EFFECTIVENESS OF VIRTUAL LABORATORY ON GRADE EIGHT STUDENTS' ACHIEVEMENT IN LEARNING ELECTRICITY

Fatma Al-Duhani[1,2]
***Rohaida Mohd Saat[1]**
Mohd Nor Syahrir Abdullah[1]
[1] Faculty of Education, Universiti Malaya
[2] The Specialized Institute for Professional Training of Teachers, Ministry of Education, Muscat, Oman

**rohaida@um.edu.my*

ABSTRACT

In the aftermath of the COVID-19 pandemic, many education systems around the world have recognized the value of using technology such as virtual laboratories to teach science subjects. This study aimed to explore the effectiveness of using a virtual laboratory on grade eight students in learning about electricity-related topics. A quasi-experimental research design was used; involving forty (40) students aged 14-15 years. Students in the control group used a physical laboratory to complete the practical activities whereas those in the experimental group used a specially designed virtual laboratory. The result indicated that the virtual laboratory significantly enhanced students' achievement in electricity-related topics more than the physical laboratory. These findings could be attributed to how students learn using the virtual laboratory. For instance, in the virtual laboratory, students can visualise imperceptible phenomena and processes. They also were able to control the variables and observe instant feedback. The findings of the research have provided several important implications for curriculum designers and science education.

Keywords: *Physical Laboratory, Achievement, Practical Activities, Virtual Laboratory*

INTRODUCTION

The international study TIMSS is the best source of information for policymakers to use to enhance mathematics and science teaching and learning. The Sultanate of Oman participated in TIMSS 2007, TIMSS 2011, TIMSS 2011, and TIMSS 2019, with the objective of developing and improving its educational system. According to TIMSS 2007, TIMSS 2011, TIMSS 2015 and TIMSS 2019, the performance of Omani students is still below the international average levels (Mullis et al., 2019).

In science subject, electricity is an important topic with widespread applications in our daily lives. However, several studies have indicated that in science classes many learners are struggling to grasp electricity- related concepts, such as electric current, resistance and voltage (Moodley & Gaigher, 2019; Stavrinides et al., 2015). One of the core reasons for this when teaching electricity-related concepts is the fact that learners are unable to see the real flow of the electric charge. It is, therefore, hard for learners to visualize the electrical flow by simply watching the bulb light go on when connected to the circuit (Stavrinides et al., 2015). Consequently, this lack of understanding may have an impact on students' comprehension and achievement (Al-Musawi et al., 2017; Ambusaidi et al., 2018; Cole et al., 2018).

Besides, international and local reports and studies revealed that the education sector including in Oman faces several challenges, the most significant of which is the need to keep up with technological changes and develop new educational methods to prepare students to live and work in the new environment brought about by the modern global economy (Nasser, 2019). Hofstein (2017) believed that the development and increasingly widespread use of digital computing technologies in school science provides new tools for gathering, visualizing, and reporting data and findings, as well as supporting science learning, particularly in supporting science laboratories. Multimedia and the web make it possible to simulate laboratories and schools can now offer students virtual laboratories via the internet or multimedia (Al-Zahrani, 2015).

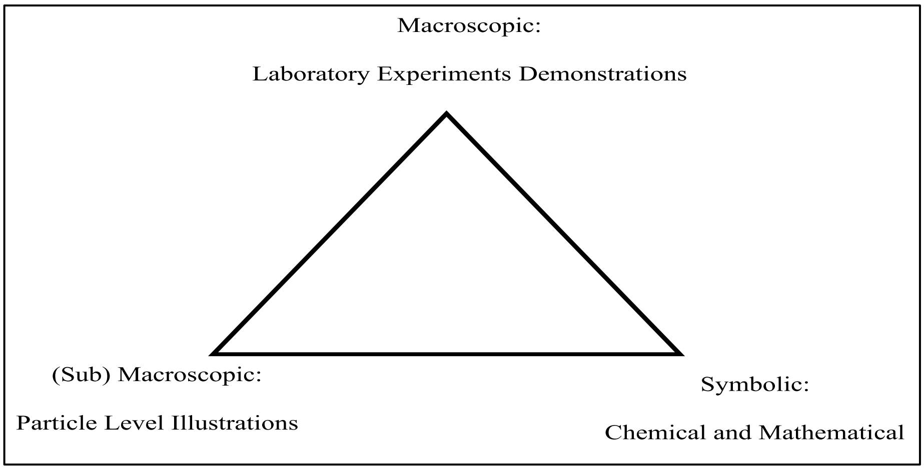
LITERATURE REVIEW

Physics is one of the most fundamental natural sciences and involves studying universal laws and the behaviours and relationships among a wide range of physical concepts and phenomena (Bajpai, 2013). Among these concepts, electricity stands as a fundamental idea in science. Its application encompasses several aspects of our daily lives. Electricity is intricately linked to many essential scientific ideas, including electric current, voltage, resistance, and more. Thus, it is crucial to dedicate attention to teaching these concepts using appropriate techniques and procedures (Zaytoun, 1994).

To incorporate electrical concepts effectively, Johnstone's three levels of representations can be applied. These levels, as referred to by Johnstone (1991) include macroscopic, (sub) microscopic or particulate, and symbolic representations, as illustrated in Figure 1.

Figure 1

The Three Levels of Representation in Johnstone's Triangle



The macroscopic level includes tangible subjects that provide observable phenomena or objects that are apparent to the senses, such as the electric circuit and the battery. On the other hand, the (sub)microscopic level deals with aspects that cannot be directly perceived or known through the senses, such as the movement of electrons in the electric circuit and the chemical reactions in the cell. The last level is the symbolic level, which involves mathematical symbols and equations, such as diagrams and symbols of electric circuit components.

According to Johnstone (1991), one barrier to students' understanding of scientific concepts is that most of these concepts occur at the most abstract (symbolic) level, where students may not always know how to interpret the symbols or translate them into the other levels of representations. Additionally, teachers frequently switch between levels, making it difficult for students to connect different mental representations and grasp abstract concepts. Students must visualize the submicroscopic view of the invisible 3D, as it is beyond the range of their experiences (Tarng et al., 2021). Consequently, students face challenges in dealing with it and linking it with the network of concepts and relationships in their knowledge structure, resulting in the development of alternative conceptions (Al-Saidi & Ambusaidi, 2018).

Previous literature reported that virtual technology enhanced students’ understanding of abstract ideas, improves their ability to remember information, and enhances their understanding (Benzer & Yildiz, 2019; Hartatiana, 2017; Latif et al., 2020). Virtual technologies, such as virtual laboratories, hold significant importance for students’ learning of Physics, especially electricity (Lucas, 2018). Virtual laboratories can be defined as non-physical environments that enable learners to carry out as many experiments as they like, individually, without supervision, or under the guidance and observation of their teacher.

Teachers may find virtual laboratories to be a valuable resource that can be utilised whenever necessary to bridge gaps and overcome obstacles that arise when using a physical lab. For instance, during the COVID-19 pandemic, many schools were closed, and there was no alternative way to carry out the practical components of the science curriculum. Therefore, teachers can use virtual laboratories as an alternative approach to conduct practical activities in science lessons when the students were at home during the pandemic crisis. It is because in virtual laboratories, students are able to conduct laboratory experiments that were previously not feasible due to a lack of equipment, the cost associated with certain experiments, or the inability to perform a physical version of the lab (Marble, 2017).

Previous Empirical Studies on the Effectiveness of Virtual Laboratories

Research comparing the effects of virtual and physical laboratories on students' achievement has yielded varied results. For instance, Luthfi et al. (2021) investigated how physical teaching materials, through the use of a virtual laboratory, can be employed in cognitive-conflict learning to assist students in understanding electricity-related topics and concepts. The authors aimed to present a new model that integrates physics teaching materials with a virtual laboratory to facilitate students' learning of physics. They attempted to adapt physics-teaching materials based on cognitive conflict by integrating virtual learning and teaching environments, thereby enhancing students' understanding of electricity concepts and topics. The authors' findings demonstrate that students learning electricity through virtual laboratories had fewer misunderstandings and misconceptions compared to those utilizing physical or traditional laboratories. Ultimately, the authors emphasize the significance of integrating virtual laboratories with physical teaching materials to effectively teach physics, promoting both a clear understanding of the phenomenon under study and practical application.

Abou Faour and Ayoubi (2018) examined the effects of using a virtual laboratory on the cognitive and conceptual comprehension of grade 10 students, as well as their attitudes toward science, particularly physics. The authors employed a quantitative research method using two instruments. The results indicate that students in both groups displayed substantial improvement in their conceptual understanding of the direct current electric circuit. In other words, both the use of physical laboratories and virtual laboratories were found to enhance students' cognitive and conceptual understanding when conducting experiments on the direct current electric circuit. However, students in the experimental group achieved significantly higher scores compared to those in the control group.

The study by Baladoh et al. (2017) also investigated the effectiveness of virtual labs in enhancing students' understanding of concepts but their study was related to electronic circuit theory and their skills in handling electronic circuits in Mansoura vocational preparatory schools in Egypt. The findings clearly demonstrated the efficiency of the virtual lab in enhancing students' academic achievement and practical skills in handling electronic circuits.

Another study, conducted by Bajpai (2013), examined the effectiveness of a virtual lab in enhancing learners' understanding of concepts in Physics. Both groups performed the same experiment on the photoelectric effect. The findings of this study revealed a significant difference between the groups, with the experimental group achieving higher scores. Based on the research results, the author recommended the use of computer-simulation-based virtual labs, such as Edison 4.0, PhET Interactive Simulation, Interactive Physics, and Crocodile Physic, to help learners grasp abstract concepts and enhance their achievements.

However, a substantial body of research has been conducted comparing student achievement in virtual labs, indicating that there is little difference in achievement. For instance, Hamed and Aljanazrah (2020) recently conducted a study to explore the effectiveness of using virtual experiments on students' achievement. The findings suggested that there is no significant difference in achievements between the two groups, indicating that a virtual lab has the same effect as a real lab on students' achievements. Similarly, Evangelou and Kotsis (2018) conducted a study to compare students' conceptual understanding of the frictional force, which is a fundamental physical law, after engaging in real-world and computer-simulated activities. The experimental group used Interactive Physics simulation software, while the control group conducted experiments using actual objects from the real world. Identical pre- and post-tests with six questions each were administered to both groups before and after the study to collect data. The results demonstrated that both methods are equally successful in assisting students in understanding the frictional force.

Studies on the effectiveness of virtual laboratory were also conducted on the enhancement of students' practical skills. Al-Musawi et al. (2017) conducted a study to examine how well Omani fourth graders utilised a 3D lab for science teaching, the development of practical skills, and the learners' attitudes toward the learning environment and the use of a 3D lab. The experimental group showed statistically significant differences in students' achievement, and the students' attitudes towards using a 3D lab in the classroom were favourable. Additionally, improvements in logical and visual reasoning were observed.

Another study done by Bugarso et al. (2021) aimed to examine the preferences of 91 students regarding science experiments in a physical or virtual lab, as well as their experience with hands-on and virtual laboratory learning. This study utilized a descriptive-correlation research design. The findings indicated that students' thinking, understanding, performing, and reasoning skills were more favourable in the hands-on laboratory compared to the virtual laboratory. Additionally, in terms of the learning environment, motivation and enjoyment, stimulation of active learning, comfort and convenience, the majority of students highly preferred hands-on laboratories. There were significant differences in the preferences of the students across in the different laboratory settings.

Ambusaidi et al. (2018) conducted a study to investigate the impact of using virtual labs on the achievement and attitudes of Omani 9th-grade learners toward science and learning through the virtual lab. The authors found that the virtual lab had no significant impact on learners' achievement or their attitudes toward science, although they did exhibit overall positive attitudes toward learning using the virtual lab. Similarly, the findings of the study carried out by Tsihouridis et al. (2013) showed no significant difference in learners' conceptual improvement in understanding electric circuits when real school labs were used for teaching compared to virtual labs. The author explained this result by pointing out that the achievement test questions primarily assessed students' mathematical and theoretical manipulations rather than their conceptual understanding and practical skills.

Another study conducted by Reese (2013) aimed to examine the differences in achievement between two types of laboratory instruction: virtual and traditional laboratories. In the virtual laboratory type, learners completed each of the ten virtual labs required for the completion of the course at their own convenience, one per week, either in a computer lab on campus or at home. Subsequently, learners attended a face-to-face lab session at a specific time the following week to submit their findings and answers to specific lab questions. The findings of this study demonstrated statistically significant differences in student achievement, as measured by average quiz scores, between traditional face-to-face labs and virtual labs. Furthermore, traditional labs resulted in greater learning gains for students compared to virtual labs.

In conclusion, the topic of electricity appears to be challenging for students, and the effectiveness of virtual laboratories in teaching science to students remains a topic of interest in various research studies. Therefore, the aim of this study is to examine the effectiveness of a virtual laboratory in 8th-grade students' achievement in three dimensions namely; Knowledge, Application and Reasoning.

METHODOLOGY

The present study is based on a pretest-posttest nonequivalent groups design. In this design, the experimental and control groups are selected without random assignment. However, random selection was conducted to choose the school from the population and to select existing classes for the control group and experimental group. Random selection is employed to ensure that the process of selecting schools and classes is unbiased and representative of the larger population. Both groups undergo a pre-test and post-test.

Participants

The sample consisted of eighth-grade students from one of the schools in the Al-Batinah South Region in Oman. The control and experimental groups were selected by randomly choosing the school from the population and existing classes. The sample comprised forty students aged 14-15 who participated in the study, twenty students assigned to the experimental group and twenty students assigned to the control group.

Instrument
To measure the impact of using the virtual laboratory on the students' achievement, a paper-based achievement test was prepared in collaboration with two specialized science teachers. The test was based on the unit 'Magnetism and Electricity' from Grade Eight Science curriculum. Seven out of the forty test items were adapted from the Determining and Interpreting Resistive Electric Circuits Concepts Test (DIRECT), which was developed by Engelhardt (1997). The DIRECT test incorporates many of the learning difficulties and misconceptions that students have been found to possess.

The achievement tests were designed according to the test descriptions provided by the Oman Ministry of Education (MOE). Both the pre-test and post-test had similar content, but the order of the questions was different to avoid the set response effect. Furthermore, the achievement test items assessed different cognitive levels based on Bloom's Taxonomy, which are remembering, understanding, applying, analyzing, evaluating, and creating. The questions were designed to cover various question types and all topics within the unit. The test consisted of 40 multiple-choice questions and aimed to assess students' achievement in the topics of the Magnetism and Electricity unit.

Furthermore, the distribution of the questions followed the criteria established by the Center for Educational Assessment and Measurement (2020) as follows: 40% (16 questions) of Knowledge Questions (remembering and understanding), 40% (16 questions) of Application Questions (applying and analyzing), and 20% Questions (8 questions) of Inference/ Reasoning (evaluating and creating). Table 1 presents the different cognitive levels of the achievement test items.

Table 1
Distributing the Questions to Different Cognitive Levels

Cognitive Level	Blooms Taxonomy	Percentage	Number of Questions
Knowledge	Remembering and understanding	40%	16
Application	Applying and analyzing	40%	16
Reasoning	Evaluating and creating	20%	8
Total		100%	40

The students were given 45 minutes to answer the questions. The maximum score for the test was 40 marks. Each question was scored either 1 (correct answer) or 0 (incorrect answer), resulting in a total score ranging from 0 to 40.

A total of twelve (12) subject matter experts assessed the content validity of the research instrument. They were asked to review the items and evaluate how well these items represented the intended content area. Based on the experts' feedback, several items were modified. Then, a pilot study of the achievement test was conducted on 63 students in the 8th Grade from public Omani schools. The purpose of the pilot study was to examine the internal consistency of the instruments and calculate Cronbach's alpha values. Cronbach's alpha value for the achievement test of the pilot study was found to be 0.830. The value is considered good as it exceeds the minimum reliability level (<0.60) (Hair et al., 2006).

Virtual Laboratory

The Virtual Lab was specially developed to give users the best possible experience in their native language. It is a web-based virtual learning and teaching environment where learners interact with various types of learning materials, including simulations, animations, learning activities and self-assessment tools. Within the virtual lab, the learner has the ability to design their own experiments and manipulate objects. Its content was developed based on Unit 12- Magnetism and Electricity in Grade 8 science curriculum.

For example, students in the experimental group had access to the virtual lab's website from both home and school, allowing them to use it at their convenience. They can interact with their teacher and peers synchronously or asynchronously.

To assist students in performing the experiments, instructions on how to conduct an experiment, collect data, and document conclusions were provided through learning activities. Additionally, 2D and 3D animation videos were used to supplement the content and enhance students' understanding of the topics covered in class. Students also had the opportunity to assess their understanding through online self-assessment tools, which could be accessed multiple times. Furthermore, students could communicate with their teacher and peers during virtual classroom meetings via email, chat, and Google Meet, all of which were integrated into the virtual laboratory.

Procedure

The research took place over a period of nine (9) weeks, and permission to conduct the research at the school was obtained. Due to COVID-19 pandemic at that time, strict adherence to the Standard Operating Procedures (SOP) was maintained during data collection in Oman. At that time, the school employed blended learning as the mode of instruction.

During the first week, the researchers provided orientation and instruction on how to use the virtual lab to both the students and the teacher. The experimental group, consisting of the virtual lab group, took the pre-test at the end of the first week. The control group, comprising the physical lab group, took the test the following week.

The treatment phase, which lasted for eighth (8) week, began in the second week, with a designated class interaction time of 3 hours (180 minutes) per week. Throughout this period, the researcher observed both the virtual lab group (VL) and the physical lab group (PL).

The control group (PL) conducted the practical experiments at the school's laboratory during the weeks they attended in person. However, during the weeks when they had remote instruction (synchronous online classes), only the theoretical aspects were covered, and the practical part could not be covered. On the other hand, the experimental group was able to conduct the experiments using the virtual laboratory throughout the entire duration of the study. Neither group experienced any learning loss in any of the unit topics.

To facilitate communication with the experimental group students during synchronized online classes, the virtual laboratory was connected to the Google Classroom platform. After the intervention, both groups received the achievement test as a post-test.

Data Analysis

To determine the significant difference between the pre-test and the post-test achievements for both groups, a paired samples t-test was conducted. Then, to determine the significant differences in achievement between the two groups, multivariate analysis of variance (MANOVA) was employed. A significance level of 0.05 was used for all statistical analyses. Prior to the analysis, assumptions for paired samples t-test and MANOVA were checked. To determine the magnitude of the learning gains between groups, Cohen's d was used to calculate the effect size. The interpretation of the learning gain results followed Cohen's guidelines, where the effect size of 0.2 indicated a small effect, 0.5 indicated a medium effect, and 0.8 indicated a large effect (Cohen, 1988).

FINDINGS

The data obtained were analyzed to compare the mean and standard deviations of the virtual laboratory group and physical laboratory group across three dimensions of the achievement test (knowledge, application, and reasoning). The results of the descriptive statistics are presented in Table 2, and Figure 2 provides a graphical representation of the results.

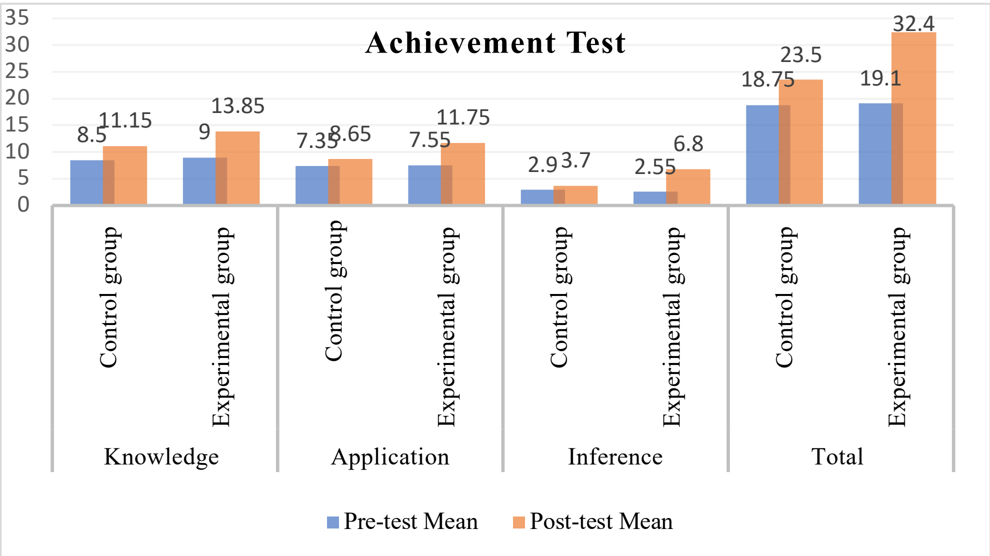
Table 2

Mean and Standard Deviation Comparison of Achievement Pre-test and Post-test Results of Experimental and Control Groups

Achievement	Group	Pre-test		Post-test		Mean Gain	Mean Difference
		Mean	SD	Mean	SD		
Knowledge	Control	8.50	2.59	11.15	2.74	2.65	2.29
	Experimental	9.00	2.20	13.85	2.91	4.85	
Application	Control	7.35	1.39	8.65	2.30	1.30	2.90
	Experimental	7.55	2.01	11.75	2.69	4.20	
Reasoning	Control	2.90	1.02	3.70	1.66	0.80	3.45
	Experimental	2.55	1.28	6.80	1.32	4.25	
Total	Control	18.75	3.85	23.50	5.64	4.75	8.75
	Experimental	19.10	3.91	32.40	6.44	13.30	

Figure 2

Pre-test and Post-test Comparison of Experimental and Control Groups in Achievement



The results show an improvement in students' achievement from the pre-test in all dimensions of achievement in both groups. The mean gain differences in knowledge, application, reasoning, and overall achievement between the experimental and control groups favour the experimental group, indicating that the virtual laboratory enhanced students' achievement more than the physical laboratory.

The significant differences between the pre-test and post-test of overall and three components of achievement for both groups were calculated using Paired-Samples t-Test. The findings are represented in Table 3 below.

Table 3

Within-Group Comparison of Achievement Test

Dependent Variable	Group	Pre-test		Post-test		df	t-value	*P-value*	d^2
		Mean	SD	Mean	SD				
Knowledge	Experimental	9.00	2.20	13.85	2.91	38	3.03	.004	0.96
	Control	8.50	2.60	11.15	2.74	38	0.65	.514	0.21
Application	Experimental	7.55	2.01	11.75	2.69	38	3.92	.000	1.24
	Control	7.35	1.39	8.65	2.30	38	0.37	.716	0.11
Reasoning	Experimental	2.55	1.28	6.80	1.32	38	6.54	.000	2.07
	Control	2.90	1.02	3.70	1.66	38	-0.96	.344	0.30
Total	Experimental	19.10	3.90	32.40	6.44	38	4.65	.000	1.47
	Control	18.75	3.85	32.50	5.64	38	0.29	.777	0.09

Table 3 shows that there are statistically significant differences exist between the pre-test and post-test mean scores of the experimental group in three dimensions of achievement; knowledge, application, reasoning, and overall achievement score. On the other hand, no significant mean difference can be observed between the pre-test and post-test mean scores of the control group in all dimensions of achievement.

The overall effect size of the experimental group is (d^2=1.47), indicating a large effect size. This result suggests that the virtual laboratory has a significant impact on enhancing students' achievement.

To investigate the significance of the differences between the two groups, MANOVA was conducted. Findings are presented in Table 4.

Table 4

Tests of Between-Subjects Effects in Post-test of the Experimental and Control Groups in Achievement Test

Source	Dependent Variable	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial η^2
Group	Knowledge	72.90	1	72.90	9.14	.004	.19
	Application	96.10	1	96.10	15.32	.000	.29
	Reasoning	96.10	1	96.10	42.76	.000	.53
	Total	792.10	1	792.10	21.63	.000	.36

Table 4 shows the between-subject effects of the achievement dimensions of knowledge, application, and reasoning of the experimental group and control group after treatment. The MANOVA analysis showed that there were significant differences between the experimental group and the control group in the achievement dimensions of knowledge, application and reasoning and in the overall score of achievement ($p < 0.05$).

Additionally, Table 4 shows that the effect size of using the virtual laboratory for the study sample is large. 36% of the total variation of the dependent variable (achievement improvement levels) is attributed the effect of the independent variable (using the virtual lab). This percentage exceeds the threshold set by Cohen (15% or more) to classify the effect size of the independent variable on the dependent variable as large (Cohen, 1977). The overall achievement estimated means can be highlighted as presented in Figure 3.

Figure 3

Estimated Marginal Means of Experimental and Control Groups in Post-test of Achievement

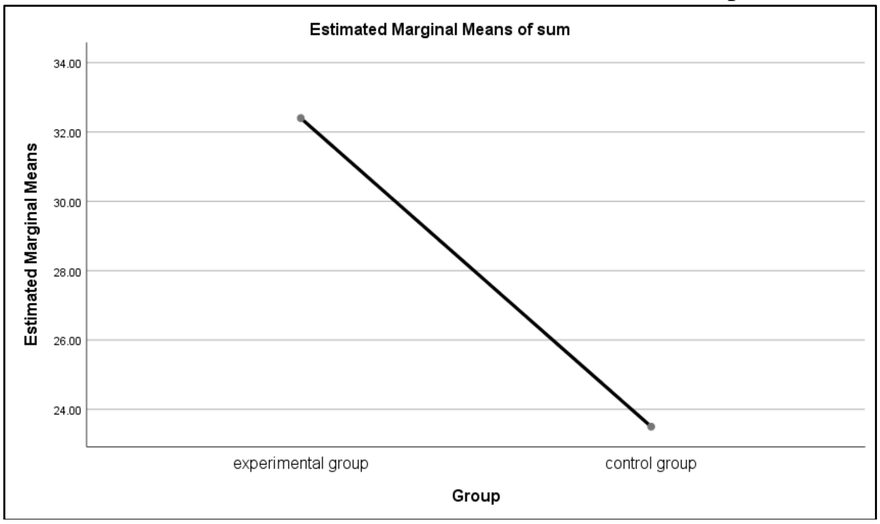


Figure 3 displays the overall estimated marginal means of the experimental group and the control group in achievement post-test scores, indicating that the virtual laboratory was more effective in enhancing students' achievement than the physical laboratory among eighth-grade students.

DISCUSSION AND CONCLUSION

The present study explored the effects of using a virtual laboratory on students' achievement. The results showed an improvement in students' achievement from the pre-test carried out in all dimensions of achievement in both groups. However, the achievement of the experimental group students proved to be significantly better than that of students in the control group in all dimensions, showing that the students gained from using a virtual laboratory. Therefore, it was concluded that the virtual laboratory scored highly on enhancing students' achievement.

This finding is well supported by different scholars and researchers (e.g. Abou Faour & Ayoubi, 2017; Falode & Gambari, 2017; and Ogbuanya & Onele, 2018) who reached the same conclusion. There are many reasons standing behind the improvement in the achievement of students who used the virtual laboratory that could be attributed to features that are embedded in the current study's virtual laboratory. For instance, the information in the virtual lab is represented in more than one format, such as text and multimedia information (videos, simulations, images, etc). According to the Cognitive Theory of Multimedia Learning (CTML), a selective amount of both visual and verbal representation is ideal for a conducive learning experience (Mayer, 2014).

As far as the generative learning theory is concerned, the present research is consistent with the key principles of this theory in that students can learn electricity concepts and topics effectively and appropriately when exposed to a virtual learning setting that allows them to select items and objects to construct their experiment. The virtual lab also allows learners to arrange and organize necessary information into a coherent detailed structure, connect and integrate the pictorial and verbal representations with one another using their already-existing information that is activated from their long-term memory, and analyze and compare the results of others (Fiorella & Mayer, 2016).

The performance of the virtual laboratory group can also be attributed to the virtual lab features and contents. For example, Wang and Tseng (2018) advocated that a virtual laboratory can be used as a powerful representation that helps students develop knowledge about abstract or complex natural phenomena. They found that the use of virtual manipulatives appeared to be more effective in reducing misconceptions rather than physical manipulatives. Therefore, in the present study, the virtual laboratory was supported with 2D and 3D animations and simulations that helped students visualize abstract concepts. For example, there was a simulation that represented the invisible electrons with blue spheres, showing their supposed movement inside the circuit and how this movement can be affected by the resistance in the circuit; therefore, it showed how the light of the lamp changed. However, this movement of the electrons cannot be made visible in the physical laboratory. This is supported by Abou Faour and Ayoubi (2017) who indicated that the importance of virtual laboratories lies in their ability to present concepts by referring to the microscopic level as opposed to the physical laboratory which only shows macroscopic properties.

Hamed and Aljanazrah (2020) clearly proved that interactive and flexible online learning environments have the potential to provide students with a deeper conceptual understanding when learning physics. In the present study, the virtual lab is web-based and therefore available to students at anytime, anywhere to provide flexible learning opportunities that can overcome barriers of time, pace, and place for learners. Students were given specific instructions and guidance in the virtual lab to help them progress smoothly through the tasks. Moreover, this virtual lab included different forms of interactivity. For instance, students were able to control the variables and see instant feedback. This enhances the process of investigation and makes them active learners. This finding is supported by Eriksson et al. (2019) who found that interactivity can help learners overcome difficulties in perception and comprehension during the learning process. This finding also agrees with the findings of Efstathiou et al. (2018) who opined that a computer-based experiment design tool enabled students to focus their attention on the task of designing experiments through the provision of instant feedback when classifying variables into independent, dependent, and controlled variables.

In addition, in the present study, students were able to go back and redo the experiment as many times as they wanted in the virtual lab. Bhargava et al. (2006) highlighted the importance of giving the students repeated opportunities to practice. Students in the present study were also required to manipulate the experiments by selecting the appropriate materials used in the experiment. They had to find the correct tools and prepare them to set up. For example, in building series and parallel circuit's experiments, students could select the appropriate materials, change the voltage of the battery and change the resistance of the lamp. Through these activities, learners are actively engaged in the learning process. This finding agrees with scholars who reported that interactivity influences learners' achievement (Proske et al., 2007; Wei et al., 2015).

The positive findings could also be the result of the fact that students were encouraged to reflect on their own work and judge how well they had performed by using a self-assessment task that was available for each topic in the virtual lab. According to Efstathiou et al. (2018), finding alternative ways to complete the formative assessment process is important because delivering effective formative assessment, which includes a timely diagnosis of learner performance and timely delivery of teacher feedback to students, is typically time constrained. In this regard, the virtual laboratory of this study was supported with student self-assessment tasks to support their learning, reflect on their own work, and identify areas for improvement. This concurs with McMillan and Hearn (2008) and Nikou and Economides (2016), who argued that student self-assessment empowers learners to guide their own learning and can promote learning that is more meaningful.

It could be concluded that virtual laboratories can be an effective tool to enhance students' science content learning and it is appropriate for carrying out practical experiments regarding electricity-related concepts. Thus, there is a need to incorporate virtual labs into the science curriculum. Besides, teachers should be encouraged to take advantage of the available virtual laboratories, which help deepen students' understanding and practice many enquiry skills.

Further research should be carried out with other students at different educational levels to establish whether the results of this study can be generalised to other research populations. The current study was limited in its quantitative findings that explore the effectiveness of virtual labs and further investigation may be needed using qualitative methods.

REFERENCES

Abou Faour, M., & Ayoubi, Z. (2017). The effect of using virtual laboratory on grade 10 students' conceptual understanding and their attitudes towards physics. *Journal Of Education In Science Environment And Health, 4*(1), 54-68. https://dergipark.org.tr/en/download/article-file/415803

Al Musawi, A., Ambusaidi, A., Al-Balushi, S., Al-Sinani, M., & Al-Balushi, K. (2017). Effectiveness of learning with 3D-Lab on Omani basic education students' achievement, attitudes and scientific thinking. *Journal of Education Training Studies, 5*(11), 177-188.

Al-Saidi, W. & Ambusaidi, A. (2018). The effect of using scaffolding in modifying alternative conceptions of electrical concepts among ninth-grade female students in the Sultanate of Oman. *International Journal of Educational and Psychological Studies* (4), 22-41. DOI:10.31559/EPS2018.4.1.2

AlZahrani, N. S. (2015). *Designing virtual science labs for the Islamic Academy of Delaware.* (Publication No. 3730250) [Doctoral dissertation, University of Delaware]. ProQuest Dissertations and Theses Global.

Ambusaidi, A., Al Musawi, A., Al-Balushi, S., & Al-Balushi, K. (2018). The impact of virtual lab learning experiences on 9th-grade students' achievement and their attitudes towards science and learning by virtual lab. *Journal of Turkish Science Education, 15*(2), 13-29. https://www.tused.org/index.php/tused/article/download/207/163/

Bajpai, M. (2013). Developing concepts in physics through virtual lab experiment: An effectiveness study. *TechnoLEARN: An International Journal of Educational Technology, 3*(1), 43-50.

Baladoh, S., Elgamal, A. F., & Abas, H. A. (2017). Virtual lab to develop achievement in electronic circuits for hearing-impaired students. *Education Information Technologies, 22*(5), 2071-2085. https://doi.org/10.1007/s10639-016-9532-7

Benzer, A. I., & Yildiz, B. (2019). The effect of computer-aided 3D modeling activities on pre-service teachers' spatial abilities and attitudes towards 3d modeling. *Journal of Baltic Science Education, 18*(3), 335.

Bhargava, P., Antonakakis, J., Cunningham, C., & Zehnder, A. T. (2006). Web-based virtual torsion laboratory. *Computer Applications in Engineering Education, 14*(1), 1-8.

Bugarso, J. M. S., Cabantugan, R. E., Que-ann, D. T., & Malaco, A. C. (2021). Students' learning experiences and preference in performing science experiments using hands-on and virtual laboratory. *Indonesian Journal of Teaching in Science*, *1*(2), 147-152.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences (rev. ed.)*. Academic Press.

Cole, M., Cohen, C., Wilhelm, J., & Lindell, R. (2018). Spatial thinking in astronomy education research. *Physical Review Physics Education Research*, *14*(1). https://doi.org/10.1103/physrevphyseducres.14.010139

Engelhardt, P. V. (1997). *Examining students' understanding of electrical circuits through multiple-choice testing and interviews. [Unpublished* Doctoral dissertation]. North Carolina State University. https://www.per-central.org/document/ServeFile.cfm?ID=11585&DocID=2500&Attachment=1

Evangelou, F., & Kotsis, K. (2019). Real vs virtual physics experiments: comparison of learning outcomes among fifth-grade primary school students. A case on the concept of frictional force. *International Journal of Science Education*, *41*(3), 330-348. https://doi.org/10.1080/09500693.2018.1549760

Falode, O. C., & Gambari, A. I. (2017). Evaluation of virtual laboratory package on Nigerian secondary school physics concepts. *Turkish Online Journal of Distance Education, 18*(2), 168-178.

Fiorella, L., Mayer, R.E. Eight Ways to Promote Generative Learning. *Educ Psychol Rev,* 28, 717–741. https://doi.org/10.1007/s10648-015-9348-9

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2006). *Multivariate data analysis* (6th ed.). Pearson Prentice Hall.

Hamed, G., & Aljanazrah, A. (2020). The Effectiveness of using virtual experiments on students' learning in the general Physics lab. *Journal of Information Technology Education: Research, 19*, 977-996.

Hartatiana, H., Darhim, D., Nurlaelah, E. (2017). Improving junior high school students' spatial reasoning ability through model eliciting activities with Cabri 3D. *International Education Studies, 11*(01), 148-154. https://doi.org/10.5539/ies.v11n1p148

Hofstein, A. (2017). The role of laboratory in science teaching and learning. In *Science education* (pp. 355-368): Brill Sense.

Hofstein, A. (2017). The role of laboratory in science teaching and learning. In K. Tabler & B. Akpan (Ed), *Science Education: An International Course Companion* (pp. 355-368). Brill. https://doi.org/10.1007/9789463007498_027

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of computer-assisted learning*, *7*(2), 75-83.

Latif, B., Nurjanah, Yuliardi, R., & Tamur, M. (2020). Computer-assisted learning using the Cabri 3D for improving spatial ability and self-regulated learning. *Heliyon, 6*(11), e05536. https://doi.org/10.1016/j.heliyon.2020.e05536

Lucas, P., Vaca, D., Dominguez, F., & Ochoa, X. (2018, July). Virtual circuits: An augmented reality circuit simulator for engineering students. In *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)* (pp. 380-384). doi:10.1109/icalt.2018.00097

Luthfi, I., Mufit, F., & Putri, M. R. N. (2021). Design of Physical Teaching Materials Based on Cognitive Conflict Learning in Direct Current Electricity Integrating Virtual Laboratory. *Pillar of Physics Education*, 14(1), 37-46.

Marble, J. E. (2017). *A Comparison of Traditional and Virtual Labs in Physics.* (Publication No. 10744612) [Doctoral dissertation, Piedmont College]. ProQuest Dissertations and Theses Global.

Mayer, R. E. (2014). Research-based principles for designing multimedia instruction. In V. A. Benassi, C. E. Overson, & C. M. Hakala (Eds.), *Applying science of learning in education: Infusing psychological science into the curriculum* (pp. 59–70). Society for the Teaching of Psychology.

McMillan, J. H., & Hearn, J. (2008). Student self-assessment: The key to stronger student motivation and higher achievement. *Educational Horizons, 87*(1), 40-49.

Mullis, I. V., Martin, M. O., Foy, P., Kelly, D. L., & Fishbein, B. (2020). *TIMSS 2019 international results in mathematics and science.* Retrieved from Boston College, TIMSS & PIRLS International Study Center website: https://timssandpirls.bc.edu/timss2019/

Nasser, R. (2019). Educational reform in Oman: System and structural changes. *In Porto Jr., G. (Ed.), Education systems around the world. IntechOpen.* https://doi.org/10.5772/intechopen.84913

Nikou, S. A., & Economides, A. A. (2016). The impact of paper-based, computer-based and mobile-based self-assessment on students' science motivation and achievement. *Computers in Human Behavior, 55*, 1241-1248.

Ogbuanya, T. C., & Onele, N. O. (2018). Investigating the effectiveness of desktop virtual reality for teaching and learning of electrical/electronics technology in universities. *Computers in the Schools, 35*(3), 226-248. https://doi.org/10.1080/07380569.2018.1492283

Proske, A., Narciss, S., & Körndle, H. (2007). Interactivity and learners' achievement in web-based learning. *Journal of Interactive Learning Research, 18*(4), 511-531.

Reese, M. C. (2013). *Comparison of student achievement among two science laboratory types: Traditional and virtual.* [Doctoral dissertation, Mississippi State University]. Retrieved from https://hdl.handle.net/11668/16860 Available from ProQuest

Reese, M. C. (2013). *Comparison of student achievement among two science laboratory types: traditional and virtual.* [Doctoral dissertation, Mississippi State University]. https://scholarsjunction.msstate.edu/td/1119/

Tarng, W., Lin, Y. J., & Ou, K. L. (2021). A virtual experiment for learning the principle of Daniell cell based on augmented reality*. Applied Sciences, 11*(2), 762-786. https://doi.org/10.3390/app11020762

The Center for Educational Assessment and Measurement. (2020). *Student learning assessment document in science.* Ministry of Education Oman.

Tsihouridis, C., Vavougios, D., & Ioannidis, G. S. (2013, September 25-27). *The effectiveness of virtual laboratories as a contemporary teaching tool in the teaching of electric circuits in Upper High School as compared to that of real labs* [Paper presentation]. International Conference on Interactive Collaborative Learning (ICL), Kazan National Research Technological University, Kazan, Russia.

Wang, T.-L., & Tseng, Y.-K. (2018). The comparative effectiveness of physical, virtual, and virtual-physical manipulatives on third-grade students' science achievement and conceptual understanding of evaporation and condensation. *International Journal of Science and Mathematics Education, 16*(2), 203-219.

Wästberg, B. S., Eriksson, T., Karlsson, G., Sunnerstam, M., Axelsson, M., & Billger, M. (2019). Design considerations for virtual laboratories: A comparative study of two virtual laboratories for learning about gas solubility and colour appearance. *Education Information Technologies, 24*(3), 2059-2080.

Wei, H.-C., Peng, H., & Chou, C. (2015). Can more interactivity improve learning achievement in an online course? Effects of college students' perception and actual use of a course-management system on their learning achievement. *Computers & Education, 83*, 10-21. https://doi.org/10.1016/j.compedu.2014.12.013

Zaytoun, Aish. (1994). أساليب تدريس العلوم [Science Teaching Methods]. Amman: Dar Al-Shorouk.