**Virtual Teaching Assistant for Electrical Engineering Science: Initial Study**

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Abstract

This paper presents a framework for a Virtual Open Laboratory Teaching Assistant (VOLTA) which provides personalized instructions for undergraduate students in an entry level electrical circuits laboratory. Traditional closed laboratory environments do not provide 24/7 access to such labs hindering the learning-on-demand paradigm that is so critical to the laboratory experience. VOLTA offers an open laboratory environment with a virtual teaching assistant where the students enjoy a self-paced learning environment with an increased level of engagement. VOLTA provides short explanations on selected topics, video instructions about instrument operation and safety, and archives of frequently asked questions. Furthermore, it can assist students in assembling, verifying, and troubleshooting circuit simulations through a circuit pattern recognition algorithm. A preliminary version of VOLTA was assessed using a focus group of 34 electrical engineering students enrolled in their second basic circuit analysis course. The ANOVA test on pre-test and post-test scores showed a *p*-value of 0.171 indicating a modest improvement in performance compared to students who took the same course taught using a traditional closed laboratory approach. This initial study suggests that VOLTA can be used as an effective learning tool in circuits laboratories.

I. Introduction

Laboratories in which engineering concepts were reinforced by hands-on experience have always been an integral part of engineering education. Traditional on-site experiment-based laboratories have many limitations including space, equipment, scheduling conflicts and limited contact hours. Therefore, numerous alternative approaches have been explored such as virtual laboratories1, table-based laboratories2, and remote laboratories3.

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 learning4. 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.

A better alternative can be an open laboratory 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”5. The popularity 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 in an open laboratory6. However, this requires self-paced labs that can be completed without direct supervision. Our goal in this work is to transform traditional laboratories to open laboratories for basic electrical engineering courses such as AC/DC circuit analysis.

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. In order to mitigate these issues, we have developed a framework that offers both the accessibility of an open lab and on-demand teaching assistance through a virtual agent. This framework is referred to as 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 repetitive assistance to the students. In this paper, we present the framework and a preliminary assessment of its application to an entry-level circuits course.

The paper is organized as follows: Section II is an overview of VOLTA design, Section III describes the assessment methods for VOLTA, and Section IV presents the assessment methods and results. Finally, conclusions are presented in the last section.

II. VOLTA Design Overview

The Virtual Open Lab Teaching Assistant (VOLTA) is a virtual assistant that can guide a student through hardware-based electrical engineering circuits laboratory. Fig. 1 provides an overview of the VOLTA architecture. The different modules of VOLTA, hosted in a server, are accessible via the Internet for the instructors, developers, and students. The students use a portable compact hardware setup for circuit implementations. 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.

VOLTA is based on the framework shown in Fig. 2, and consists of five modules and a database. The modules are (i) instructor module, (ii) student module, (iii) help module, (iv) circuit recognizer module, and (v) speech module. The instructor module is used to administer VOLTA. The student module is a web-based graphical user interface. The help module in conjunction with the circuit recognizer and speech modules provides feedback to the students. VOLTA is implemented using Python (version 2.7.1) and Django (version 1.6.5)7.



**Figure 1.** An overview of the VOLTA architecture

The instructor module provides a flexible environment for an instructor or teaching assistant to administer the laboratory class. It authorizes students to access VOLTA. The instructor can update the lab contents via an administration panel. The instructor module also is used to upload supporting materials for the help module into the database.



**Figure 2.** VOLTA framework



**Figure 3.** Student Interface of VOLTA

Students interact with VOLTA using the student module. This module guides students through an experiment step-by-step. It evaluates student progress using pre-tests and post-tests that consist of multiple choice questions. The same set of questions were asked in pre- and post-tests. In post-tests, the multiple choice options were 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. A future release will incorporate a functional circuit recognizer for verification of the simulated circuit.

The hardware section provides instructions for building circuits on a breadboard. Students use a Digilent EE (Electronics Explorer) board8 (Digilent Inc., Pullman, Washington, USA) for the hardware implementation. 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. 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.

The results section contains guidelines for the contents of report. Students take a theory test and a laboratory test that are pre-lab and post-lab tests in the form of multiple-choice based questions. At any point of the lab assignment, the student can type questions related to the lab assignment in the dialogue box. The answers are fetched from the help module. Fig. 3 shows the interface used by the students.

The help module is one of the most important parts of VOLTA and is shown in Fig. 4. This module provides multiple sub-modules consisting of definitions of circuit terminology, questions and answers about basic circuit analysis, safety tutorials, tutorials on basic instrumentation and a forum for discussing problems. It works in conjunction with a circuit recognizer module and a speech module.



**Figure 4.** Help module

The circuit recognizer module is one of the more unique features of VOLTA. It helps students verify their simulated circuits and debug their hardware circuits. This module contains an image processing algorithm for automatic recognition of the circuit schematics. Fig. 5 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 processing performs background removal, contour filtering, and component recognition via template matching. Finally, the module outputs a schematic with labeled nodes, components with values, and an HTML formatted netlist (word description of the circuit). This module also aids the hardware debugging process by providing a trace guide.



**Figure 5.** Circuit recognizer module

III. Assessment Methodology

VOLTA was evaluated from two perspectives: usability and effectiveness. Usability focused on ease of use, effectiveness, efficiency, ease of learning, motivation and quality assurance. The assessment of effectiveness compared the focus group to a control group taking the traditional laboratory. We obtained IRB approval from Temple University (protocol number 22447).

Usability

The survey included 20 questions using a 5-point Likert scale (where 1 = strongly disagree and 5 = strongly agree) and 3 open-ended questions. The 20 questions covered seven broad categories:

1. Did the students think the VOLTA is useful for their learning? (Learning environment)
2. Did the students find the software motivating? (Motivational value)
3. Did the students find the VOLTA easy to use? (Ease of use)
4. Did the students perceive the usefulness of various features of the VOLTA? (Perception of usefulness)
5. Did the students “buy into” the virtual laboratory environment? (Authenticity of virtual learning)
6. What was the perceived quality of the VOLTA? (Quality assurance)
7. What additional features or learning situation the students would like to see in the VOLTA? (Expectations)

The usability evaluation data were collected through student surveys. Data was collected in Fall 2014 from sixteen 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 56% 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 44% of the students agreed that they enjoyed using VOLTA. In category C, three questions were asked regarding the ease of use of VOLTA. 63% of the students found VOLTA easy to use and 91% found it easy to navigate. However, the students felt that the use of VOLTA was less intuitive (44%). In category D, four questions were asked regarding what aspects of VOLTA’s features were helpful. 44% students found the help module useful, 69% students thought the VOLTA Youtube channel was useful, 50% found the lab results verification tool useful, and 19% found the forum feature useful. The students indicated that the instructional videos were the most helpful feature. In category E, two questions were asked regarding the authenticity of virtual learning. 50% students felt the labs seemed like a real lab. 37% students felt the teaching assistant was directly helpful. In category F, two questions were asked to assess the quality of the videos and the overall experience. In both cases, 69% students agreed the videos were of good quality and VOLTA was trouble free. In category G, two questions were asked about their expectations of VOLTA. 81% students expected a feature to verify their simulation results. 69% of the students expected a feature to ask human teaching assistants lab-related questions.

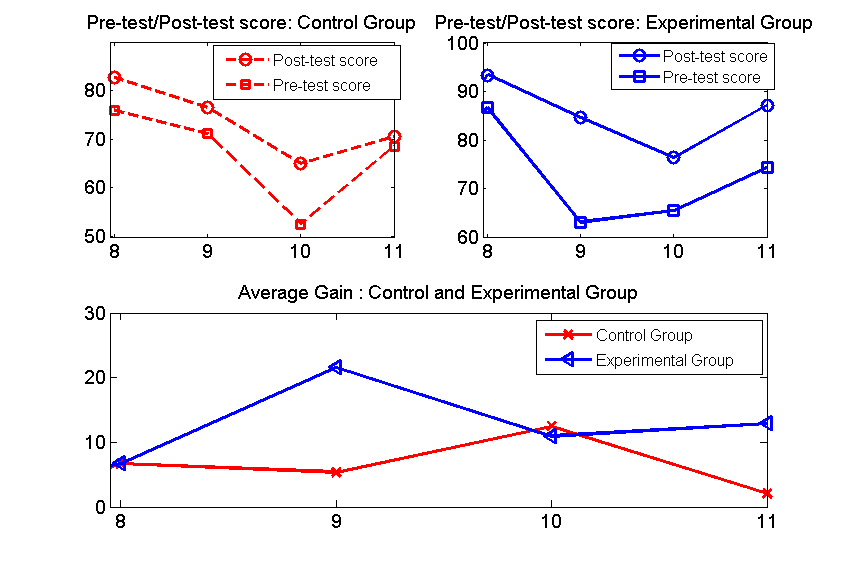
Effectiveness

The course was split into two sections. The students were randomly 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 VOLTA. The students in the control group received the traditional course curriculum. The effectiveness was assessed using gain score analysis of pre-test/post-test design9,10.

A total of 34 students participated in this study. The experimental group consisted of 16 students, while the control group consisted of 18 students. The experimental and control groups were taught different days and times of the week. A total of eleven lab assignments were performed in eleven weeks. In each 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.

A two-group pre-test/post-test design approach was used to evaluate the effectiveness of VOLTA. A major question guided the evaluation of effectiveness: Did the students who used VOLTA (experimental group) learn more than their counterparts in the control group (e.g. score higher on gain measures)? Gain score analysis was used to 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 on the gain scores of 34 students in 11 lab assignments. The ANOVA *p*-value was 0.17 indicating that the null hypothesis cannot be rejected if we consider a significance level of 0.05 (95% confidence interval). In other words, there is not sufficient evidence that the students taught by VOLTA performed better than their counterparts in the traditional labs. Our results are significant at an 80% level of confidence, which implies students who had access to VOLTA performed significantly better than their counterparts in the traditional labs.

During the course of the experiment, students were not told that the post-test grades will be used in their lab grade. Not surprisingly, they assumed that the pre- and post-test grades did not matter. Before lab 8, the experimental group was informed that the lab post-test results would be counted towards the calculation of their final grades. This reduced the *p*-value to 0.0117 and improved the experimental group performance significantly as shown in Fig. 6.



**Figure 6.** Pre- and post-test score from lab 8 to lab 11

IV. Conclusions

VOLTA is a framework for providing the students open laboratory environment with virtual teaching assistance. Compared to traditional closed laboratories, VOLTA provides a self-paced environment, on-demand help, and an increasing level of engagement. Our initial study shows a small improvement on students’ performance in the class conducted by VOLTA with a *p*-value of 0.17. When we announced that the post-test grades will count towards the laboratory grade the *p*-value decreased to 0.0117, which indicates a significant increase from the pre-test to post-test grades.

We are repeating the experiment in Spring 2015 using a more advanced version of VOLTA that includes a functional circuit recognizer, hardware assembly instructions and a richer help module. The circuit recognizer will verify the students’ simulated circuit. The hardware assembly instructions will be generated according to the multisim netlist. The help module is loaded with revised information about lab assignments. These two enhancements are designed to decrease user frustration thereby enhancing the user experience.

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