Journal of Information Technology Education: Research

An Official Publication of the Informing Science Institute
InformingScience.org

JITEResearch.org

Volume 19, 2020

THE EFFECTIVENESS OF USING VIRTUAL EXPERIMENTS ON STUDENTS' LEARNING IN THE GENERAL PHYSICS LAB

Ghadeer Hamed	Birzeit University, Ramallah, Palestine	ghadeer.hamed.27@gmail.com
Ahmad Aljanazrah*	Birzeit University, Ramallah, Palestine	ajanazrah@birzeit.edu

* Corresponding author

ABSTRACT

Aim/Purpose	The objective of this study is to explore the effectiveness of using virtual experiments on students' level of achievement and on their practical skills as well as their views on applying the virtual experiments in a general physics lab.
Background	There is a continuous debate in the literature on the effect of using virtual experiments/ lab on students' physics learning and whether those virtual experiments can substitute and/or enhance students' performance in the real lab. Also, there is a need to design effective learning environments which are more suitable to students' characteristics in the digital age and can help them to acquire science inquiry and practical skills.
Methodology	Mixed research methodology is adopted including quasi-experimental design, achievement test, participatory observation, and semi-structured interviews. Two groups of students were selected: an experimental group (45 students) and control group (45 students).
Contribution	The study results contribute to the ongoing discussion on the role of virtual lab in learning and teaching general physics lab and provide a model of combining virtual and real lab as well as an alternative solution under the times of COVID 19.

Accepting Editor Athanassios Jimoyiannis │Received: August 25, 2020│ Revised: October 29, November 15, November 17, 2020│ Accepted: November 22, 2020.
Cite as: 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,* 976-995. https://doi.org/10.28945/4668

Findings	The results of the study showed that substituting face-to-face theoretical preparation in the general physics lab is at least equally effective as using virtual experiments. Students with virtual components acquired deeper understanding of physics concepts and were better prepared for carrying out real experiments. Attending online videos spared students' time and provided them with a more flexible and rich learning environment.
Recommendations for Practitioners	Faculty members are encouraged to use virtual experiments instead of face-to-face lab preparation. It is important to include more interactive multimedia and short online videos in the design of the virtual experiments.
Recommendations for Researchers	The development of virtual experiments can be extended to other experiments and topics in science. Researchers are encouraged to combine both quantitative and qualitative data collection tools to allow deeper exploration of students learning in the virtual environments.
Impact on Society	Virtual labs have the potential to save time and cost for both students and university as they reduce presence hours at the university in the real lab. Virtual experiments provide flexible learning opportunities that can overcome time, pace, and place barriers for learners from the community. They also provide a solution for physical distancing needed due to the emergency conditions imposed by the pandemic.
Future Research	Further investigations are needed to include the development of the whole introductory physics lab into virtual course and to explore the digital (virtual) transformation of other topics in physics and science as well.
Keywords	virtual lab, blended learning, lab performance, achievement in physics

INTRODUCTION

Lab work is an essential component of the study of physics as well as other natural science disciplines. It helps students to learn concepts and hands-on skills and to illustrate theory (Johnstone & Al-Shuaili, 2001). Furthermore, the practical laboratory increases students' curiosity and positive attitudes toward science (Bretz et al., 2013). Despite its importance, lab work is still facing many challenges such as the high cost of lab equipment and materials and dangers encountered when working with dangerous experiments (Kapting'el & Rutto, 2014). At the same time, evidence in literature is showing that the integration of Information and Communication Technologies (ICTs), such as simulations, animation, videos, and visualizations, with real practical work is very promising (Hofstein & Kind, 2012). One form of using ICT in a learning physics lab is to combine a virtual lab with a real practical lab (Darrah et al., 2014). A virtual lab can be defined as an online environment that consists of a set of experiment simulations and videos that allow students to run experiments virtually (Bajpai, 2013) and has the potential to support and enhance face-to-face practical-based learning (Darrah et al., 2014; Sullivan et al., 2017). Students can learn the scientific concepts and gain new skills using virtual lab in anytime and anywhere through laptops and smartphones (Ramesh, 2019). In a virtual lab, students will have the opportunity to make mistakes with minimal negative consequences compared to real lab, thus improving their confidence in carrying out real work. In addition, a virtual lab can help students to conduct experiments virtually that were difficult to be conducted in a real lab due to lack of equipment, costly materials and/or dangerous situations. Furthermore, in virtual labs, students can observe visual representations of natural phenomena, collect data, make predictions, and write hypotheses, so that students will become actively involved in inquiry scientific processes (Sypsas et al., 2019).

In spite of the benefits of virtual lab, there is continuous debate on the role/effect of using virtual experiments/lab in students' physics learning (Swan et al., 2015). Many studies showed positive effects of using virtual experiments on students' level of achievement (Alneyadi, 2019; Penn & Umesh, 2019; Pyatt & Sims, 2012; Tatli & Ayas, 2013; Yang & Heh, 2007) while others showed no significant differences (Ambusaidi et al., 2018; Crandall et al., 2015; Darrah et al., 2014; Klahr et al., 2007). Alneyadi (2019) showed that virtual labs had significant effects on students' knowledge, skills, attitudes, and achievement. However, Ambusaidi et al. (2018) conducted a study to investigate the impact of using virtual labs on 9th grade students' achievement by applying pre-test and post-test to experimental group (34 students) and control group (35 students), and the results showed no impact on students toward student's achievements.

In addition, many studies showed that virtual experiments helped students to gain better practical skills, which was reflected on their performance in the real lab (Aljuhani et al., 2018; Klahr et al., 2007; Malderlli et al., 2009; Radhamani et al., 2014; Yang & Heh, 2007) while the study of Sommer and Sommer (2003) revealed no difference. More specifically, Aljuhani et al. (2018) found that the virtual lab was an effective environment because it allowed users to conduct experiments individually and repeat them multiple times if needed. On other hand, Crandall et al. (2015) compared a traditional lab with a simulated, detected-based scene investigation of why a famous food sorbet had become a solid. Although there were no differences in the learning outcomes between the two laboratory-formats, students who preferred the simulated lab felt they could control at their own pace and were able to stop and review the simulation to understand the concepts more clearly. Traditional lab proponents liked working in groups and having immediate access to instructors.

The ongoing debate, as pointed out above in the literature, showed a need toward carrying out more investigations on the use of virtual lab in learning and teaching physics within different contexts. This is especially important when it comes to the first-year physics lab course (FYPLC) which is offered as a standard basic course in different bachelor programs for science and engineering students at Birzeit University as well as many universities in the world (Pols, 2020). Thus, the aim of this study is to explore the effect of combining a virtual lab with a real practical lab on students' achievement and performance as well as to evaluate this combination from their perspectives. This combination is done by replacing the first-hour introduction of the lab by online environment including interactive simulations, online calculations, and videos.

Since review of previous research revealed that the use of virtual labs has a mostly positive impact on students' practical physics learning (Sypsas et al., 2019), our hypothesis is that, when virtual lab/experiments are combined with real practical work, students' achievement will be enhanced in the general physics lab.

The importance of this study lies in trying to fill the gap created by the mixed results of the research conducted so far on the effectiveness of using virtual labs on students' achievement in physics. The results will offer evidence of the role/effect of using virtual experiments/lab on students' performance using the suggested model of using virtual labs. In addition, the model suggests saving of students' time to be spent in the lab as well as providing them with the opportunity to prepare and perform the experiments virtually at home (or wherever they have internet access) in the time and pace of learning that suits them. It also offers the opportunity to reduce the physical contact hours among students and tutors in the times of COVID-19. The results of this research will provide university education with solutions and alternatives to continue distant learning and provide students with necessary practical and scientific inquiry skills even under the movement and other type of restrictions due to the pandemic.

LITERATURE REVIEW

The effectiveness of virtual experiments in science education has gained considerable popularity in research (Aljuhani et al., 2018; Darrah et al., 2014; Hurtado-Bermúdez & Romero-Abrio, 2020; Radhamani et al., 2014; Swan et al., 2015; Sypsas et al., 2019; Tatli & Ayas, 2013). Wong et al. (2020) found several distinct benefits of using virtual experiments in education: They reduce equipment needs, they are available at anytime from anywhere, and they offer students the opportunity to learn at their own pace while exploring difficult or interesting concepts. However, there are different views in how to use virtual experiments in science and their impact on students' learning outcomes. Reviewing related previous studies revealed the following three categories:

I. NATURE AND MODELS OF USING VIRTUAL EXPERIMENTS

Studies focused on the nature of virtual experiments and the percentage in which they can replace real lab experiments: according to Li et al. (2011) virtual experiments can be used as cognitive tools that engage students in learning activities and help them to formulate hypotheses in problem solving situations. Recent studies indicated different models and forms of using virtual experiments in learning and teaching science. One of the models was through blended learning (Aljanazrah, 2006) in which virtual experiments were blended with hands-on (real) experiments, sometimes the lab started with virtual experiments followed by real experiments and vice versa (Verlage et al., 2019; Zacharia & Constantinou, 2008). Some models used virtual experiments to replace the real lab totally (Maldarelli et al., 2009; Rajendran et al., 2010) while other models used virtual experiments as support and enrichment resources (Ramesh, 2019). Results revealed by the study of Kapici et al. (2019) confirmed that the combination between hands-on labs and virtual labs gives better outcomes than using virtual labs alone and that virtual labs are as effective as hands-on labs for acquiring new knowledge and developing students' inquiry skills.

As the above literature suggests, the model to be adopted in this study will involve the combination of a virtual lab in form of interactive simulations and online videos with real practical lab using blended learning strategy.

II. VIRTUAL EXPERIMENTS AND STUDENTS' ACHIEVEMENT

Studies explored the effect of using virtual experiments on students' learning outcomes and acquisition of knowledge. Many studies revealed that virtual experiments improved students' level of achievement (Alneyadi, 2019; Penn & Umesh, 2019; Pyatt & Sims, 2012; Tatli & Ayas, 2013; Yang & Heh, 2007) while other studies' results showed no difference (Crandall et al., 2015; Darrah et al., 2014; Klahr et al., 2007). Adegoke and Chukwunenye (2013) examined the effect of computer simulated experiment on student's learning outcomes in practical physics. There were three groups: computer simulated experiment only, computer simulated experiment with hands-on experiments, and hands-on experiment. The results showed that the students who have studied by computer simulated and hands-on experiments are the best among three groups. They explained that the computer simulated experiments removed the mathematical reasoning effect and reduced the abstract nature of physics that will attract students to learn physics. Penn and Umesh (2019) examined the effects of using virtual learning environments (VLEs) on students' achievement in a physics content test. A sequential mixed method explanatory research methodology was followed, sixty-eight (n=68) third year physical sciences education students participated in this study. A physics content test was given pre and post Physics Education Technology (PhET) simulation laboratories and the activities, then it was followed by semi-structured focus group interviews. Findings from the study revealed that mean achievement scores in physics content tests improved significantly post intervention in VLEs. In Addition, Yang and Heh (2007) compared the impact of a virtual physics laboratory and a traditional laboratory in physics academic achievement. The sample (75 students) was equally divided into an experimental group and a control group. The experimental group has a significantly higher mean score than the control group in the physics achievement test. However, Darrah et al. (2014) evaluated using the virtual lab of an introductory physics course and compared it with hands-on experience. Each virtual lab contains objective, theory, 3D simulation, brief video, data collection tools, pre- and post-lab questions, and post lab quiz. They concluded that the virtual lab is effective as a traditional hands-on lab. Furthermore, Crandall et al. (2015) concluded that simulation could be used as replacements for hands-on laboratory experiences.

The reviewed research above, revealed different results of studies on the effect of using virtual lab on students' achievement, as a result, this study will investigate the effects of using virtual labs in learning physics on the level of achievement.

III. VIRTUAL EXPERIMENTS AND STUDENTS' PERFORMANCE

Of the studies that explored the effect of using virtual experiments on students' practical skills, many studies showed that virtual experiments helped students to gain better practical skills, which was reflected on their performance in the real lab (Alneyadi, 2019; Maldarelli et al., 2009; Radhamani et al., 2014; Yang & Heh, 2007) while the study of Sommer and Sommer (2003) revealed no difference. Maldarelli et al. (2009) explained that students improved their experiences with the lab techniques after viewing the videos on a biology course. Moreover, virtual labs improved student' performance in biotechnology course (Radhamani et al., 2014). Aljuhani et al. (2018) found that the virtual lab was an exciting, useful, and enjoyable learning environment because it allowed users to conduct experiments individually and repeat them multiple times if needed. In addition, Altun, Demirdağ et al. (2009) showed that the virtual chemistry laboratory is a helpful tool for students and teachers, especially those who have limited experiences in chemistry labs and making experiments. However, Klahr et al. (2007) explained that they were equally effective in producing significant gains in learners' knowledge about causal factors, in their ability to design optimal cars, and in their confidence in their knowledge. Tatli and Ayas (2013) concluded that virtual chemistry laboratory software was shown to be at least as effective as real chemistry laboratories because students felt self-confident; they could associate the experiment with daily life; and they had the opportunity to examine macroscopic, molecular, and symbolical levels of each experiment.

Based on the literature review above, qualitative tools will be used in this study to observe students' performance during conducting real lab after virtual lab. In addition, interviews will be conducted as well to explore students' views on using virtual experiments.

THEORETICAL FRAMEWORK

VIRTUAL LAB AS A TECHNOLOGY ENHANCED PHYSICS LEARNING ENVIRONMENT

Laboratory courses constitute a compulsory part of any bachelor program in physics and in science in general. They allow students to develop their practical skills, give them a feel of the complexity of the natural phenomena, and help them to understand how difficult it is to get secure knowledge about it (Josephen & Hvidt, 2015). In the digital age, technology enhanced physics learning environments offer opportunities to increase students' engagement, motivation, and positive attitudes toward science (Kapici et al., 2020). One form of those environments is the virtual lab. Virtual labs enable students to carry out experiments in an online environment and they can be used alone or in combination with other real hands-on labs (Roblyer & Hughes, 2019). Instructional design of virtual labs may involve the use of animation and simulation tools and instructional videos as well as interactive presentations. The theoretical perspective behind this instructional design is to provide a constructive learning environment, in which students can interact with online learning content in any time and place where internet is available and according to their pace of learning. Within the virtual lab, students can perform online experiments several times with less costs and safer conditions than in physical labs (Brinson, 2015). In addition, visualization of data and phenomena helps students to understand abstract physical concepts and ideas. According to the cognitive theory of multimedia learning, CTML (Mayer, 2005), the use of multimedia representation of concepts in both visual and verbal format allows learners to use both information processing channels at the same time and thus allows them to build their own mental representations and schemes.

INQUIRY-BASED VIRTUAL LAB IN PHYSICS EDUCATION

The primary goals of physics lab introductory courses are to help students to understand basic concepts and general ideas and to involve them in the discovery of the general principles. Research results suggest that such goals can be best achieved by inquiry-based learning (IBL) or inquiry instruction (Hofstein & Kind, 2012) in which students are involved planning an experiment, observing, collecting data, hypothesizing, analyzing experimental results and making predictions (Pedaste et al., 2012). According to Keselman (2003), inquiry-based learning is an instructional approach in which students follow methods and practices as scientists in order to construct knowledge. Thus, inquiry-based learning emphasizes active participation and learner's responsibility for discovering new knowledge (De Jong & Van Joolingen, 1998). The use of Information and Communication Technologies (ICTs) have the potential to support scientific inquiry as they can foster higher order thinking skills that are essential to scientific ways of thinking. In a virtual lab environment students can learn important inquiry processes, such as investigating scientific questions and issues through different web resources and digital content, gathering data through data logging with sensors and video measurement, analyzing data through online statistical programs, and communicating results online with tutors and peers (Roblyer & Hughes, 2019). In addition, dynamical modeling (collecting data from the theoretical world, theoretical inquiry) helps students to realize a system's structure, interaction between the objects, and their reactions. It engages the teacher and students in the modeling process in science by analyzing the situation, identifying the problem, translating into a model, generating and interpreting the outcomes including a graphical representation and text based modes using equation and text representation, and evaluating the model (Van Buuren et al., 2010). Banchi and Bell (2008) classified inquiry approaches into four levels (confirmation, structured, guided, and open) depending on how much information and guidance are provided by the teacher. Review of recent research revealed that learners acquire deeper understanding of science when virtual labs are combined with real hands-on labs in inquiry learning (Sypsas et al., 2019).

In this study, the virtual lab was so designed to encourage students' active participation and engagement in constructing their knowledge and acquiring mind and practical skills. This was done by developing interactive simulations that allowed students to perform the experiment online and to practice inquiry skills, for example, in an experiment titled "Measuring the Acceleration of Gravity, g" students changed the variable of length of pendulum and measured the period many times to collect different readings, draw graphs, and find out relations. Students are directed (directed-inquiry approach) to formulate hypothesis, perform experiments related to the learning material, and make conclusions. Another important component of the virtual lab design are the online videos. The development of those videos aimed at allowing the students to construct their knowledge on their own pace of learning so that they are well prepared to carry out the real experiments on their own. For example, the video on the experiment titled "RC Circuits" provided explanation on core scientific concepts like charging and discharging of capacitor as well as the procedure to build the circuit and collect data. In designing both, interactive simulations and online videos, multimedia representations of scientific concepts and ideas were strongly used. For example, in the experiment titled "Half-life of a draining water column" animation was used to illustrate the half-life of a draining water column, to collect data (length of water column and time), to draw a graph, and to calculate the half time.

RESEARCH OBJECTIVE AND QUESTIONS

The main objective of this study was to explore the effect of using virtual experiments on students' achievement and their performance in the hands-on lab in the general physics lab course at Birzeit University. It also aimed to explore the student's views about their learning and experiences of using blended learning model in learning physics lab course.

Research questions that guided the study are:

1. What is the effect of using virtual experiments on students' level of achievement?
2. How did the use of virtual experiments affect students' performance while conducting the real experiments?
3. How did the students evaluate the use of virtual experiments in their physics lab learning?

RESEARCH METHODOLOGY

In order to answer the study questions, mixed methodology has been followed. The quasi-experimental design was used for exploring the effect of using virtual experiments on students' level of achievement. In this regard, two groups of students have been compared: a control group of 45 students who studied the course using the traditional method (face-to-face theoretical presentation followed by practical work) and an experimental group of the same number of participants in which the theoretical presentation has been replaced by virtual session followed by practical work. Three virtual experiments were designed according to the principles of cognitive theory of multimedia learning. A test was applied to both groups after finishing the course. Observation was used to explore students' performance in the lab and semi-structured interviews have been conducted to identify students' views about using those virtual experiments for their learning.

THE SAMPLE OF THIS STUDY

The population of this study consisted of 272 students (12 sections) who were attending the general physics lab course and registered in the science and engineering faculties at Birzeit University. A convenient sample of 90 students (4 sections) was selected in this study. The selected sections had the same average score of a midterm exam that was conducted in the same course. The sample size is suitable to the quasi-experimental design followed in this study (Creswell & Guetterman, 2019) and within the range of samples used in similar studies (Penn & Umesh, 2019; Yang & Heh, 2007). The sample composed of two groups: the experimental group which consisted of two sections (section 1 n= 22, section 2 n=23), and the control group which consisted also of two sections (section 3 n=24, section 4 n=21). Twelve students were selected to be interviewed according to their reports provided on Moodle and asked about their experiences of using virtual experiments during their learning.

THE MODULE DESCRIPTION

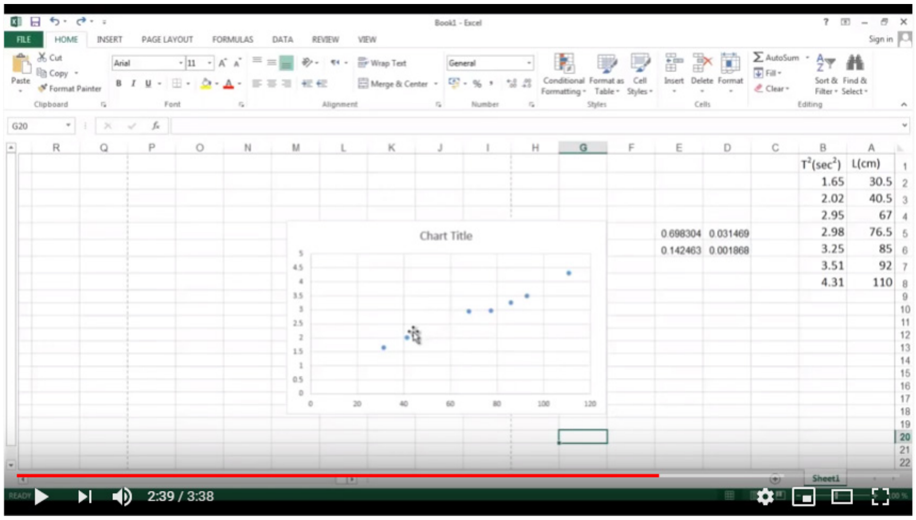
The virtual lab/experiments design started by identifying students' needs, course outcomes, resources, and infrastructure in cooperation with the physics department at Birzeit University. The next step was designing and creating the online activities and storyboard. Then, online videos and materials were produced and the platform of the experiments was developed. Three experiments were chosen from a physics lab course: Measuring the acceleration of gravity (g) at BZU, half-life of a draining water column, and RC circuit. These experiments were delivered online by a dynamic webpage and integrated within Moodle. Students have accessed these experiments through Moodle then conducted the practical work in the hands-on lab. More specifically, students have carried out the online and face-to-face activities as follows:

(1) Watching videos that explain the theoretical background and the physical concepts with animated graphics. For example, in measuring the acceleration of gravity (g) at BZU experiment, they learned about the relation between the length and period of the pendulum, the derivation of the equations, and how to use it for finding acceleration of gravity (g).

(2) Observing demonstrations of experiments' procedures using online videos. In these videos, the instructor introduced the equipment, how to construct the experiments as well as how to gather data as mentioned in the manual. For example, one of the videos presented how to hang the ball with the string on a stand and how to measure the period of pendulum with different lengths of pendulum, as represented in Figure1.

Figure 1. An example of a demonstration of an experiment procedure

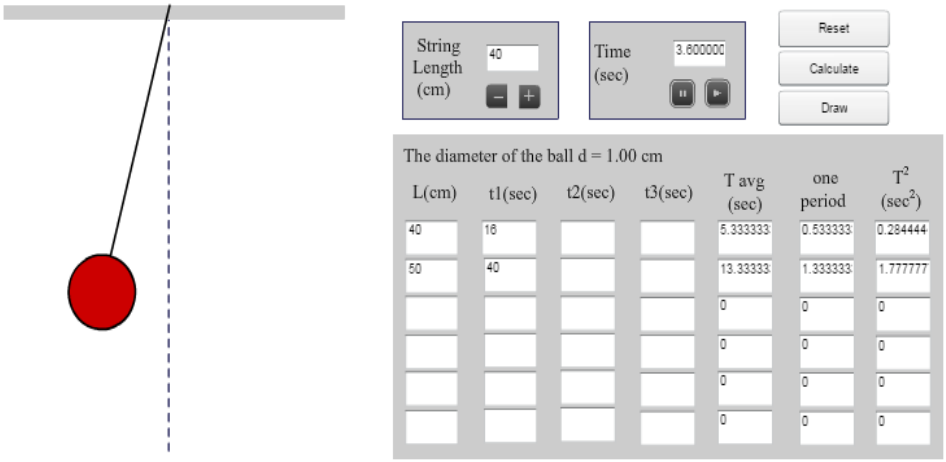
(3) Observing videos on how to find the required variables using the collected data. One good example is demonstrating how to use the Excel program to draw a chart between the period and the length of pendulum and find the slope, as shown in Figure 2.



A	B	C	D	E
L(cm)	$T^2(sec^2)$			
30.5	1.65			
40.5	2.02			
67	2.95			
76.5	2.98		0.031469	0.698304
85	3.25		0.001868	0.142463
92	3.51			
110	4.31			

Figure 2. An example of how to make the calculation using video

(4) Interacting with online simulations to gather data by changing the variables and get the values (online drill and practice). For example, the student will collect data by changing the length of pendulum then measuring the time needed after one period for many tries, as shown in Figure 3.



String Length (cm): 40

Time (sec): 3.600000

The diameter of the ball d = 1.00 cm

L(cm)	t1(sec)	t2(sec)	t3(sec)	T avg (sec)	one period	T^2 (sec^2)
40	16			5.333333	0.533333	0.284444
50	40			13.33333	1.333333	1.777777
				0	0	0
				0	0	0
				0	0	0
				0	0	0

Figure 3. Example of a simulation for pendulum (string length vs. period)

(5) Solving problems/questions on the main concepts and equations for each experiment and get prompt feedback from the system.

(6) Communicating with the instructor and collaborating with peers through open forums in Moodle before coming to hands-on lab.

(7) Conducting hands-on experiments in the lab after carrying out the online activities, students brought equipment and built experiments using the demonstrations provided in the online videos. Students worked as groups (face-to-face) on gathering data as mentioned in the report, and there was a teaching assistant to help them when needed.

(8) Each student has to write her or his own report outside the lab which consists of the aim of experiment, the methods used, background, the collected data, calculation, results, and conclusion. The instructor reviewed the reports and provided students with written feedback.

THE INSTRUMENTS AND DATA COLLECTION

Three research instruments were applied to collect data. The first instrument is a test that was utilized to identify the effect of using virtual experiments on students' level of achievement. Several researchers used tests to uncover the effect of using virtual labs/experiments on students' learning (Altun et al., 2009; Bajpai, 2013; Darrah et al., 2014; Yang & Heh, 2007). This test was considered valid (logical or face validity) as it was prepared by a group of instructors of the different sections in the physics department and built based on the learning objectives of experiments (Appendix A). Test-retest reliability was examined by repeating the exam after three weeks and calculating Pearson's r which was 0.75.

The second is observation, which was used to collect data on students' performance during the real lab (hands-on experiments). Both groups (experimental and control) were observed during conducting each of the three experiments. This instrument was used by many researchers to explore students' performance using virtual labs (Hatherly et al., 2009; Koretsky et al., 2008). The role of researcher was a balanced observer. This approach allowed adequate observation and recording of data during conducting the experiments (Savin-Baden & Major, 2013). The observation focused on: students' grouping and their discussion, teaching assistants' help (how much and what kind of help), peers support, ability to identify necessary equipment and experiments' construction, the ability to collect data and conduct experiments within the expected timeframe and speed, as well as body language. The above observed components were identified by consulting the course instructors and based on the study of Karagoz and Özdener (2010).

The third research instrument was semi-structured interviews that were conducted to explore students' views about using virtual experiments in their learning. Those interviews mainly used to ask students about the effects of using virtual experiments on their physics learning and about the pros and cons of that use (Appendix B). The development of the interviews' questions was based on the research question and literature review (Aljuhani et al., 2018; Scheckler, 2003). The interview protocol followed the structure outlined by Savin-Baden and Major (2013). It consisted of three main open-ended questions followed by probing questions to extract the responses of the participants for a deeper understanding. In addition, some of the questions that were raised tried to address the observations during the lab sessions. The interview questions were reviewed by three other physics educators and were modified accordingly. Interviews were audio recorded (after the acceptance of interviewer) and then transcribed to text for analysis.

DATA ANALYSIS

Quantitative data was analyzed using SPSS tabulating frequencies and descriptive statistics. An independent sample t-test was conducted to compare the students' level of achievement in virtual experiment (experimental group) and traditional lab (control group).

Thematic analysis was used to analyze the qualitative data collected through the observations and interviews. In this kind of analysis, the codes were assigned to the data and then patterns were determined by finding the frequency of the idea and categorizing them into themes (Savin-Baden & Major 2013). In order to ensure reliability of the analysis, the collected data was analyzed by another researcher and the reliability coefficient was calculated using Holsti equation (Holsti, 1969). The reliability coefficient of analyzing data collected in the interviews was 0.93 and 0.92 for the data collected in the observation. All quotes that were related to the themes were used as evidence to support the results.

RESULTS

After analyzing the data, the results are as follows.

EFFECT OF VIRTUAL EXPERIMENT ON STUDENTS' ACHIEVEMENT

Independent sample t-test was applied to examine the differences between two groups using student's mark in final exam. As shown in Table 1, the average of control groups is 3.42 and the average of experimental group is 3.07, and full mark is 5.00. The significant level (ժ) is 0.17 that infers there is no difference between two groups in achievements, which means that virtual lab has the same effect as traditional lab on student achievements.

Table 1. T-Test results for the mean difference between the control and experimental groups on the test

Group	N	Mean	Std. Deviation	Std. Error Mean
Control	45	3.42*	1.08	0.17
Experimental	45	3.07*	1.33	

Note. *The total mark of this test is 5.00

EFFECT OF VIRTUAL EXPERIMENTS ON STUDENTS' PERFORMANCE

Thematic analysis of the data collected using observation has revealed that students who learned with the virtual lab (experimental group) managed to prepare experiment equipment and devices and started to work without the introductory explanation from the instructor. They were also able to identify missing equipment, for example, a student asked for the caliper when he didn't find it on his desk in the hands-on experiment. The time spent to conduct the hands-on experiment and gather data was nearly the same for both students' groups (about 40 mins); however; students in experimental group managed to save about one third of the whole lab time as they did not need to attend the one-hour theoretical introduction.

The results showed mixed students' feelings. For instance, most students (about 60%) in the experimental group felt stress and anxiety at the beginning of the first experiment (#1) then the stress was gone as they went on to conduct the experiment. Other students (about 40%) started with confidence when they conducted the experiment. On the second and third experiments (#2 and #3), the level of stress and anxiety was much more reduced, and students become familiar and more confident in carrying out the real experiment.

The role of the teaching assistant was very critical in hands-on labs; he helped students to conduct the experiment in both students' groups. The type of assistance was same, but the percentage in experimental group was more than in control group, as shown in Table 2.

Table 2: Comparison of students' needed assistance in both experimental and control groups

Title of Experiment	Type of assistance provided by teaching assistance	Percentage of students needed support from experimental group (with virtual lab)	Percentage of students needed support from control group (traditional lab)
Measuring the acceleration of gravity g	put the pendulum string in handler split for swing	32 students out of 45 (~ 70%)	18 students out of 45 (40%)
Half-life of draining water column	made the titration of draining water column	22 students out of 45 (~50%)	13 students out of 45 (~30%)
RC Circuit	helped students in the circuit connection	12 students out of 45 (~25%)	7 students out of 45 (~15%)

STUDENT VIEWS ON USING VIRTUAL EXPERIMENTS IN THEIR PHYSICS LEARNING

Interviews with 12 students in the experimental group revealed the following themes in terms of the effectiveness of virtual lab in their physics lab learning.

Deeper understanding of physics concepts and better preparation for carrying out the experiments

The videos explained the physical concepts and the procedure of constructing and implementing the experiments very well, and that helped ten students (out of 12) to understand the experiments before and through the hands-on labs. For example, students were able to find the acceleration of gravity using the relation between the length of pendulum and period ($T^2=4\pi^2L/g$) by watching the online videos of this experiment. Students understood the derivative of this equation by finding the net force on the pendulum and analyzing the vertical and horizontal components of forces. They also figured out the reason for collecting period and the length of pendulum data before conducting the experiment. One of the students (participants) said: "Watching videos help me to understand exactly the experiments and how to conduct them, ... that made it easy to understand what was mentioned in the manual before the real lab." In addition, these videos assisted the students to make calculations such as calculating the slope and the error from the graph which was drawn using Excel as demonstrated in the video step by step; for example, a student said: "I watched the videos again when I wrote the reports, it is easier than the course manual because it was summarized and organized well, also videos assisted me in the implementation more than the traditional method." However, two students stated that the concepts in the theoretical videos need more details and explanation and have to be produced in a more attractive and interesting way.

Saving time in the lab

In the traditional lab, the instructor spent nearly one hour demonstrating the theoretical background and the procedure. Some students felt bored and exhausted by the long lab's time and like to finish the lab early. By using virtual experiments, all students agreed that saving one hour of staying in the lab encouraged them and gave them the feeling of being more comfortable during conducting the experiment in the lab. One of the participants described his experience in saving lab time as following: "My lab session started at 2:00 pm, I'm exhausted and very tired because I had many lectures before, that leads me to implement the experiment quickly to finish lab earlier without being focused. So, I liked saving lab's time using the virtual experiments."

Pace of learning and online videos

All students liked the feature of being able to watch the online videos again and again for different reasons. Ten students mentioned that they can repeat the theoretical videos to ensure that they understood well or to make sure that they understood the difficult scientific ideas and concepts. Four students liked that feature, because they felt shamed and confused when they asked the instructor to repeat the explanation face-to-face. One of the students said: "I liked the possibility of watching the online videos again, because when I ask the instructor to explain again, I feel sometimes that I interrupted her/him and that made me ashamed and I don't like to ask again."

In addition, six students needed to watch the videos again when they had to make calculations for the experiment report instead of asking the instructor during the office hours. A student stated: "The online videos assisted me in making calculations; I repeated them to review how to find the values which saved my time and effort for visiting the instructor in office hours to re-demonstrate. I found the answers of my questions through watching videos immediately without postponing the written report until visit the instructor." They also used the videos to study and prepare themselves for the final exam. Three students reflected how those videos helped in study and preparation by: "it is useful at the end of course, those videos were more accessible reference than instructor, because of many students have questions before the final exams that cause a pressure on the instructors' office."

Flexible learning environment

Twelve students liked the flexibility of the learning environment with virtual experiments. It allowed students learning at any time, for example, some students watched the videos before the lab's time while others watched them at night. In addition, it allowed the students to learn from anywhere as their home, library, or computer labs as they mentioned. The virtual experiments, which have been delivered to students through a dynamic webpage, allowed students to interact with them using personal computers, tablet, smartphones or other devices which encouraged them to study easily. The following are some quotations mentioned by students which supported this result:

> "I watched videos at convenient times; sometimes I watched videos at home."
> "I watched videos in the cafeteria using my phone."
> "I went to computer's lab to watch videos at the university."

Face-to-face interaction with the instructor

Five students preferred to have face-to-face interaction with the instructor in the lab because they felt more comfortable and safer. The following quotations represent one side of students' view about the presence of instructor in the lab:

> "We can't dispense with the instructor presence in the lab, even if we don't need her help. Her presence gives us the feeling of comfort and safety."
>
> "If the instructor is not there, I feel, as if something is missing. I think my instructor has extra knowledge that she may want to add … psychological matters!"
>
> "We like the way in which the instructor is asking questions and encouraging us to think, ... that's not available in virtual experiment."

However, seven students felt better to be more responsible for their learning and considered it as a chance to search and find solutions. For example, students said:

> "I prefer virtual experiments because I like to search myself for knowledge rather than to listen to the instructor's explanation."
>
> "It is a radical change in our learning, everyone depends on himself totally (100%), he/she is responsible to understand or not."
>
> "The presence of the instructor is not necessary; I can ask the teaching assistant if I need."

Participants encourage the use of virtual experiments

All students encouraged using more virtual experiments for their learning in this course and in other lab courses at the university. Here are some student's statements that support this result:

> "I encourage virtual experiments and I hope that all experiments in this course will be developed to be virtual."
>
> "I hope all experiments will be virtual in the future."
>
> "I hope all experiments will be developed with the same methods also the physics lab 2."
>
> "I think this model will be more effective in practical than theoretical courses."

DISCUSSION

For the first research question, results showed no significant difference on students' achievement between the experimental and control students' groups due to the use of virtual experiments; those results come in line with the results of other studies, such as Ambusaidi et al. (2018), Crandall et al. (2015), Darrah et al. (2014), and Klahr et al. (2007). This means that the online component including visual and verbal representations of knowledge succeeded to replace the face-to face-introduction part (Mayer, 2005). Despite that, the results of the first question did not prove our hypothesis; still the replacement of the real face-to-face practical lab by virtual lab represents a viable option. This is especially important in the emergency conditions that we are living in due to the COVID 19 pandemic. In addition, the level of achievement in the written test reflected knowledge acquisition rather than uncovering practical and science inquiry skills.

Results of the second question showed that students in both experimental (virtual lab) and control groups managed to perform well in the real lab. They were able to identify equipment and devices, construct experiments, collect data, make calculations, and find out the results and conclusion without attending the face-to-face theoretical introduction (as in the traditional lab). This comes in line with other research results that revealed that virtual labs managed to help students acquire necessary scientific inquiry and practical skills (Darrah et al., 2014; Keselman, 2003; Klar et al., 2007; Roblyer &

Hughes, 2019; Sommer & Sommer, 2003; Tatli & Ayas, 2013) and participate actively in constructing their knowledge (De Jong & Van Joolingen, 1998).

In addition, students in both groups spent almost the same time for building experiments' apparatus, using suitable devices, and collecting data (about 40 minutes). Also, students in both groups made similar errors while conducting the experiments but the quantity of errors done by students from the experimental group was more than the control group, because the videos need to be more precise and should pay more attention to the expected errors that usually students fall in, especially, in the "RC Circuit" experiment.

Third research question results confirmed the effectiveness of virtual lab in understanding and conducting the experiments. This is in line with the results of research conducted by Sypsas et al. (2019), which found that integrating virtual labs with practical labs help students to acquire a deeper understanding of science. More specifically, students mentioned that having the videos available online provided them with a flexible learning environment. They were able to watch the videos anytime, anywhere, and repeatedly according to their pace of learning which agrees with results found by Ramesh (2019). This allowed students to get better understanding of physics concepts and ideas and motivated them to continue learning. For example, interviews with students uncovered a deeper understanding of finding the value of unknown capacitor by calculating the time constant(τ) in charging and discharging cases, and then using the equation ($c= \tau/R$). Students explained that watching online videos to demonstrate charging and discharging of capacitors using graphs helped them to get a better understanding of how to find the time constant (τ).

In general, results showed that the combination of virtual lab with real lab is at least as effective as traditional real lab in terms of achievement but also has more advantages in terms of providing flexible and rich learning environments. The results regarding students' achievement test were different from the results revealed by observation and interviews. This can be explained due to the fact that questions in the achievement tests focused on students' theoretical and mathematical manipulations rather than examining students' conceptual understanding and hands-on skills. As the achievement test used in this study was the same final test that was set by the department, it didn't succeed to uncover the real impact of virtual lab on students' learning, which is a limitation of this study.

CONCLUSION AND FUTURE WORK

A major conclusion of this study is that online and interactive virtual experiments can replace theoretical presentations by the instructor before the practical lab as they provide similar students' performance and level of achievement. Those results support previous research results that showed that virtual instruction is at least as good as face-to-face traditional instruction. A core implication of the study results is that interactive and flexible online learning environments have the potential to provide students with a deeper conceptual understanding in learning physics. Virtual experiments have the potential to save time and cost for both students and university as they reduce presence hours at the university in the real lab and offer a solution of COVID-19 movement restriction as students can learn practical and scientific inquiry skills from home. Virtual experiments provide flexible learning opportunities that can overcome time, pace, and place barriers for learners from the community.

One limitation of this study is that we could not transform all experiments in the physics lab to virtual experiments. This study focused only on three experiments in different topics in physics; however, the nature of the experiment may affect the results. Another limitation is due to the use of written tests focusing on mathematical manipulations as a main tool to identify the level of students' achievement.

Thus, we recommend further investigations to include the development of whole physics introductory courses into virtual courses and to explore the development of other topics in science as well. We recommend also that future researchers combine both quantitative and qualitative methodologies to explore other factors that contribute to students' learning. We recommend expanding research on virtual lab to be conducted across different universities within different social and cultural contexts.

Results also showed that the virtual experiments (online environment) educational design has a critical role in getting the expected results. We recommend physics lab instructional designers and tutors to combine virtual lab with real lab in order to improve students' science inquiry and practical skills. In addition, we recommend educational practitioners to design the virtual lab with more interactive activities and make sure to design videos with short periods. Faculty members are also encouraged to use virtual labs instead of face-to-face lab theoretical introductions.

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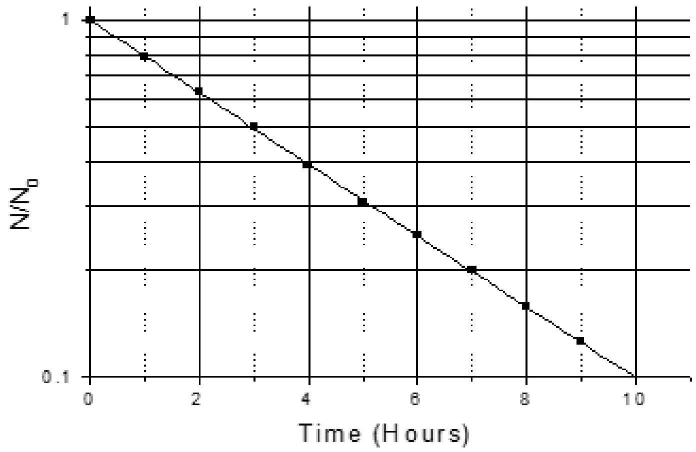
APPENDICES

APPENDIX A: ACHIEVEMENT TEST

1) A simple pendulum has a length of meters and a mass of 0.250 Kg (take $g = 9.8\ m/s^2$), then the period of the pendulum is:

a) 2.6 sec.
b) 2.7 sec.
c) 2.653 sec.
d) 2.65 sec.
e) 2.75 sec.

The following two questions are related to the exponential law of decay $N = No\ e^{-lt}$, where N is the number of nuclei (انوية) at time t. If N vs t is plotted on a semi-log graph paper, the following graph is obtained. Answer the following two questions



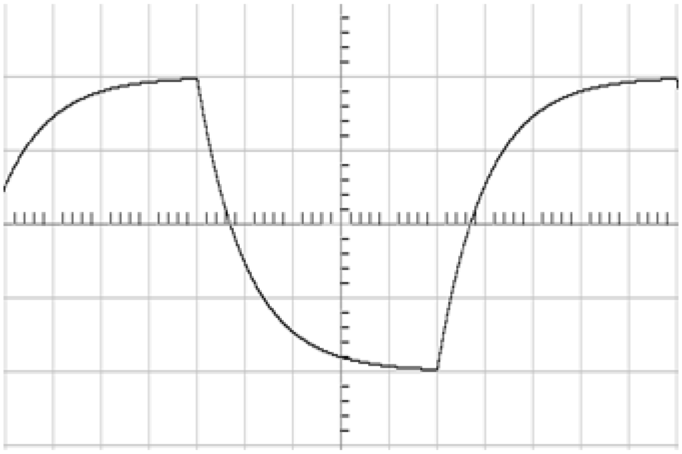
2) The decay constant l is equal to

a) 0.32 hr^{-1}
b) 0.09 hr^{-1}
c) 0.10 hr^{-1}
d) 2.30 hr^{-1}
e) 0.23 hr^{-1}

3) The half-life time of the decay is:

a) 0.38 hours.
b) 0.693 hours.
c) 1.0 hour.
d) 3 hours.
e) 0.16 hours.

The following graph represents the oscilloscope display of the voltage on the capacitor of an RC circuit. If R = Ω, and the voltage multiplier of the oscilloscope is set to volts/div, while the time base is set to 50 μs/div, then answer the following two questions



4) When discharging the capacitor, then the time it will take the voltage across the capacitor to drop 2.0 volts from the maximum, is approximately

- a) 10.0 μs.
- b) 20.0 μs.
- c) 40.0 μs.
- d) 100 ns.
- e) None of these

5) The value of the capacitor used in the circuit is closer to which of the following:

- a) 0.5 μF
- b) 1.0 μF
- c) 5.0 μF
- d) 2.0 μF
- e) None of these

APPENDIX B: SEMI-STRUCTURED INTERVIEW

Research: The effectiveness of using virtual experiments on students' learning in physics lab

Time of interview: ………… Date:.................................... Place:……………………………

Interviewer:... Interviewee:....................................

Interview procedure

You are being asked to participate in a research study titled ": The effectiveness of using virtual experiments on students' learning in the general physics lab". The purpose of this study is to explore the effect of using virtual experiments on students' achievement, their performance and their views in the hands-on lab in the general physics lab course at Birzeit University. The aim of interview is to explore students' view of using virtual experiments in their physics lab learning. During this interview, you will be asked to respond to several questions. You may choose not to answer any or all questions. The procedure will involve recording the interview, and the recording will be transcribed to text. Your results will be confidential, and you will not be identified individually.

Informed consent

Please sign the informed consent from signaling your willingness to participate.

Interviews' Questions:

1. How did the virtual lab affect your learning while studying the general physics lab course?

   a) How did the online videos affect your learning?
   b) Do you think that the online environment encourages you to learn? How?
   c) Do you think the presence of the instructor is necessary in the real practical lab? Why?

2. What are the cons and pros of using virtual labs in learning physics? Do you encourage using the virtual lab in all experiments in the same course?

3. What are your recommendations to improve the virtual labs?

Closing

Thank you for your participating in this interview. We appreciate you taking the time to do this. We may contact you in the future for the purpose of follow up interviews. Again, let me assure you of the confidentiality of you responses. If you have any questions, feel free to contact me by telephone at XXXXXXXXX

BIOGRAPHIES

Ghadeer Hamed is a senior instructional designer of e-Learning in higher education. She completed her Bachelor's in Physics minor Computer Science, and she received her Master's degree in Science Education at Birzeit University. She worked as instructional designer at Al-Quds Open University from 2011 to 2020 in designing self-paced courses, blended courses in different fields of specialization. In addition, she is a trainer for instructional designers, teachers, and students on the use Information & Communication Technologies (ICTs) in education. Her research focuses on the use of new educational technologies and their role to enhance learning and teaching.

Ahmad Aljanazrah is the dean of faculty of education at Birzeit University (BZU). He earned his Ph.D. in the field of Chemistry Education at Goethe University in Frankfurt am Main in 2005 and had his Postdoc research on the use of Web 2.0 Technology in Chemistry Education at the Technical University of Berlin in Germany in 2013. During his work at BZU, he worked as director of Ibn Rushd Unit for Educational Development and as a Program Officer in UNESCO Office in Palestine. His research interests lie in the area of using Information and Communication Technologies (ICTs) in Science and Higher Education, more specifically digital habits of students and teachers, flipped classroom and the use of virtual labs in science education.