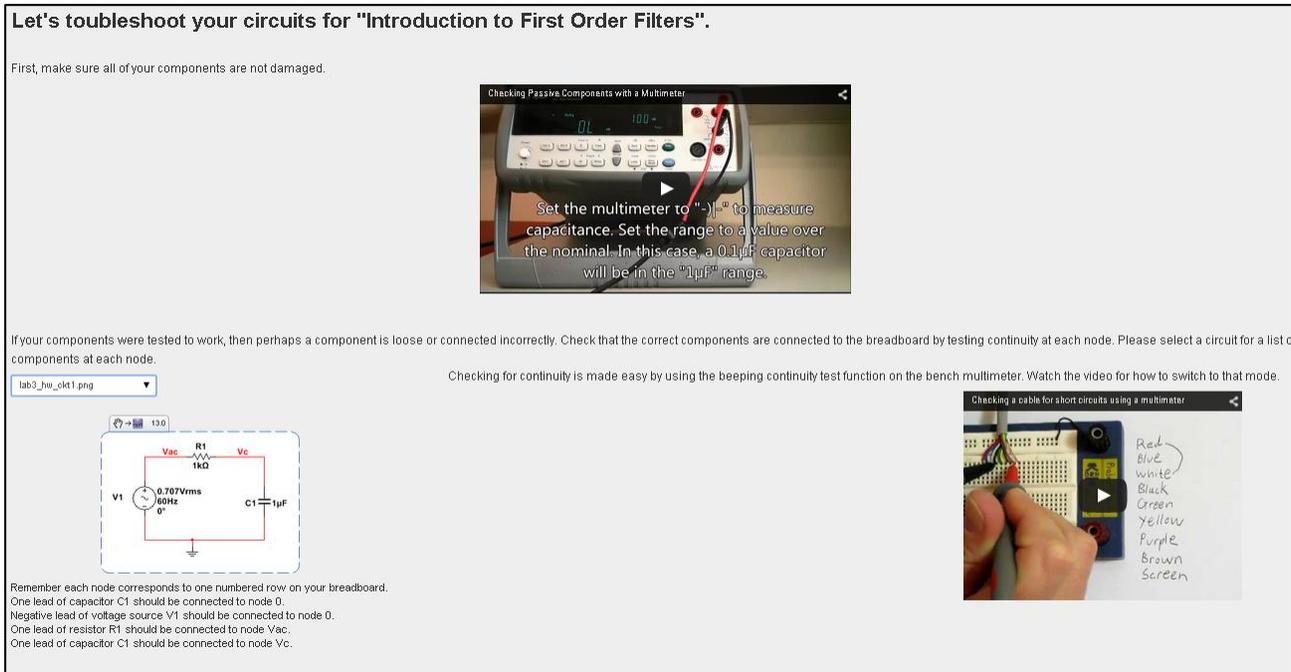


Fig. 8: Circuit tracer in VOLTA.

- A. Did the students think the VOLTA is useful for their learning? (Learning environment)
 - B. Did the students find the software motivating? (Motivational value)
 - C. Did the students find the VOLTA easy to use? (Ease of use)
 - D. Did the students perceive the usefulness of various features of the VOLTA? (Perception of usefulness)
 - E. Did the students buy into the virtual laboratory environment? (Authenticity of virtual learning)
 - F. What was the perceived quality of the VOLTA? (Quality assurance)
 - G. What additional features or learning situation the students would like to see in the VOLTA? (Expectations)
- B. Effectiveness Assessment**
- The study involves the students enrolled in a course on circuits. The course had two sections. The students were ran-

domly assigned to each section. The sections were randomly chosen as experimental and control groups. The students in the experimental group received a curriculum in which the instructor integrated the VOLTA. The students in the control group received the traditional course curriculum. The effectiveness of the VOLTA is assessed using gain score analysis of pre-test/post-test design [19].

Eleven lab assignments were developed to use to with VOLTA. With each lab assignment, there were one pre-test and one post-test. The lab assignments were as follows:

- Lab 1 Introduction to Multisim using RC circuit,
- Lab 2 Introduction to Digilent board using RC circuit,
- Lab 3 Introduction to first order filters,
- Lab 4 Step response of a second order filter,
- Lab 5 Frequency response of a second order filter,
- Lab 6 Second order circuit design based on step response,
- Lab 7 Impedance measurement of AC circuit,
- Lab 8 Bass booster implementation using active filters,
- Lab 9 Gain bandwidth product and slew rate of op-amp,
- Lab 10 Introduction to boost converter, and
- Lab 11 Introduction to amplitude modulation.

V. RESULTS

A. Usability

In this study, the usability evaluation involved participation of the students and the data were collected through student survey. During Spring 2015, the usability data were collected from ten students in a single group design. These students were enrolled in an introductory AC circuit lab “EE Science II”. They volunteered to use the VOLTA and complete the survey questionnaire.

In category A, five Likert-type questions were asked to understand how successful VOLTA was as a learning environment. At least 57% of the students agreed that they viewed the VOLTA as a useful learning tool. In category B, two questions were asked to assess the motivational value of VOLTA. At least 43% of the students agreed that they enjoyed using the VOLTA. In category C, three questions were asked regarding the ease of use of the VOLTA. 99% of the students found the VOLTA easy to use and easy to navigate. The students also felt that the use of the VOLTA was intuitive (85%). In category D, four questions were asked regarding what degree the VOLTAs features were helpful. 71% students thought VOLTA Youtube channel was useful, 50% found the VOLTA as lab results verification tool. The students indicated that the instructional videos were the most helpful features of the VOLTA. In category E, two questions were asked regarding the authenticity of virtual learning. 57% students felt the labs seemed like a real lab. In category F, two questions were asked to assess the quality of the videos and the VOLTA overall. In both cases, 85% students agreed the videos were of good quality and the VOLTA was trouble-free. In category G, two questions were asked about the expectations from the VOLTA. 56% students expected a feature to verify their simulation results in the VOLTA.

B. Effectiveness

A total of 28 students participated in this study in Spring 2015. The experimental group consisted of 18 students, while the control group consisted of 10 students. The experimental and control groups were taught on different day and time of the week in closed laboratory environment with and without VOLTA, respectively. A total of eleven lab assignments were performed in eleven weeks. In each of the lab assignment, there were a pre-lab test and a post-lab test. The pre-lab test comprised five questions in multiple choice formats. Each question carried 20 points. The post-lab test comprised the same five questions with the multiple choices in different order. The same instructor taught both sections. Table I and II show the pre-test post-test scores of the control and experimental group of students, respectively. The average gain is the difference between the mean post- and pre-test score.

Fig. 11 shows pre-test and post-test score versus lab assignment index and average gain versus lab assignment index plot. From the figure, we see that students taught by VOLTA performed significantly better in lab assignments 2, 3, 4, 5, 6, 7, 8, 9, 10, whereas traditionally taught students scored better in lab assignments 1 and 11.

A two-group pre-test/post-test design approach was used to evaluate the effectiveness of the VOLTA. The major question guiding the evaluation of the VOLTAs effectiveness on learning: Did the students who used the VOLTA (experimental group) learn more (e.g. score higher on gain measures) than their counterparts in the control group? The gain score analysis approach were used analyze data from the two-group pre-test/post-test research design. The gain score is defined as the difference between the post-test and pre-test score. The null hypothesis is that there is no difference among the mean gains of the experimental and control groups for eleven assignments. We performed ANOVA test [20] on the gain scores of 28 students in 11 lab assignments. The ANOVA test was performed using R (version 3.1.2). The ANOVA p -value was 3.54×10^{-7} (much less than 0.001) indicating that the null hypothesis can be rejected. In other words, there is sufficient evidence that the students taught with VOLTA performed better than their counterparts in the traditional labs. Our results are significant at a 95% level of confidence, which implies students who had access to VOLTA performed significantly better than their counterparts in the traditional labs.

VI. DISCUSSION

The results from this study were encouraging, and showed the benefits and challenges of VOLTA. The effectiveness assessment showed VOLTA students performed better than those of traditional lab students in eleven pair of similar tests. We observe that the control group did not score equal to/more than 90 in post-tests in any of the labs, while the experimental group was able to score equal to/more than 90 three times. The VOLTA students were taught in a similar way as the traditional lab students, except without any handouts. While outside the lab, the VOLTA students obtained help from VOLTA and TAs, the traditional lab students got help from TAs only in office hours. The VOLTA students received a greater amount help

TABLE I: Control Group's ($n = 18$) Pre-test and Post-test Score

Lab Assignment no.	Pre-test		Post-test		Average gain
	Mean	Standard Deviation	Mean	Standard Deviation	
1	61.11	19.40	68.89	15.23	7.78
2	48.89	23.31	54.44	8.96	5.56
3	67.06	13.62	68.24	13.82	1.18
4	74.44	26.50	83.33	30.73	8.89
5	85.56	17.39	84.44	15.71	1.11
6	77.78	22.00	77.78	20.96	0.00
7	54.44	23.86	47.78	23.23	6.67
8	76.67	30.00	81.11	27.06	4.44
9	85.56	17.39	83.33	17.95	2.22
10	54.44	28.91	54.44	29.67	0.00
11	47.78	20.15	48.89	20.25	1.11

TABLE II: Experimental Group's ($n = 10$) Pre-test and Post-test Score

Lab Assignment no.	Pre-test		Post-test		Average gain
	Mean	Standard Deviation	Mean	Standard Deviation	
1	68.00	16.00	76.00	8.00	8.00
2	44.00	12.00	56.00	12.00	12.00
3	76.00	12.00	88.00	9.80	12.00
4	54.00	20.10	66.00	26.91	12.00
5	84.00	24.98	90.00	18.44	6.00
6	76.00	26.53	90.00	18.44	14.00
7	62.00	10.77	68.00	9.80	6.00
8	70.00	28.64	84.00	14.97	14.00
9	70.00	18.44	96.00	8.00	26.00
10	56.00	24.98	74.00	20.10	18.00
11	74.00	15.62	76.00	14.97	2.00

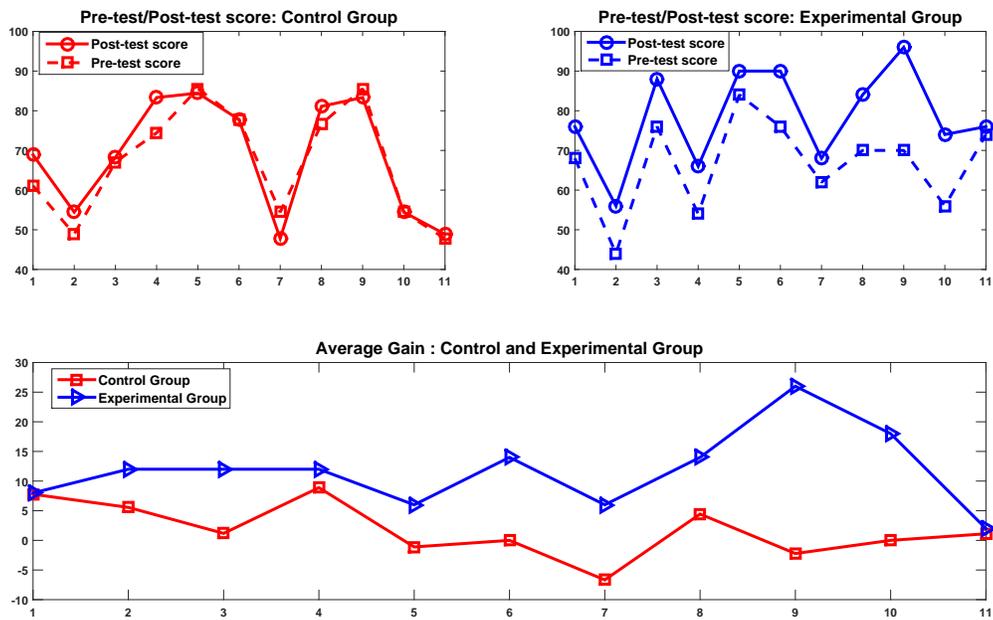


Fig. 11: Pre-test and Post-test score of Spring 2015.

compared to the traditional students, which were reflected in effectiveness analysis.

The Spring 2015 version of VOLTA achieved a p -value of 3.54×10^{-7} , which was much better. The Spring 2015 version of VOLTA had one new feature “Hardware help”, which provide a hardware assembly instruction based on Multisim netlist. Also, the help module of Spring 2015 version of VOLTA had more questions and answers included. In the Fall 2014, the VOLTA was used for the first time. The feedback in Fall 2014 enriched the Spring 2015 VOLTA, which result into a positive outcome.

The survey and in-class discussion showed that the students require some time to adjust with the VOLTA format, but the period was fairly short. After fourth week the VOLTA students seemed to learn more, which was reflected in their post-test results from Lab 5. The students also felt that a verification of their simulation and hardware circuits would help them to a great extent. That justified the development of a circuit recognizer for VOLTA. If the circuit recognizer functionality could be added, the VOLTA lab would be able to be run without any TAs.

Finally, the implementation of the VOLTA initially requires a substantial amount of time. Creating lab contents and videos required a significant portion of time. Additional time was required to identify the questions the students could ask during the lab. Once the course material was developed, the TAs were required to spend less time before each lab than in the traditional setting. Most of the course materials are reusable. Therefore, in future semesters VOLTA will reduce TAs workload.

VII. CONCLUSION

VOLTA is a framework for providing the students with an open laboratory environment equipped with virtual teaching assistance. VOLTA provides a self-paced environment, on-demand help, and an increasing level of engagement. We received positive feedback from the students on various VOLTA contents such as instructional videos, safety videos, short topic and explanations. The students taught by traditional lectures and VOLTA were compared using the pre- and post-test performance. The ANOVA test showed a p -value of 3.54×10^{-7} indicating VOLTA had a significant effect on students’ performance. An advanced version of VOLTA development is currently in progress which will feature a functional circuit recognizer. Also, the speech module development is in progress, which can be helpful in detecting the user frustration and offering assistance. This functionalities will decrease user frustration thereby enhancing the user experience.

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Firdous Saleheen Firdous Saleheen received the B.Sc. degree in electrical and electronic engineering from Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, in 2008, and the M.S. degree in electrical engineering from Temple University, Philadelphia, PA, USA in 2013. From 2008 to 2010, he was with Mango Teleservices Ltd., Dhaka, an international IP bandwidth provider of Bangladesh, as a Senior Engineer in the Research and Development Department. He is currently pursuing the Ph.D. degree in electrical engineering

in ECE department of Temple University. His research interests include tactile sensation imaging, diffuse optical imaging, biomedical imaging systems development, machine learning, and statistical control theory.

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Brian Butz

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Joseph Picone Joseph Picone received his Ph.D. in Electrical Engineering in 1983 from the Illinois Institute of Technology. He is currently a Professor in the Department of Electrical and Computer Engineering at Temple University. His primary research interests are currently machine learning approaches to acoustic modeling in speech recognition. His research group is known for producing many innovative open source materials for signal processing including a public domain speech recognition system. He is a Senior Member of the IEEE and has been

active in several professional societies related to human language technology. He has authored numerous papers on the subject and holds several patents in this field.

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Chang-Hee Won Chang-Hee Won is an associate professor of electrical and computer engineering in the Department of Electrical and Computer Engineering and the director of Control, Sensor, Network, and Perception (CSNAP) Laboratory at Temple University. Previous to coming to academia, he worked at Electronics and Telecommunications Research Institute as a senior research engineer. Currently, he is actively guiding various research projects funded by National Science Foundation, Pennsylvania Department of Health, and Department of Defense. His

research interests include stochastic optimal control theory, sensing systems, and virtual laboratory assistant.