

DEVELOPMENT OF A SUITE OF VIRTUAL EXPERIMENTS FOR PHYSICS AND CHEMISTRY UNDERGRADUATE LABORATORIES

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Abstract

Remote Labs have been able to provide students and instructors with the avenue to perform experiments anytime. Several virtual laboratories are readily available on the internet some of which were also developed by the iLab OAU team. However, most of the virtual laboratories developed are focused on desktops and also require the installation of one or two plugins for runtime for the execution.

Inadequate funding and lack of equipment are the bane of undergraduate laboratory practice in Physics and Chemistry. If it is possible for students to have virtual equivalents of these experiments, they can easily perform them on-line thereby increasing their understanding and speed of completion if and when they get to the real lab.

Using Physics and Chemistry laboratory manuals of freshmen at a university, the authors have developed virtual laboratories for selected experiments. These include Calorimetry (Specific Heat Capacity and Latent Heat of Fusion of Ice), Ohm's law, pH measurement and Acid-base Titration. This work involved a synergy of faculties in Physics, Chemistry, Electronics and Computer Engineering. This paper presents three of the developed experiments. The idea is to eventually upgrade all of the designed experiments in the future to a MOOCs suite that a number of universities can use.

Introduction

In the study of science, experiments are indispensable for development of skills to deal with physical processes and instrumentation. Experiments are performed to verify the theories

taught in class, analyze systems and ultimately translate laboratory experience into real life applications. The use of traditional laboratories has been adversely affected over time as a result of the rising cost of laboratory equipment and the increasing number of students enrolling into schools [1]. As the number of students participating rises, there is a need for a complementary provision of platforms for experiments to be performed or at least to perform them with a close replica of the actual laboratory experience.

Virtual laboratories are software applications that use the theory behind the experiment to model a laboratory setting. Virtual laboratories have a number of advantages. First, with virtual laboratories, the student can repeat a particular experiment multiple times with different parameters to observe different scenarios [2] with, relatively, no extra cost per performance of the experiment. Secondly, and this partly derives from the above, virtual laboratories allow students to learn from failures that may arise without causing any real damage to systems. Learning from failure is one of the objectives for engineering education as defined by ABET [3]. Another benefit of virtual laboratories is that they can be adapted to Open On-line Courses for several students in different locations, hence opening up to the benefits of Massive Open On-line Courses (MOOCs).

Many emerging technologies have been used to develop laboratories. Recent research has indicated the use of techniques and software such as LabVIEW and Matlab/Simulink, Java applet, Flash, Ajax etc [4]. However, many of these laboratories require the user to have one software or the other installed on their systems before using the laboratories.

To solve this problem, the work reported here not only develops virtual laboratories for undergraduate experiments but also uses a technology which is readily available on most browsers and does not require any pre-installation by the user. This helps to bring the laboratory experience as close as possible to the users.

Developing the Virtual Laboratories

Two points which were borne in mind during the development process of the virtual laboratories are as stated by Dr Mark Schulz in his paper[5]:

1. Not all experiments are well suited to being performed online and some are more so than others.
2. Remote experiments cannot completely replace traditional laboratories. They cannot completely deliver the traditional laboratory experience but can be very useful in cash-strapped institutions as well as in well-funded institutions for additional student exercises.

Intricate to making a virtual laboratory is pedagogy. A virtual laboratory is simply a model of a traditional (physical) laboratory. As with every model, the virtual laboratory only represents the "essential characteristics" of the traditional laboratory. The most essential characteristic of any laboratory is its pedagogy i.e. the aim of the experiment and the skills the student is expected to learn by performing the experiments. For example, in a titration experiment, while the student is expected to be able to identify colour change and hence the point at which to stop the titration, there is little or no pedagogic value in the student knowing how much force he would need to turn off the tap of the burette. Hence, in modelling a titration experiment, mouse clicks or arrow keys on the keyboard can be used to open and close the burette's tap but good graphics or a webcam must be used to show the colour of the solution in the conical flask during the titration process.

Once the pedagogics of the laboratory had been sorted out, technical / technological issues were then taken into account. These included issues like which online technologies to use and how much required bandwidth would be acceptable. Research has shown that there is pedagogical value in implementing a realistic virtual laboratory interface[6]. Presenting a realistic interface hence meant taking a careful look at graphics. The technical / technological issues were thus divided into two major parts: Graphics and Programming

Technologies Used for Design Process of the Virtual Laboratories

To provide the ease of use of virtual laboratories across various devices and platforms, the authors employed HTML5 which is a technology readily available on most browsers alongside JavaScript that has contributed immensely to interaction on the web. [7] HTML5 also makes it possible to have one lab which works both on desktop and laptop computers as well as all mobile devices[8]. Other technologies which have been used to create lab clients include ASP.net, C#, Java,[9] LabVIEW[10,11], MATLAB[12] and Adobe Flash[13]. There are also a plethora of software which are used for developing native apps for mobile devices, apps based on iOS, Android and Windows Phone 8 operating systems[8,14,15].

Construct 2 which is an HTML5 based multimedia content creator developed by Scirra Limited was used in the development. Construct 2 provides an easy to learn drag and drop programming platform with the use of a visual editor and a behaviour-based logic system[16]. Development in Construct 2 is achieved with the use of behaviours and event systems which allows the developer to think logically and grasp real programming concepts easily[17]. Flexibility and extensions can be achieved with the use of third-party plugins and those created by the developer himself with the use of the available JavaScript SDK[16]. Some of the available objects and plugins (built in and third-party) in Construct 2 are shown in Figure 1.

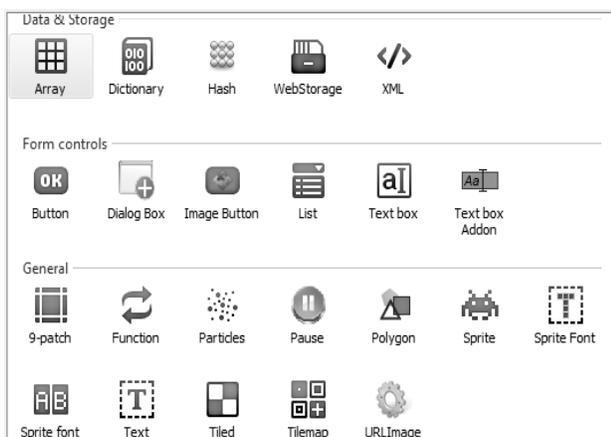


Figure1: Construct 2 with built in and third-party plugins.

Graphics

In order to make the graphics interface as realistic as possible, the favoured ways of obtaining images for the developed labs could be to take pictures of actual laboratory setups or to download open-source images of the apparatus from the internet. Images can however also be drawn using Photoshop and CorelDraw.

Image sizes are a main concern in virtual laboratories as large image sizes means large application sizes which requires a larger bandwidth to perform the experiments or else long times for the loading of the images. On the other hand, small image sizes generally mean low image resolutions which can greatly reduce the pedagogical value of the virtual laboratory.

Programming

The programming component is the functionality component. Here, the logic for the virtual laboratory was developed while constantly referring to the pedagogics of the traditional laboratory being modelled. Layouts and event sheets were created using the Construct 2 tool and then testing and debugging of the developed suite was done.

The Developed Virtual Experiments

We will now present three of the developed virtual experiment suites, which are associated with physical first year labs in Physics and Chemistry.

Acid-Base Titration Experiment

Titration is a process by which the concentration of a solution (called the analyte or titrand) can be calculated by use of another solution of known concentration (called the titrant or titrator). Titration is the process of adding a measured volume of the analyte to a known volume of the titrant until full reaction has taken place between these two solutions. This point of full-reaction is often found by observing the colour of an indicator which has been added to the titrant before the titration started. In acid-base titration, an acid is placed in the burette and is added to a base in a conical flask until the solution in the conical flask has been neutralized. The concentration of the analyte can now be found using equation (1).

$$C_A V_A = C_B V_B \dots \dots \dots (1)$$

where:

- C_A is the concentration of the acid solution used
- V_A is the volume of the acid
- C_B is the concentration of the base
- V_B is the volume of the base

While the above is accurate, it should be noted that the base in the conical flask can as well be the analyte in which case titration would involve adding a measured volume of an acid of known concentration (titrant) to a known volume of a base of unknown concentration (analyte). Equation 1 still holds true in this case.

Apparatus: Burette, Beaker, Pipette, Conical (Erlenmeyer) flask, Retort stand

Materials: Titrant, Analyte, pH indicator

Procedure:

1. The burette is placed on the retort stand.
2. The burette is filled with the acid.

3. The beaker is filled with a known volume of the base solution.
4. The pipette is used to take a known volume of the base solution from the beaker to the conical flask
5. A few drops of the indicator are added to the base solution in the conical flask.
6. The conical flask containing the base-indicator mixture is placed beneath the burette on the retort stand.
7. The tap on the burette is opened to titrate while carefully watching the solution in the conical flask for a colour change which would indicate the solution has been neutralized.
8. At the point of neutralization, the tap is closed.
9. The volume of the acid used is recorded.
10. Calculation of the unknown concentration is done using equation (1).

The Developed Virtual Acid Base Titration Experiment: The graphic design of this experiment was broken down into three modules (shown in Figure 2). Each module was handled by a different layout.

Figures 3 to 5 show some screenshots in the graphic representation of the experiment.

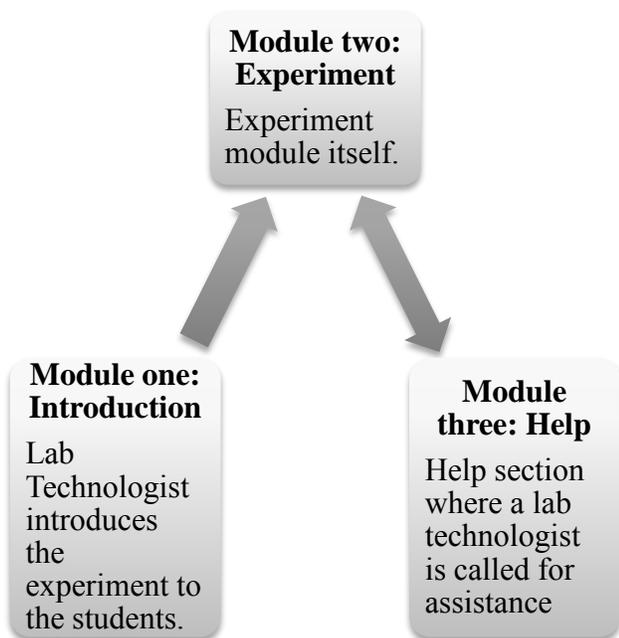


Figure 2: Modules of the Titration lab suite.



Figure 3: A Screenshot showing the laboratory technologist introducing the experiment(module 1).

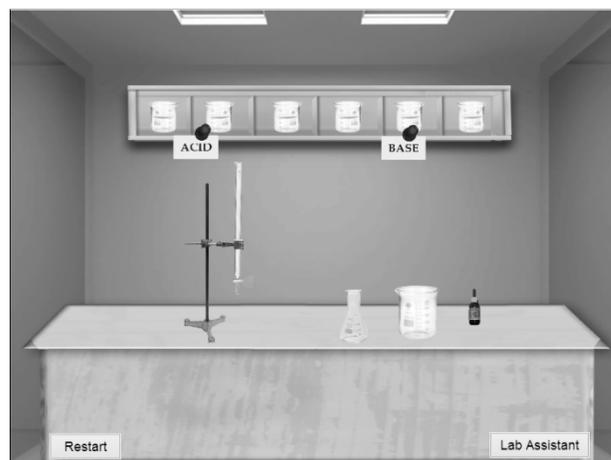


Figure 4: A Screenshot showing the beginning of the acid-base titration (module 2).

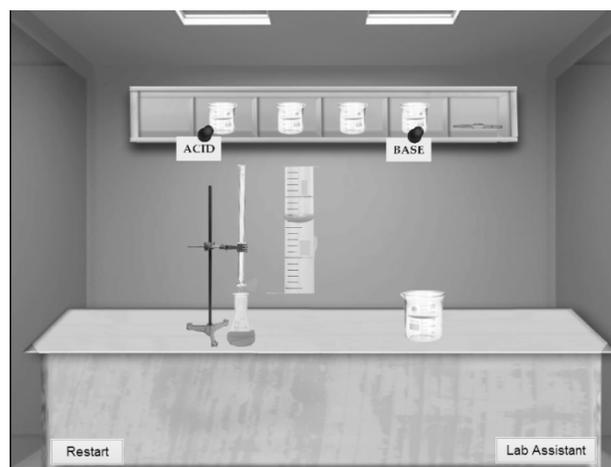


Figure 5: Screenshot showing the end point of the acid-base titration (also module 2).

The complete virtual experiment for the titration experiment can be found at the following site: <http://ilabs1-titration.appspot.com>.

Measurement of Specific Heat Capacity

Calorimetry is the measurement of the flow of heat energy into or out of a system. While heat flow may be difficult to be directly measured, its effect (temperature change) can easily be measured. We indirectly measure heat flow by measuring the change in temperature in a system. A change in the temperature of a substance is an indicator of heat having flowed into or out of a substance. Hence, heat flow can be measured by measuring the amount of temperature change a substance undergoes given that the mass of the substance and the specific heat capacity of the substance are known.

Calorimetry is done by using a device called a calorimeter. Using a calorimeter, heat flow can be calculated using equation (2).

$$q = mC\Delta T \dots\dots\dots(2)$$

where

q is the amount of heat that flowed

m is the mass of the substance

C is the specific heat capacity of the substance

ΔT is the change in temperature of the substance

Apparatus: Calorimeter, heater, digital scale, thermometer

Material: Water, metal samples (with known specific heat capacities).

Procedure

1. The mass of the empty calorimeter is measured and recorded.
2. The calorimeter is filled about half way with water.
3. The mass of the half-filled calorimeter is measured and recorded.
4. The mass of the water in the calorimeter is now calculated.

5. The temperature of the water in the calorimeter is measured.
6. A metal sample is selected from the available samples
7. The mass of the selected sample is measured and recorded.
8. The sample is heated to about 100°C.
9. The heated sample is transferred to the calorimeter filled with water.
10. The thermometer is watched until a steady temperature is attained.
11. The change in temperature is computed and then the heat flow is computed using equation (2).

The Developed Specific Heat Capacity Experiment:

The experiment was set up with five major layouts which handled all the procedures. Each layout is made up of a lab assistant with guidelines on how to navigate the layout. At the end of the experiment the necessary details and standard parameters needed are provided for the student. Figures 6 to 9 show some screenshots of the Specific Capacity Experiment.

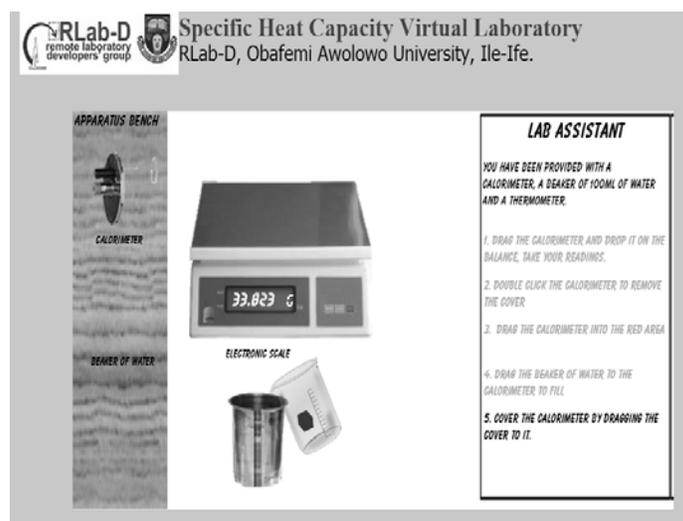


Figure 6: Screenshot showing filling of calorimeter with water (Step 2 of the experiment procedure).

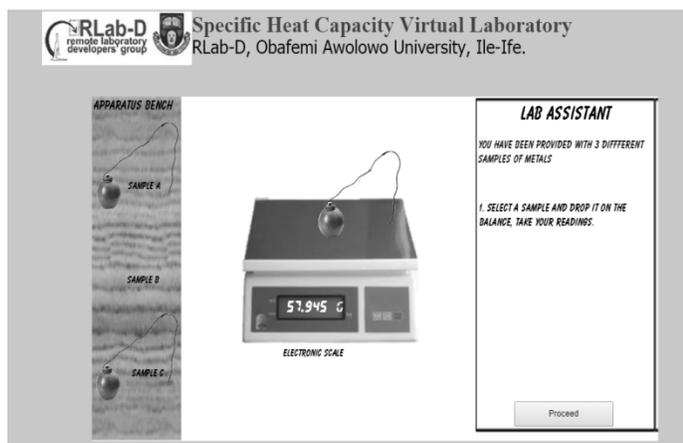


Figure 7: Screenshot showing measuring of the mass of selected metal sample B (Step 7 of the experiment procedure).

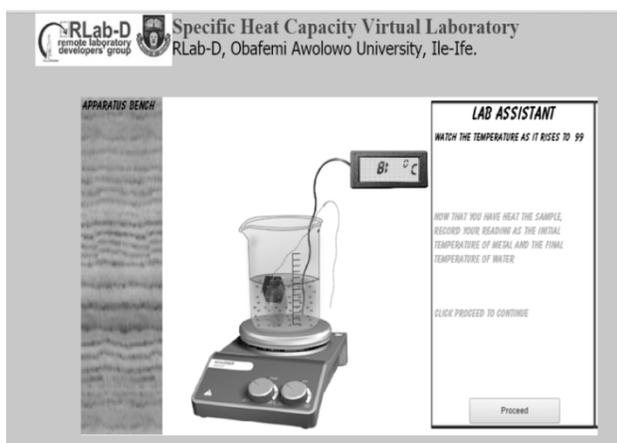


Figure 8: Screenshot showing heating of sample (Step 8 of the experiment procedure).

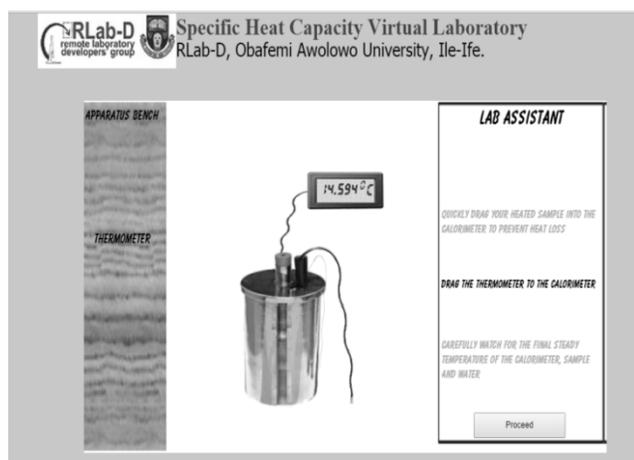


Figure 9: Screenshot showing taking of the final steady temperature reading (Step 10 of the experiment procedure).

The complete virtual experiment for the specific heat capacity experiments can be found at the following site: <http://ilab-heatcapacity.appspot.com>.

Latent Heat of Fusion of Ice

Latent heat of fusion is the heat which melts a solid at its melting point without raising its temperature. The word latent comes from the fact that though the heat is being applied to the solid, its temperature does not rise (hence, the heat seems to be "hidden"). Instead, the solid melts. This only occurs at the solid's melting point.

The amount of heat needed to melt a solid at its melting point (latent heat of fusion) is dependent on the mass of the solid. Equation (3) gives the relationship between the heat absorbed by the solid and the latent heat of fusion.

$$Q = ML_f \dots\dots\dots (3)$$

where

Q is the amount of heat absorbed by the solid,
 M is the mass of the solid
 L_f is the latent heat of fusion.

Apparatus: Calorimeter, heater, digital scale, thermometer

Material: Ice, water

Procedure

1. The mass of the empty calorimeter is measured and recorded.
2. The calorimeter is filled about half way with water.
3. The mass of the half-filled calorimeter is measured and recorded.
4. The mass of the water in the calorimeter is now calculated.
5. The temperature of the water in the calorimeter is measured.
6. Several dry pieces of ice are added to the calorimeter until the temperature of the mixture is between 5-10⁰C below room temperature.

7. When all the ice has melted the equilibrium temperature is measured and recorded.
8. The new mass of the calorimeter (plus water plus water from the melted ice) is measured.
9. Equation (3) is used to compute the latent heat of fusion of the ice.

The Developed Latent Heat of Fusion Experiment:

The experiment was set up with four major layouts which handled all the procedures. Each layout is made up of a lab assistant with guidelines on how to work through the layout. At the end of the experiment the necessary details and standard parameters needed are provided for the student. Figures 10 to 12 show some screenshots of the Latent Heat of Fusion Experiment.

The complete virtual experiment for the latent heat of fusion experiments can be called at the following site: <http://ilab-latentheat.appspot.com>.

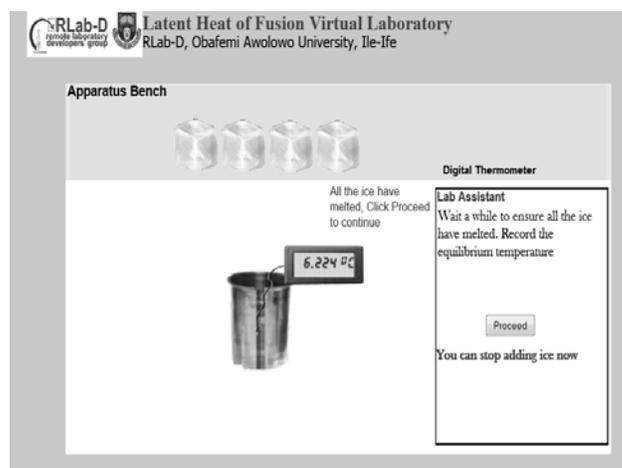


Figure 11: Screenshot showing the student taking temperature reading after all ice has melted (Step 7 of the experiment procedure).

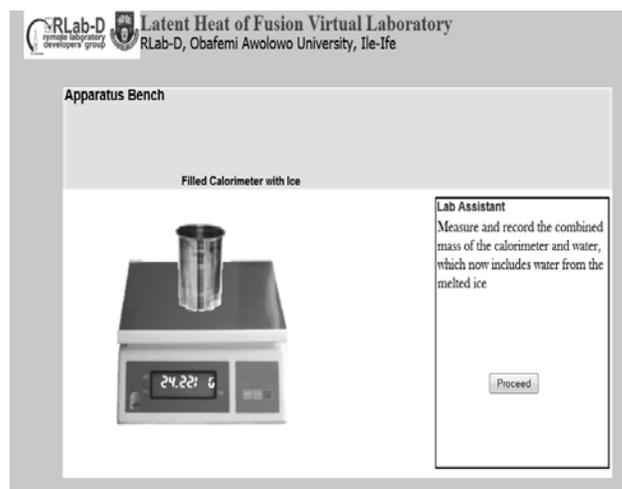


Figure 12: Screenshot showing the student taking reading of calorimeter with water including water from melted ice (Step 8 of the experiment procedure).

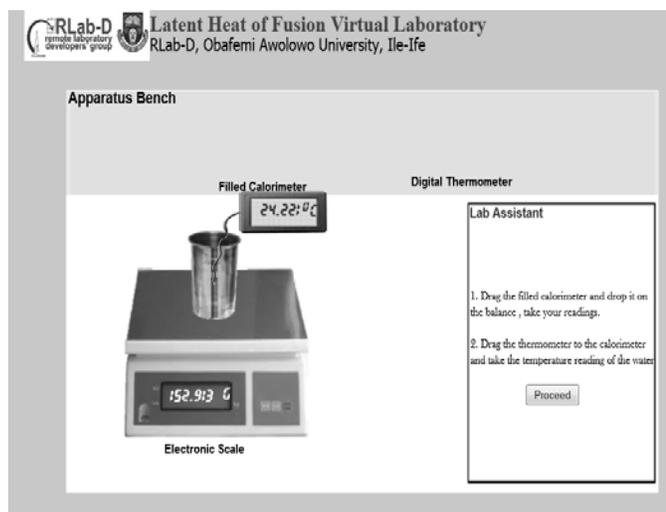


Figure 10: Screenshot showing the student taking temperature reading of water (Step 5 of the experiment procedure).

Basic Electronics

This experiment provides the student with the opportunity to make various circuit connections and use a digital multi-meter to take various readings as required. The laboratory contains three experiments namely:

a. Ohms law verification: This uses a simple circuit to demonstrate Ohms Law. That is, the relationship between voltage, current and resistance.

b. Series connection: Here, two resistors are used to illustrate the effect of variation of the value of one resistance on the voltage across the individual resistors and its relationship with the total voltage across the circuit.

c. Parallel connection: Here also, two resistors are used to illustrate the effect of variation of the value of one resistance on the current flowing through the individual resistors and the relationship with the total current flowing in the circuit.

The student is provided with a set of questions after each of these experiments to test that there is a good understanding of the concepts as illustrated by the laboratory manual used in developing these laboratories.

Equation (4) represents Ohms law which shows the relationship between voltage, current and resistance in a circuit. Equation (5) and (6) also shows the total resistance in a circuit with more than 1 resistor connected in series and parallel respectively.

$$V = IR \dots\dots\dots(4)$$

where

R is resistance of Resistor,
 V is the voltage across the resistance R ,
 I is the current through the resistor.

$$R_T = R_1 + R_2 + \dots + R_N \dots\dots\dots(5)$$

where

R_T is total resistance of a series circuit.
 R_1 to R_N are the resistances of the individual resistors in series.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_N} \dots\dots\dots(6)$$

where

R_T is total resistance of a parallel circuit.
 R_1 to R_N are the resistances of the individual resistors in parallel.

The procedure for carrying out the basic electronics laboratories is quite similar for each experiment except for little differences depending on the specified exercise. The general procedure is:

1. The battery and resistor are connected accordingly to complete the circuit.
2. The value(s) of the resistors are set as desired.
3. The multi-meter is turned on and set to the appropriate position to take voltage readings.
4. The probe is connected across the resistors to take the voltage reading.
5. To take resistance reading the multi-meter is also set to the appropriate position.
6. To take a current reading, the circuit is broken at particular point to make room for connection of the multi-meter in series with the circuit.
7. The multi-meter is also set to the appropriate position to take the current reading.
8. Equations (4) to (6) are used to find the voltage, current or total resistance depending on the experiment being carried out.

The experiment suite provides the student with a help option, which gives information on how to navigate the experiment, and an exercise option which contains problems for the students to solve after carrying out the experiment. Figures 13 to 15 are screenshots showing different instances during the experiment.

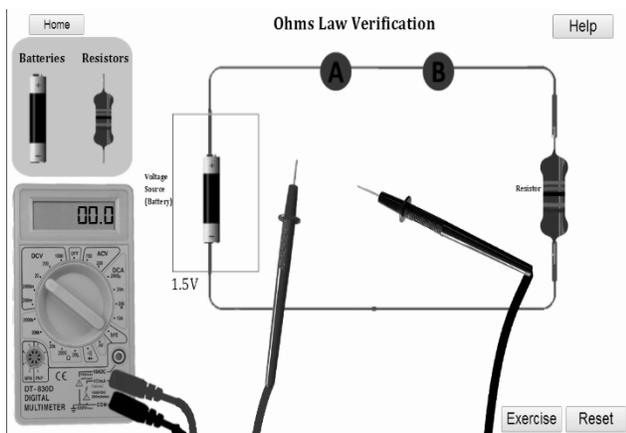


Figure 13: Screenshot showing the student completing the circuit for Ohms Law verification (Step 1 of the experiment procedure).

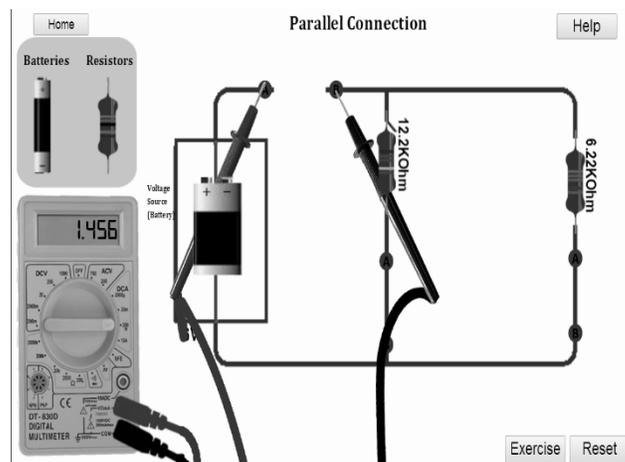


Figure 15: Screenshot showing the student taking current reading for the parallel resistance experiment (Step 6 of the experiment procedure).

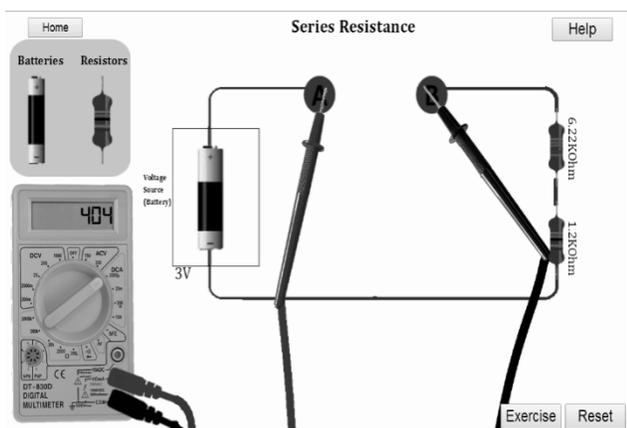


Figure 14: Screenshot showing the student taking current reading for the series resistance experiment (Step 6 of the experiment procedure).

Lab Assessment

Assessment I

This involved the assessment of the labs developed for Physics and Chemistry. The laboratories are the specific heat capacity, specific latent heat and titration laboratories. In order to improve the interface and functionality of the developed laboratories and also to get a general overview of these lower level students' responses to the virtual laboratory, an initial quick general survey was carried out using 25 first year students from different Science and Engineering departments at the Obafemi Awolowo University.

In the survey, after carrying out the virtual experiment, students were asked to respond to the following 5 questions using a 5-point scale where 1 was bad and 5 was excellent:

1. How well did the lab communicate the supposed experiment?
2. How was the user experience?
3. Have you performed the experiment in a real laboratory before? If yes, how well does the virtual lab compare to the real lab?
4. How easy was it getting your way around the lab?
5. How appealing was the lab interface?

Students' overall responses are shown in Table 1.

Table 1: Students' assessment of the virtual lab.

	1 (Bad)	2	3	4	5 (Excellent)
Question 1	2	5	5	7	6
Question 2	2	3	6	9	5
Question 3	No:2				
	Yes:23	3	5	4	5
Question 4	3	5	1	9	7
Question 5		3	8	9	5

A general comment section was also provided for the students. From this section it was obvious from the various comments, that the virtual experiment was a new experience for most of the students, the experience was however a good one as most of them are looking forward to it being a full part of their curriculum. While this initial assessment looks rather positive, it is inconclusive due to the few number of students involved and the fact that the work is still ongoing.

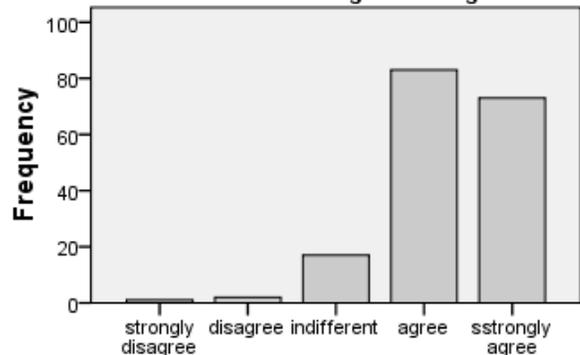
It is planned to include these experiments as part of the laboratory coursework for the students in the next sessions. The students would be expected to use the virtual laboratories as a support to the real laboratories for the upcoming session. The results and report prepared from these experiments would also be graded. Finally, each student would be expected to provide feedback after performing the experiment, to help improve the laboratories further.

Assessment II

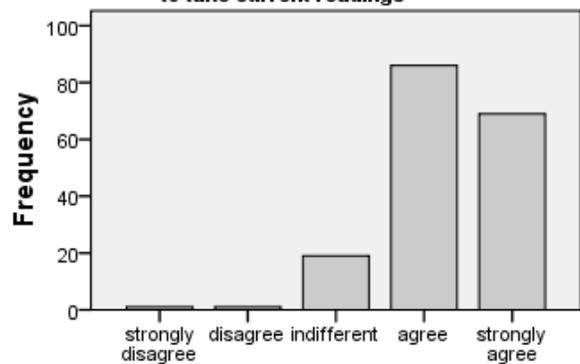
This assessment was for the three experiments under the ohms law laboratory. 180 student responses were analysed to get results and inferences. Several questions reviewing the pedagogy, learning experience, quality of interface, comparison of real and virtual experiments amongst other were asked. Various analyses of the results are illustrated below.

Learning Experience

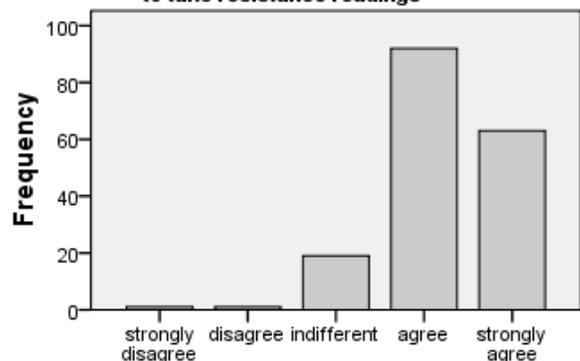
I got a better understanding of how to use the Multimeter to take Voltage Readings



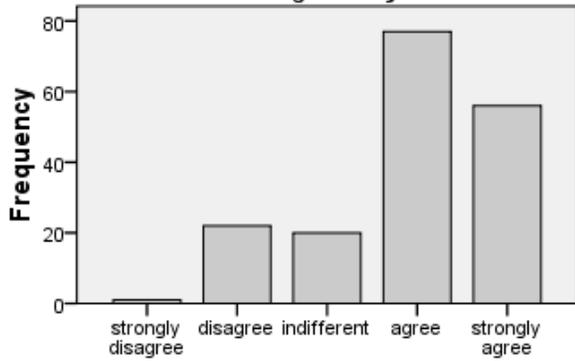
I got a better understanding of how to use the multimeter to take current readings



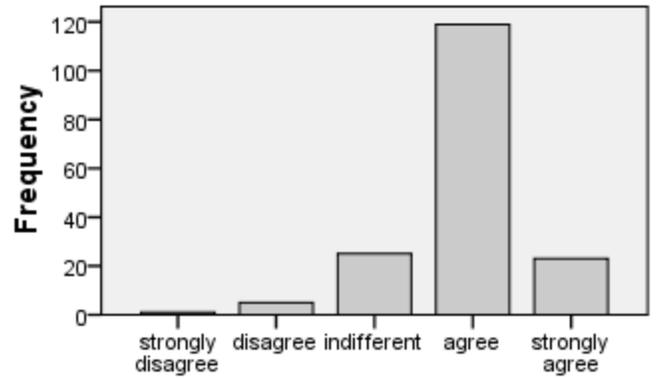
I got a better understanding of how to use the multimeter to take resistance readings



I got a better understanding of how to use the multimeter generally

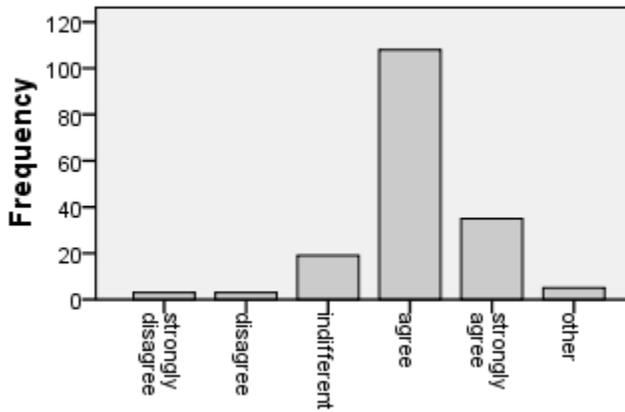


The experiment properly depicts the real experiment



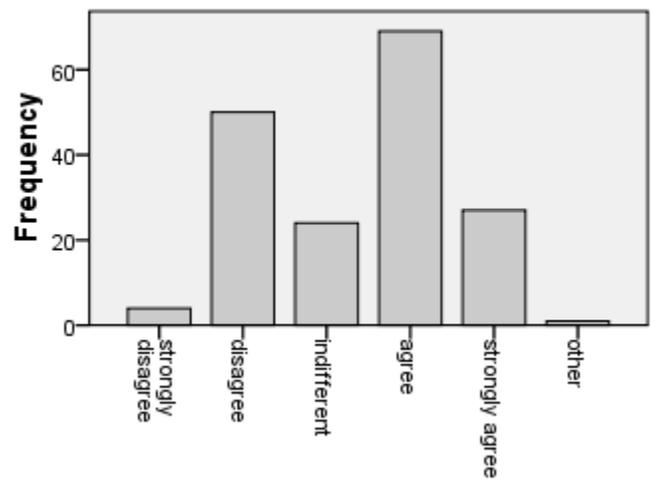
Lab design (Parallel Connection)

The interface was appealing

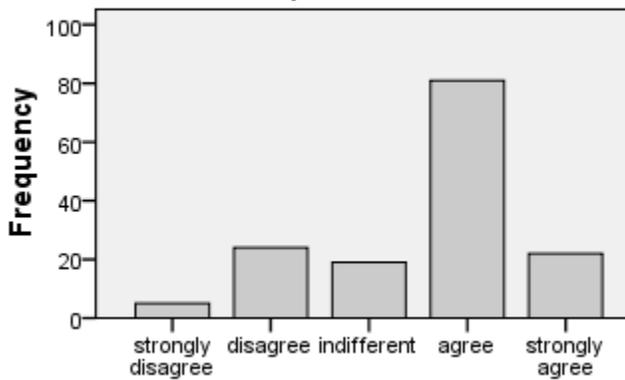


Virtual versus Real (Ohms Law Verification)

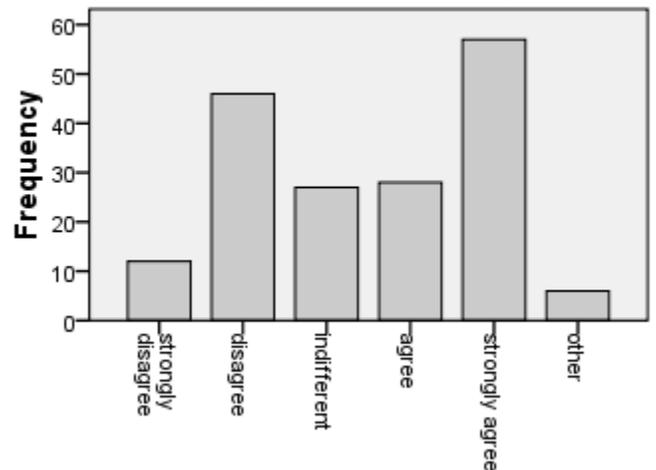
The lab experience is better than the real experiment



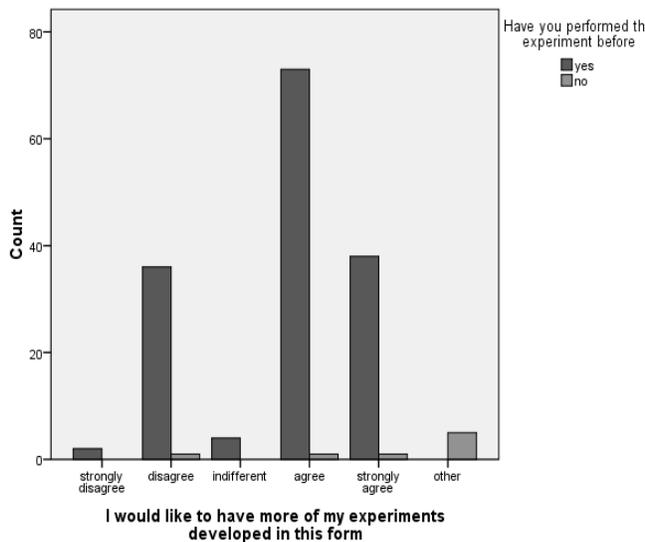
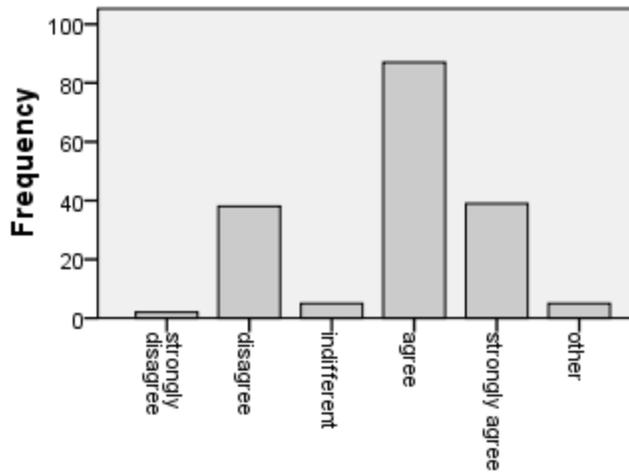
I did not get confused while performing the experiment



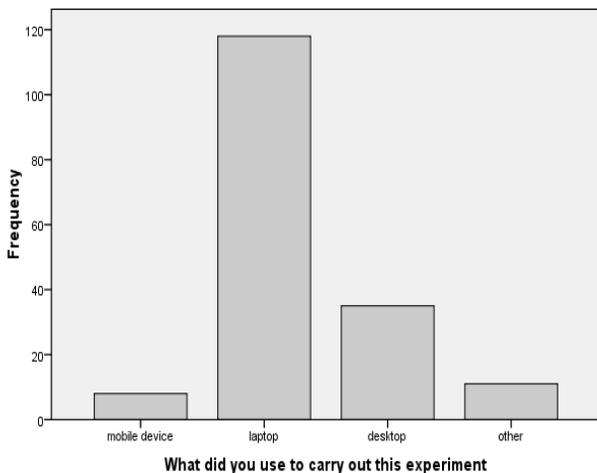
The lab should replace the real experiment



I would like to have more of my experiments form



What did you use to carry out this experiment



Findings

- A good number of the students enjoyed the experiments and want more of such.
- The number that disagree is significant and shouldn't be ignored.
- We can say they had a good experience but they do not want the virtual experiments to ever replace the real ones.

We can thus infer that the virtual experiments can never replace the real experiments. They can only COMPLEMENT THEM to make learning easier and more robust.

Cost

Since this is an on-going work, the final cost has not been determined. However, Table 2 presents the expenditure so far, for the developed virtual laboratories. It should be noted that while the following purchases were made for the particular laboratories developed, the cost of the purchased software is independent of the number of laboratories developed. Hence, the cost of each virtual laboratory reduces with the increase in the total number of virtual labs developed.

Table 2: Budget for virtual labs.

S/N	Item	Cost
1.	Construct-2	\$119
2.	Microsoft Visual Studio	\$1,199.00
3.	The GIMP (Graphics Editing Tool)	Freeware

The developed virtual labs are currently being hosted on Google's free app platform, the Google App Engine (<http://appengine.google.com>). While this is presently free, it presents limitations which could prove vital for virtual labs. For example, the Google App Engine would make it difficult to have a service broker which handles authentication and a separate database from the experiment engines' database hence making authentication and user monitoring quite impossible.

Challenges

Although it is strongly desired to depict reality as much as possible, limitations arise when trying to render 3D actions in 2D. As optimization is considered in terms of memory usage, animations implemented in design also have to be minimized to an extent.

Construct 2 is a new tool that is experiencing continuous development. Each release of a different version may require the developer to update his work. This is the case when some new updates in the software provides a means for the developer to produce a better version of some actions which have already been inefficiently implemented hence, a need to go back and rework some of the implementation.

Another major challenge is the support for multiple screen sizes. Although the HTML5-based laboratories can work on various devices another limitation is the multiple screen sizes. It is a challenge to design images that will likely fit into screens when different platforms are used.

Future Works

The authors focused on the development of laboratories for lower level Science and Engineering subjects as these are the subjects in which there are the largest number of students and hence the greatest shortage of equipment to handle the class sizes. Pedagogic success with these experiments will serve as a pedestal to obtain funding for the advanced experiments for higher level Science and Engineering subjects. Some of the authors have also previously designed Re-crystallization and Melting Point Experiments, Electrical Conductivity Measurements and Chloride measurement Experiments for the UK Open Science Lab.. These experiments can be found at:

<http://chloride-ilab.appspot.com/>,
<http://conductivity-ilab.appspot.com/> and
<http://recrystallization-ilab.appspot.com/>

The Ohms Law experiment had been initially designed using LabVIEW but it would require installation of LabVIEW, hence the need for a new design using graphics. The issue of efficient cross platform usage will also be considered. It is to be noted however that the experiments developed for the UK Open Science Lab site were developed using Adobe Flex and Adobe Flash.

Conclusion

The experiments developed by this project are part of the introductory experiments used in the teaching of chemistry and physics in lower level classes in universities and also the science classes in high schools. The project would therefore serve the purposes expected by a virtual laboratory in terms of making it easier for the students to relate to the experiment when seen in the real laboratories. They would also provide the means for students to revise the steps involved in the experiments when reading or preparing for examinations in cases where they cannot go back to the laboratory.

This work has helped to provide a complement to the limited real experiment set ups available in order to enhance learning, it has also helped to bring virtual experiments a step closer to the users, by being able to use the laboratories without expecting the user to make any pre-installations.

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