Experiential Learning through “Tangible” Lab Assignments for an Undergraduate Course in Electrical Circuits-I

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***Abstract*— “Experiential learning” as a method of delivering course material is well recognized at all levels of education including higher education. This project aims at introducing several laboratory experiments in a second-year engineering course in Electrical Circuits-I. These new experiments have light and sound as their input/output variables and thus referred to as “tangible labs”. The goal is to increase students’ engagement in the course and enhance their understanding of the electrical circuit concepts by allowing them to observe the operation of electrical circuits in a more tangible form. These experiments are designed to complement the existing laboratory experiments which are conventionally adopted in electrical circuit courses.**

Keywords—Engineering education, Electronics education, Experiential learning, Electrical circuit laboratory, Student engagement

I. INTRODUCTION

As an effective learning approach, experiential learning emphasizes learning through reflection on doing and has been widely applied in various education fields.

Playing an active role in the learning process can lead to students experiencing greater gratification in learning. Experiential learning encourages student to have first-hand experiences with the materials. Research indicated that participating in experiential learning activities can greatly increase student learning performance and shows a positive effect on student’s understanding of the learning content and concepts [1].

In relation to STEM concepts, tangible playful learning is a promising approach which allows learners to have a multisensory experience in relation to the concepts and facts of learning which are not easy to learn through the traditional ways, e.g., text books and lectures. Learning through tangible objects can help students to better understand the physical properties in STEM related subjects and address difficult problems in systemic settings [2]. In tangible learning, learner’s manipulation of information are enhanced through interacting with the objects physically [3].

In this article, we present the “experiential learning” component of the course “Electric Circuits-I”, a fundamental course for undergraduates majoring in Engineering Science at Simon Fraser University. The course in its status quo has a hands-on laboratory component. The project presented in this article, includes adding up to five new laboratory experiments referred to as “Tangible” experiments to the existing labs. We start by providing a more detailed literature review of “experiential learning” and “tangible playful learning” in Section II. Section III describes the objectives of the project and methodology in implementing it. In Section IV we focus on the main part of Phase I of the project, which is the design of tangible labs. Five tangible lab experiments are described in this section together with the conventional experiment related to each experiment. Finally, in Section V we briefly explain Phase II of this project which is currently ongoing.

II. LITERATURE REVIEW

A. Experiential Learning

In higher education, experiential learning focuses on directing learner experience in efforts to improve individual knowledge and the associated skills [4]. According to the constructivist experiential learning theory, concrete experience merged with cognitive practice and conceptual application is a foundation [5]. As Hoover & Whitehead [6] noted, experiential learning involves the responsible participants, and the cognitive, affective, and behavioral process of knowledge, skills, and attitudes.

The IEAust (Engineers Australia) requires that the graduate students from engineering programs should be able to demonstrate that they have mastered the necessary techniques and skills for practice in a complex environment [7]. Applying experiential, project-based learning in the program is one of the most effective ways to help students acquiring the skills to meet the competencies [8].

In [9], the authors studied the impacts of experiential learning on college student learning outcomes. The results suggested that experiential learning has positive effect in several aspects, such as improving higher order thinking in the senior year, enhancing overall educational experience, and increasing cognitive gains.

Ernst investigated the impacts of experiential learning on the cognitive achievement of preservice technology teachers [10]. The study results also showed some major benefits of experiential learning, including the hands-on nature, the real-world experiences, and the reinforcing of learning content.

Authors’ study in [11] showed that experiential learning helped guiding students to reach the correct solution and strengthen their understanding of course concepts through MATLAB exercises in a MOOC on communication systems. Hajshirmohammadi’s study of incorporating experiential learning in university engineering courses also received positive feedback from students [12].

In [13], the authors presented the design of the Light Up platform and noted that experiential learning enables students to be able to look inside everyday consumer electronics to figure out how things worked. This learning experience allows students to learn about powerful ideas in engineering and mathematics dynamics, and help students to better understand the complex systems in a tangible constructionist way.

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B. *Tangible Playful Learning*

According to Hornecker & Buur, tangible interactive learning encompasses a broad range of systems and interfaces and builds upon learning approaches from different disciplinary areas [14].

Nedic, Nafalski, and Machotka showed that: 1) Students are highly motivated in participating in experiments that applies newly acquired knowledge and skills to create tangible products; 2) Tangible laboratory projects encourage students to further their studies of related learning contents later in their program; and 3) Students are strongly motivated to build an artefact, to explore the working principal behind it and the reasons why the task is carried out in that specific way [15].

As a common application of Tangible User Interfaces (TUI) in education, tangible programming languages allow users to express algorithms without learning complex language syntax. With tangible programming languages, novice learners with no technical background can also do coding through physical interactions with the user interfaces and/or collaboration with other users [3].

As Jong, Linn, and Zacharia argued, according to theories of embodied cognition, taking advantage of tactile information that fosters the development of conceptual knowledge is a big affordance of physical laboratories [16].

III. Objectives and Methodology

This project includes the design and implementation of several new laboratory experiments, referred to as "tangible labs". These tangible labs include elements of "light" or "sound" as part of their design. In other words, the operation of the circuit and/or the effect of changing parameters within the circuit, can be observed through changes in these variables. The goal of this project is to increase students' engagement in the course and enhance their understanding of electrical circuits. This is done by transformation of electrical energy, which can only be measured or observed in abstract form using devices such as multimeter and oscilloscope, to tangible forms of energy, i.e., light and sound. It should be noted that the tangible labs are designed to complement the existing conventional methods of experimentation, not to replace them. Scientific measurement and analysis of electrical circuits is still required to be performed using measurement devices and not just by sensory observations of the results.

A. *The Research Questions*

The study aims to address these research questions: How does adding tangible labs affect students' interest and engagement in the course? What is students' perception of how tangible labs affect their interest and engagement in the course? How does adding tangible labs affect students' learning? What is students' perception of how tangible labs affect their learning?

B. *Method and Procedure*

The project will be implemented in two phases. Phase I consists of the design and testing of new tangible labs. This phase is now complete and is the focus of the rest of this article.

Phase II consists of implementing the new tangible labs as part of the course assignments. While these new labs are to complement the existing conventional labs and not to fully replace them, adjustments need to be made in order to accommodate the new tangible labs considering time limitations and volume of various course activities. Once the new labs are implemented in the offering of the course, data will be collected to answer the above research questions. The data will be collected in two ways: 1) observing students' activities during lectures and labs, and measuring parameters such as attendance and active participation in course activities, 2) administrating a students' survey at the end of the semester.

C. *Implications*

The idea presented in this study can be applied to various STEM courses with a lab component. The findings may enrich the relating academic literature.

IV. Tangible Laboratory Experiments

A total of five Tangible lab exercises were designed. These experiments all have audio or visual signals as input and/or output, thus provide students the opportunity to see the operation of the circuits in a more real life format as compared with when signals are only available in form of voltage and current and measurable only by using a multimeter or an oscilloscope. These experiments are related to electrical circuits topics such as resistors in series and parallel; operational amplifiers (op-amp), natural and step response of RC circuits, and filters.

As mentioned before, the tangible lab exercises are not designed to replace the existing traditional lab exercises but rather to complement these exercises by increasing students' engagement in the activities and thus improving their understanding of the topics.

These experiments are described below. For each experiment the existing (conventional) lab exercise is briefly described under the subtitle "*Conventional Experiment*" and the related tangible lab exercise is described under the subtitle "Tangible *Experiment*".

A. *Resistors in parallel and series*

Conventional Experiment

Students construct a resistor network and measure various voltages and currents in order to verify Kirchoff's Current/Voltage Laws (KCL and KVL) as well as voltage and current division through resistors connected in parallel and series as shown in Fig. 1. The resistive circuits are constructed on breadboards, with typical ceramic resistors. Voltages and currents are measured using a Digital Multi Meter (DMM). Students verify KCL, KVL, and effect of resistors in parallel and series using these measured values.

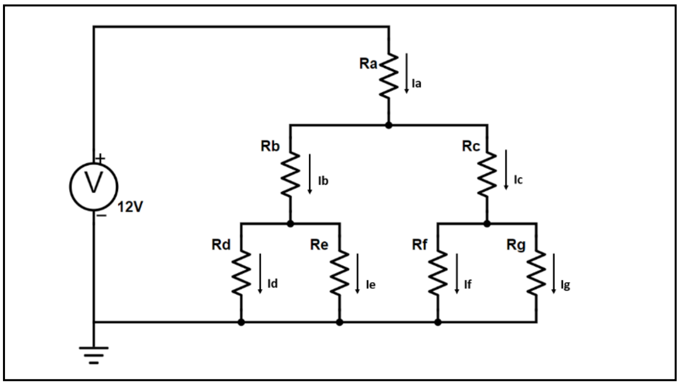

Fig. 1. Conventional circuit for study of resistors in series and parallel

Tangible Experiment

This experiment uses identical incandescent light bulbs to provide a visualization of effect of resistors in series and parallel. Incandescent bulbs act quite close to linear resistors. When electric current flows through the filament of the bulb, electric power is transformed to heat and light emitting from the filament. Although the relationship between luminosity and current (or power) is highly non-linear and beyond the scope of this course, it is correct to assume that larger current flowing through the light bulb results in higher luminosity of the bulb, as long as the current is within the operation range of the bulb. Thus, through this experiment students will visually observe how current and voltage are divided when resistors are connected in series or parallel by observing the brightness of the bulbs in various configurations.

Students construct three simple circuits on the same breadboard. The first circuit is the benchmark circuit consisting of one light bulb connected to the voltage source (Fig.2-a). The second circuit consists of three bulbs connected in series (Fig. 2(b), Configuration 1). The third circuit consists of one bulb connected in series with the parallel combination of two bulbs (Fig. 2(c) Configuration 2). All circuits are supplied with the same value of DC voltage. By lighting up circuits 2(b) and 2(c) and observing the luminosity of the light bulbs in comparison with each other and with that of the benchmark light bulb, students can observe the effect of these configuration on division of voltage/current (Fig. 3).

B. Operational Amplifiers

Conventional Experiment

In this exercise students conduct a number of experiments in order to verify the open loop and closed loop characteristics of simple Operational Amplifier (Op-Amp) circuits. The Op-Amps used are of the TL07X series.

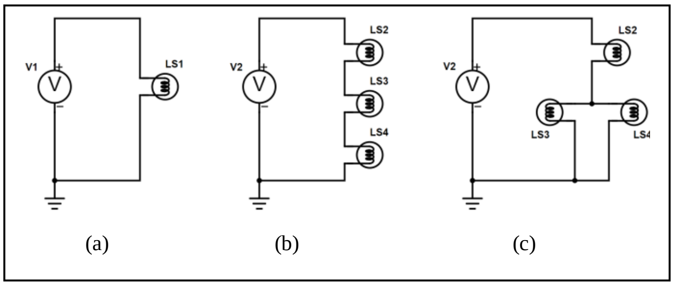

Fig. 2. Tangible lab for visualizing the effect of resistors in parallel and series. (a) Single light bulb as benchmark, (b) Configuration 1, (c) Configuration 2

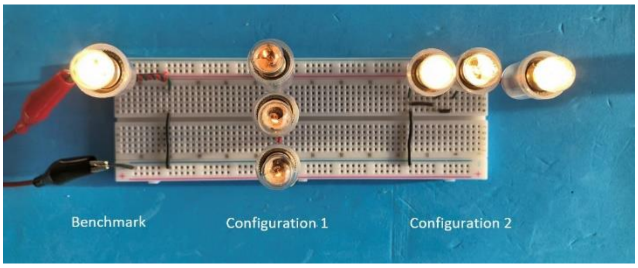

Fig. 3. Configurations 1 and 2 in comparison with the benchmark circuit

In this exercise students conduct a number of experiments in order to verify the open loop and closed loop characteristics of simple Operational Amplifier (Op-Amp) circuits. The Op-Amps used are of the TL07X series.

For the closed loop Op-Amp operation students construct a typical inverting amplifier circuit as shown in Fig. 4. They choose R1 and R2 resistors for a gain of around five. After powering up the Op-Amp with DC power supply, an input sinusoidal signal is applied to the circuit and the input and output signals are observed on the oscilloscope. Students make measurements to verify the amplification factor of the inverting amplifier.

Tangible Experiment

In this part the same inverting amplifier is modified into an audio amplifier as shown in Fig. 5. The modifications include adding a microphone to the front end of the circuit, an audio connector to the back end of the circuit, and replacing the feedback resistor with a variable resistor. Students then play a low volume audio clip close to the microphone of the system and listen to the output of the amplifier by connecting the audio connector to speakers or personal headphones. By changing the value of the variable resistor, they can hear the changes in the volume level at the output of the circuit. A video demonstration of the experiment can be viewed at the following link: https://youtu.be/rMpn4moWRUM

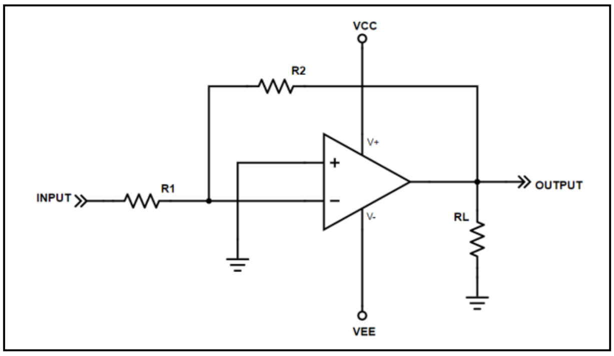

Fig. 4. Conventional circuit for study of the inverting amplifier

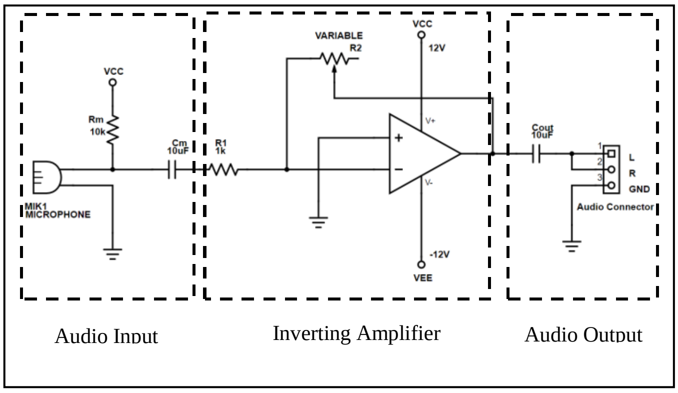

Fig. 5. Tangible lab circuit for an audio amplifier

C. RC Natural and Step Responses

Conventional Experiment

Students construct a simple RC circuit as shown in Fig. 6(a). The circuit is designed with a time constant of around 10(µs). A square waveform with 50% duty cycle and voltage values of zero and 5 (V) is applied as the input signal. The frequency is chosen such that the capacitor has enough time to fully charge and discharge during each half period of the signal. By observing the input and output waveforms on the oscilloscope students can see the Step and Natural responses of the RC circuit. They also make measurements to calculate the time constant of the circuit and compare with theoretical results.

Tangible Experiment

To provide students with a visual experience the same RC circuit is modified as shown in Fig. 6(b). Two LEDs connected in parallel and with opposite polarities are connected in series with the RC circuit. At the beginning of each half period of the square waveform, one of the LEDs will turn on instantaneously and turn off gradually, following the exponential rate of charging or discharging of the capacitor. The important design step here to increase the time constant of the circuit such that the operation of the LEDs is visible to humans. A capacitor of 470 (µF) is provided to the students and they are asked to find the appropriate value for the resistor. Students can also view the low frequency input/output signals on the oscilloscope observing the exponential trend of the response of the RC circuit as well as the voltage drop across the LEDs. A video demonstration of the experiment can be viewed at the following link: https://youtu.be/gfh2cLTp0qQ

D. Relaxation Oscillator

Conventional Experiment

The Relaxation Oscillator uses a simple circuit to generate AC voltage (square wave) by using only DC voltages to power up the circuit. Students construct the circuit as shown in Fig. 7(a). They design the circuit to achieve a given frequency of output oscillation. They observe the output voltage of the oscillator on the oscilloscope and make appropriate measurements to compare with theoretical results.

Tangible Experiment

The modification here is by adding a parallel combination of two LEDs in series with R1 as shown in Fig.7 (b). The resistor and capacitor values should also be modified in order to bring down the frequency of oscillation to around 1 Hz, so the blinking of LEDs is visible to human eyes.

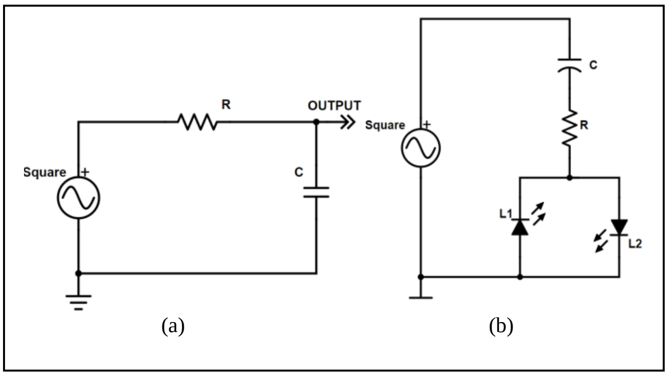

Fig. 6. RC Circuit (a) Conventional lab circuit (b) Tangible lab circuit

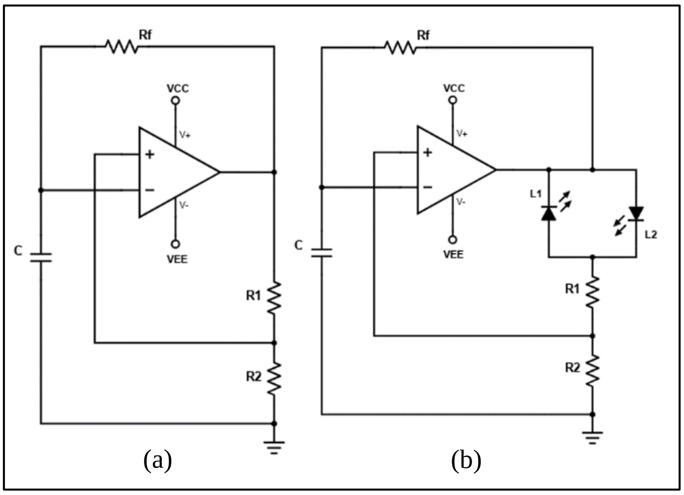

Figure 7. Relaxation Oscillator (a) Conventional lab (b) Tangible lab

E. Traffic Light Sensor Simulator– Filters

Conventional Experiment

Students construct low pass, high pass, and band pass filters using resistors, capacitors, and inductors. They then study the frequency response of the filter by providing sinusoidal signals of various frequencies as the input to the circuit, and observing and measuring the output signal on the oscilloscope. An example the RLC band pass filter is shown in Fig. 8.

Tangible Experiment

In this experiment students learn about the type of traffic light sensors that use a loop inductor as part of their sensor circuit to detect the presence of a vehicle at the intersection [17]. They then construct the circuit shown in Fig. 9, which is in fact a band stop filter. For this experiment students use inductors that they build in the lab by winding enameled wire around a plastic hollow tube. Students measure the capacitor and inductor values to calculate the resonance frequency of their circuit. If the function generator is set to this frequency the impedance of the LC circuit is theoretically equal to infinity and thus no current should flow to the LEDs. In practice this may not be exactly the case, so students will adjust the frequency of the function generator around the resonance frequency until they get the lowest possible intensity in the LED lights. This mimics the sensor circuit when no vehicle is present. By taking an iron or steel rod and pushing it inside the hollow core of the inductor, the inductance will increase, the impedance of LC combination will decrease and thus the LEDs will light up, mimicking the condition when a vehicle arrives at the traffic light intersection. A video demonstration of the experiment can be viewed at the following link: https://youtu.be/x4r_aPPtr1U

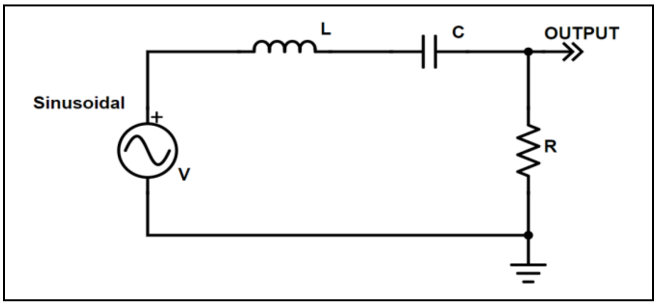

Fig. 8. Conventional lab for an RLC high pass filter

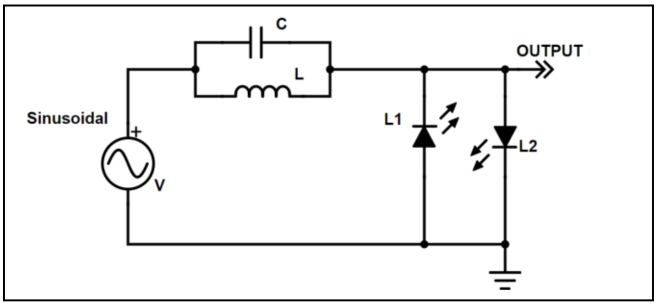

Fig. 9. Tangible lab simulation of a traffic light sensor using a band pass filter

V. FUTURE DIRECTIONS

In addition to design and testing of tangible labs during Phase I of this project, data was also collected on students' engagement and involvement in active learning while the status quo of the course was unchanged. In Phase II of the project, adjustments will be made to the current lab assignment in order to include the newly designed tangible labs. In a similar approach to Phase I data will be collected for comparison with data from Phase I. These results will be shared with the academic community in future communications.

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