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Effect of Using Virtual Lab Simulations on Student's Learning in Online General Physics Courses

Abdellatif Alsharif[1,*]

[1]CBT, Parker University, Dallas, TX USA

*Corresponding author: CBT, Parker University, TX, USA. E-mail: abdellatifalsharif@parker.edu

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Abstract

A survey was conducted to collect the student's learning outcomes when using virtual (simulation) labs in teaching. Two general physics courses [Phys I (2425) and Phys II (2426)] were chosen to conduct the survey. Five simulation experiments were performed by our students in Physics I and five experiments in Physics II. PhET (University of Colorado) interaction simulations were used by our students. The simulation experiments are covering most of the General Physics courses topics (Mechanics, Electricity, Heat, Thermodynamics, and Waves). Survey results show that performing the conventional simulation labs enhances the student's understanding of the theory and the physical concepts covered by the simulation. The resemblance of most simulations to real-life enables some of the students to improve or think of improving the simulation scenarios. The responses of our students indicate that the majority prefer that virtual experiments to be part of the conventional lab and not to be fully substituted.

Keywords: simulation experiments, virtual laboratory, online laboratory

1. Introduction

The COVID-19 pandemic focused the attention of worldwide educational institutions (Universities, Schools,) to adopt online learning in their teaching delivery systems. The pandemic forced every school, college, and university to switch to virtual online learning at the beginning of the pandemic. Adopting effective and suitable delivery methods is the main concern for the educators. What is required, is to adopt systems (computer networking, programs, software,) that allow delivering the teaching materials to the students effectively and cover different forms of learning activities and interactions (Barton et al, 1991, Kocijancis et al, 2002 Rogers et al, 1994) with the same level of knowledge that the students obtain in regular ground classes (on-campus).

Online virtual courses are not a new learning method. In the last 30 years, virtual online learning systems is used by many colleges and universities around the world. The technological advancements in computers (hardware and software) make online learning available to students worldwide. Simple computer knowledge will be enough to make this type of learning accessible to students. In the USA and since early-90 of the last century, thousands of classes are offered yearly in most universities in many programs and levels (non-degree/certificate/diploma/Bachelor up till Ph.D.). Online teaching is the fastest growing teaching delivery method preferred by most students, where this learning system enables the students to attend or/and watch the recorded lectures several times for more understanding and enables them to perform other duties and balance their personal and professional responsibilities with their studies.

Virtual labs, which are an important part of most science/engineering online courses, are defined as a learning module in which the theoretical concepts can be verified and demonstrated through experimental activities (simulations/animations) conducted by computers via the internet (Bajpai, 2013, Scheckler, R. K., 2003). The user has full control over the conditions, variables, simulation tools, and measurements to perform and direct the experiment in a way to achieve the best understanding and verification of the theory. Virtual labs used simulations and ready models like real-world activities and problems. Students are more attracted to real-world problems simulated/animated in the virtual labs. Virtual labs are being part of the learning tools for more than twenty-five years. Virtual labs are a very important part of the online learning modules for many science and engineering courses (Makinster et al, 2002, Noguez et al, 2006, Stuckey-Mitchell et al, 2007, Tatli et al. 2013). The obvious advantage of the virtual labs for the students is to enable them to repeat the simulations as needed, and to understand the theoretical concepts explained by the simulations and their results. Another (cost-wise) advantage, virtual labs reduce the cost on the educational institutions since tools/space lab requirements are being reduced (Hamed et al, 2020). To run the virtual labs effectively, what is needed is a suitable lap-top/pc/smartphone to run the lab (simulations/videos/models). The main disadvantage of virtual labs is the lack of immediate and direct interaction between the instructor and the students. In many sciences (Physics, chemistry, biology,) and engineering courses, the instructor/student interaction is a must and that's why many educators recommend that hybrid (virtual/conventional) labs are the favorite choice for most instructors and students.

Physics concepts in most of its aspects are practical and can be easily modeled to real-life experiences and observations. All general physics courses have a lab portion. This lab portion is an essential part of demonstrating practically what the students cover in their lectures. Student/Instructor in-class interaction considers an essential element in any physics lab. However, the COVID 19 pandemic forces the educators in many countries where online virtual labs were not yet adopted in their teaching systems, to consider virtual labs as an effective substitution when the direct interaction between the instructor and the students is not possible. The effectiveness of physics virtual labs on students' learning was investigated by several research groups (Bajpai, 2013, Adegoke et al, 2013, Darrah et al, 2014, Crandall et al, 2015, Jimoyiannis, 2001). Most of these studies concluded that physics virtual labs can be integrated with conventional labs. This integration will affect positively the student's understanding and their hand skills abilities.

2. Aim of This Work

1. Investigate the effect of using virtual simulation experiments on students learning in general physics courses.

2. Investigate the possibility of partial or complete replacement of the conventional labs of general courses with virtual labs and see the outcome of this on students learning and achievements.

3. PhET Interactive Simulation

PhET Interactive Simulations were used in our online virtual labs. Founded in 2002 by Nobel Laureate Carl Wieman, the PhET Interactive Simulations project at the University of Colorado - Boulder creates free interactive math and science simulations. PhET simulations are based on extensive education research and engage students through an intuitive, game-like environment where students learn through exploration and discovery.

4. Methodology

To study the effect of virtual simulation lab on the students learning for general physics courses, a survey was prepared focusing on the simulation processes and how these simulations affect the student's understanding of the material covered in class. Two courses offered were chosen for this study, Physics I-2425 (Mechanics) and Physics II - 2426 (Waves, Thermodynamics, Electricity and Magnetism). The survey was made available to the students online, after running at least four simulations. The experiments and the links are provided in table 1.

Table 1. The Virtual (simulations) Experiments Performed by the Students in Phys I (2425) and Phys II (2426)

Experiment	Physics	Link
The Moving Man	Motion in 1-D	https://phet.colorado.edu/en/simulations/moving-man Physics I-2425
Projectile Motion	Motion in 2-D	https://phet.colorado.edu/en/simulations/projectile-motion. Physics I-2425
Force and Motion	Newton's Laws	https://phet.colorado.edu/en/simulations/forces-and-motion. Physics I-2425
Ladybug Revolution	Circular Motion	https://phet.colorado.edu/en/simulations/rotation Physics I-2425
Energy Skate	Conservation of Energy	https://phet.colorado.edu/en/simulations/energy-skate-park. Physics I-2425
Torque	Rotational Motion	https://phet.colorado.edu/en/simulations/torque Physics I-2425
Wave on a String	Waves	https://phet.colorado.edu/en/simulations/wave-on-a-string. Physics II-2426
Wave Interference	Waves	https://phet.colorado.edu/en/simulation/legacy/wave-interference. Physics II-2426
Gas Properties	Ideal Gas	https://phet.colorado.edu/en/simulations/gas-properties Physics II-2426
State of the Matter	Phase Transition	https://phet.colorado.edu/en/simulations/states-of-matter. Physics II-2426
Electric Field	Electricity	https://phet.colorado.edu/en/simulations/efield Physics II-2426

A lab handout was distributed for all experiments. These lab handouts instruct to perform the simulation with several questions testing the understanding of the students. Our students performed five different virtual labs (simulations) in Phys I and five different simulations in Phys II. Table 1 shows the experiments performed by the students with its links in both courses (Phys I-2425 and Phys II-2426).

5. Results and Analysis

The results of the survey are shown in Tables 2 and 3 and in Figures 1 and 2. The main findings of the survey for Physics I (see table 3 for Physics II survey results) are summarized by the following points:

1) About 89 % of the surveyed students taking Physics I indicate that the simulations enhanced their knowledge and understanding of the physical concepts covered in the lectures (the rest of the students are neutral).

2) About 78 % of Physics I students approved that the simulation events were very close

to real-life events (the rest of the students are neutral).

3) More than 67 % of Physics I students think that the simulations are very exciting and attract their attention throughout the simulations (22 % of the students disagree and 11 % are neutral).

4) About 56% of Physics I students indicate that they felt that they are part of the experiment (33% of the students are neutral and the rest disagree).

5) More than 66% of Physics I students indicate that the simulations enhanced their creativity to think about other scenarios for the simulations (22 % of the students are neutral and 11 % disagree).

6) All students in Physics I believe that one important advantage of virtual labs is the ability to repeat any part of the simulation.

7) About 67% of Physics I students believe that performing lab simulations improved their IT abilities (22% of the students are neutral and 11 % disagree).

8) About 67 % of Physics I students supported using virtual labs as part of the conventional labs (33 % are neutral).

Careful analysis of the results indicates that using virtual labs has a positive effect on student learning. Virtual (simulation) labs visualize the material that the students cover in class and this will make understanding it easier for the students than just using the concepts/theories/equations they covered in lectures in solving physics problems. The ability of the students to repeat the simulations as much as is required till they achieve the best results and more understanding of physical concepts encourage the students to repeat the experiments till they obtain good results and understand the physical concepts. We believe that the students learning outcomes in virtual labs are much more than what they achieve in the conventional lab due to much more principles that can be verified by performing several parts of the simulations. This will increase the student's confidence in their abilities and break the barriers between them and physics as a hard subject to study.

Providing the students with a carefully prepared and clear handout will enable them to perform the simulation effectively and let them feel that they are part of the simulation. This is very important in the process of learning because feeling what you learn makes it faster and easier for one to understand. The lab handouts will minimize the direct and immediate instructor guidance to the students and allow them to depend on their understanding and abilities to work/repeat the simulation until they achieve better understanding. Some educators believe that the immediate and direct contact between the instructor and the students is essential, this is true to a certain extent, but this will also limit the student's dependence on their knowledge and abilities and slow the process of learning.

Table 2. The Survey Questions and the Percentage of the Answers for Each Question (Physics I-2425)

Question No.	Question	Agree %	Strongly Agree %	Neutral %	Disagree %	Strongly Disagree %
1	The simulations enhanced my knowledge of the concepts covered in the lectures	55.5	33.3	0	11.1	0
2	The simulation scenarios were very close to the real events.	33.3	44.4	22.2	0	0
3	The simulation events enhance students' understanding of the theory.	55.5	33.3	0	11.1	0
4	Virtual experiments are very interesting and attract attention throughout the simulation.	11.1	55.5	11.1	22.2	0
5	Working with simulations resembling real-life scenarios makes the lab exciting.	55.5	33.3	11.1	0	0
6	I got the feeling of being part of the experiment while performing the simulation	22.2	33.3	33.3	11.1	0
7	Lab simulations are easy to operate.	22.2	44.4	11.1	22.2	0
8	Lab simulation helped me to formulate other scenarios (creativity).	33.3	33.3	22.2	11.1	0
9	One important advantage of lab simulations allowing me to repeat the lab (or part of it) to verify my results	33.3	66.7	0	0	0
10	The objectives and the goals of the simulations were achieved.	44.4	33.3	22.2	0	0
11	At the end of the virtual lab, I feel that virtual labs improve my IT abilities.	44.4	22.2	22.2	11.1	0
12	Virtual laboratories must be used more in teaching.	22.2	22.2	55.6	0	0
13	Virtual labs should be part of the conventional labs.	44.4	22.2	33.3	0	0

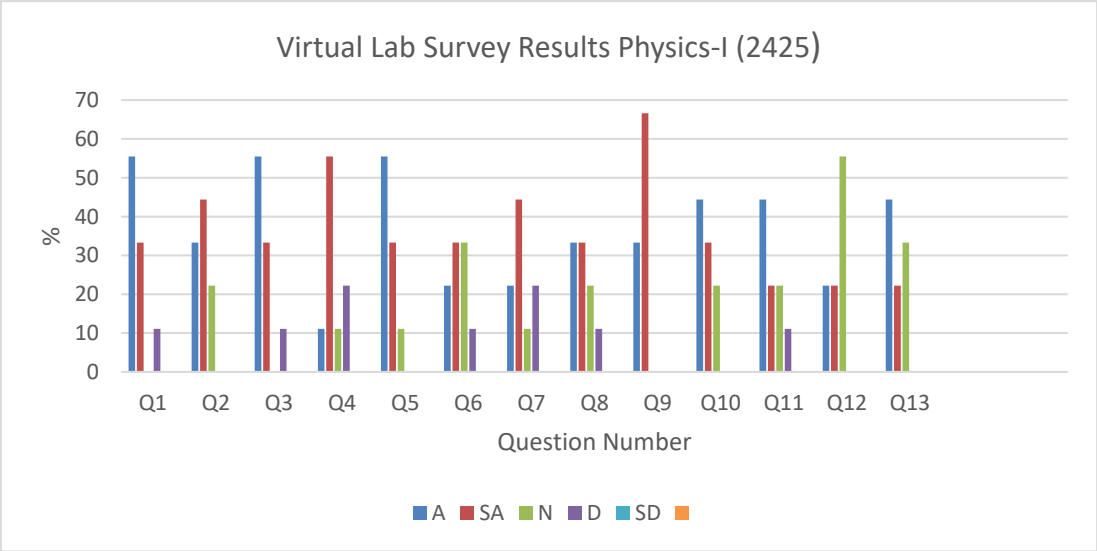

Figure 1. The Bar Diagram for the Phys-I student's Answers (Q: question, A: Agree, SA: Strongly Agree, N: Neutral, D: Disagree, and SD: Strongly Disagree)

Performing virtual (simulation) labs using instructors' prepared lab handouts, will help students to create their simulation scenarios by adding more steps to the lab handout. When students start to add more steps to the instructor's handout this means they understand and know what they are doing. The instructors must encourage this by adding extra points for the students who participate in such a process. One recommendation here, we believe that including a lab project in the student's assignments, where the students should write their handout for certain simulation links provided to them will enhance their creativity and understanding of the lecture's materials. We did this for one physics course at Parker University (Phys-1401), where a lab project assignment was added to this course. Three simulation links for three simulations were provided to the students to write a lab handout for one of these three simulations. The outcome of this assignment project is encouraging, and it will be discussed in a future paper.

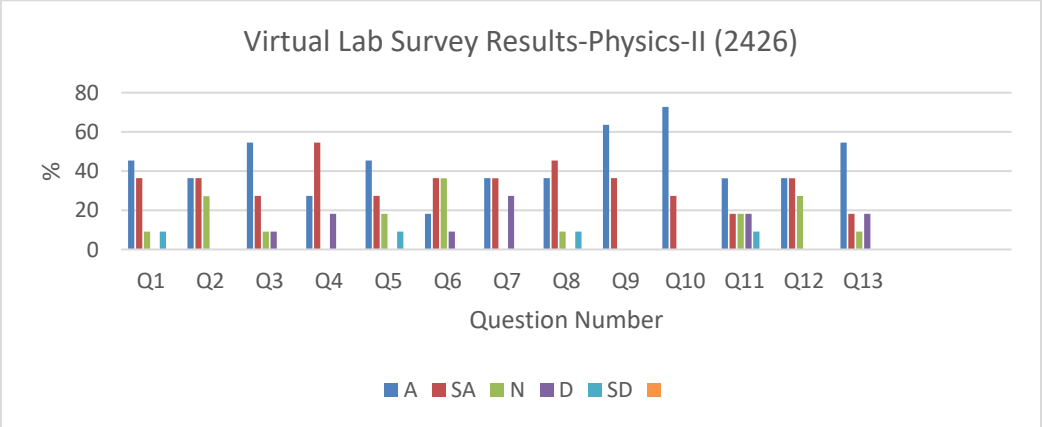

Figure 2. The Bar Diagram for the Phys-II student's Answers (Q: question, A: Agree, SA: Strongly Agree, N: Neutral, D: Disagree, and SD: Strongly Disagree)

Table 3. The Survey Questions and the Percentage of the Answers for Each Question (Physics II-2426)

Question No.	Question	Agree %	Strongly Agree %	Neutral %	Disagree %	Strongly Disagree %
1	The simulations enhanced my knowledge of the concepts covered in the lectures	45.4	36.4	9.1	0	9.1
2	The simulation scenarios were very close to the real events.	36.4	36.4	27.2	0	0
3	The simulation events enhance students' understanding of the theory.	54.5	27.3	9.1	9.1	0
4	Virtual experiments are very interesting and attract attention throughout the simulation.	27.3	54.5	0	18.2	0
5	Working with simulations resembling real-life scenarios makes the lab exciting.	45.4	27.3	18.2	0	9.1
6	I got the feeling of being part of the experiment while performing the simulation	18.2	36.4	36.3	9.1	0
7	Lab simulations are easy to operate.	36.4	36.3	0	27.3	0
8	Lab simulation helped me to formulate other scenarios (creativity).	36.4	45.4	9.1	0	9.1
9	One important advantage of lab simulations allowing me to repeat the lab (or part of it) to verify my results	63.6	36.4	0	0	0
10	The objectives and the goals of the simulations were achieved.	72.7	27.3	0	0	0
11	At the end of the virtual lab, I feel that virtual labs improve my IT abilities.	36.3	18.2	18.2	18.2	9.1
12	Virtual laboratories must be used more in teaching.	36.4	36.3	27.3	0	0
13	Virtual labs should be part of the conventional labs.	54.5	18.2	9.1	18.2	0

We believe that full substitution of virtual labs is not adequate for a subject like physics. We think that implementing virtual labs within conventional labs will be more suitable. Developing both hand and IT skills in our students to make our students ready for all kinds of challenges in their future careers. The survey supported this, where about 67 % of the students supported it while the rest were neutral. Extensive comparative analysis of the student's grades for virtual labs and conventional labs shows that the grades of the virtual labs are much better than the grades of the conventional labs. We believe this is due to the ability of the students to repeat the simulation till they get a better understanding and perform the simulation with high accuracy and obtain good experimental results.

One important advantage of working virtual labs is working individually not in groups as in conventional labs. Working labs individually will enhance and develop the process of students learning. Good students for certain simulations go beyond the instructions given in the lab handout and this will help in developing their creativity and self-understanding (Sypsas et al., 2019). Through our long experience in teaching physics laboratory, one of the major problems facing the instructors in conventional labs is the unequal participation of the lab group members in working the experiments. In most lab groups there is a dominant student and the rest are listeners. This of course will affect the process of learning among most of the students.

Another advantage of virtual (simulation) experiments is the ability to perform experiments that require extended large space, which is hard to achieve in a conventional lab environment/space. A similar conclusion was reached by many research groups (Hamed et al 2020, Chan C. et al,). For example, projectile motion simulation can be performed using a large horizontal range, with a wide range of velocities and angles. This will enable our students to verify all theoretical aspects of projectile motion that they covered in class.

6. Conclusions

Survey results show that performing the conventional simulation labs enhances the student's understanding of the theory and the physical concepts covered by the simulation. This is due mainly to the ability of the students to repeat the simulation or part of it when they are not sure about their results and its accuracy as they do obtain from applying the theory (equations, Laws, Postulates,). This is a direct advantage of the simulations which enhances our student's understanding.

The resemblance of most simulation to real-life scenarios makes it easy for our students to feel the simulations as they are part of it. This resemblance enables some of the students to improve or think of improving the simulation scenarios (creativity).

The space and time limit we usually encounter in virtual labs can be eliminated when performing simulation labs. Some of the experiments (e.g. Projectile Motion) need a large space and require a longer time than the usual period of the lab to work it. This space-time requirement can be attained when working on these experiments virtually.

One last important conclusion, the responses of our students indicate that the majority prefer

that virtual experiments be part of the conventional lab and not be fully substituted. We believe this is an important thing to take into consideration because one of the goals of the labs is to train our students to improve their hand skills to work in scientific environments properly. Combining virtual lab simulation experiments with the hands-on lab will achieve all the goals behind the labs in physics and most science and engineering courses.

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