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Virtual Simulation Lab Experiments versus Conventional Experiments in Teaching Physics - Comparative Study

Abdellatif Alsharif[1,*]

[1]Dept of GE – CBT, Parker University, Dallas, TX -USA

*Corresponding author: Dept of GE – CBT, Parker University, Dallas, TX -USA. E-mail: abdellatifalsharif@parker.edu

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Abstract

The debate regarding the use of virtual (online) labs and conventional (in lab) labs in teaching is still going on. The educators are divided into three groups regarding this issue, some are in favor of using virtual labs more than conventional ones, others are in favor of using the conventional labs more in teaching and the third group are in favor in implementing virtual experiments side by side with the conventional ones. The student opinions are very important for educators to get an in-field insight into their experience of using virtual labs. This will help the educators to decide which is more effective in teaching. We have conducted a survey on one of our Physics-2425 classes, seeking the opinions of the students about the use of virtual-simulation experiments versus the use of conventional experiments. During the lab period, the students worked on both types of experiments and some of the experiments were about the same physics principles. Our results show that working virtual labs enables the students to get more understanding than when working the conventional one due to the reduced limitations that the students usually encounter when working conventional labs due to the limited space/time. Other findings will be presented in this paper.

Keywords: online teaching, online physics lab, PheT simulation, conventional labs

1. Introduction

Since the adoption of virtual learning methods by many universities/colleges, an extensive debate started between the educators about the effectiveness of virtual learning and whether to widen its use for most programs (pure and applied sciences). One of the main goals for schools and universities/colleges is to provide the students with suitable learning delivery tools that facilitate the student's understanding. Laboratory portions are a very important part of many science and engineering courses. This lab portion is an essential part to clarify and strengthen the student's understanding of the material covered in classes [Clough, M. P. (2002), Magin, D. J. et. al. (1986), Nersessian N.J, (1991)]. Conventional labs are those labs performed by the students using their knowledge and their hand skills abilities to get a better understanding of the theory covered in lectures. These labs performed using ready on experiments, or those labs where the student combine the different parts of the experiment to set up the experiment (using the lab manuals) to reach to the proper design that allows the students to perform the experiment skillfully and accurately [Scanlon, E. et. al. (2002)]. One of the main problems when students are working in the conventional labs is that some of these labs are boring and do not attract their attention effectively to understand what is behind working these labs. This will affect the students' understanding due to the robotic performance of these experiments (following the instructions in lab manuals) without getting any more clarification of the material discussed in class. This raises a legitimate question within the educators whether the lab portion of any course satisfies all or most of the goals behind it. The answer to this question can be obtained directly from the student through a deep scientific investigation based on well-prepared surveys with adequate analysis.

In the last thirty years virtual labs started to take part in education [Albu, M. M. et. al., (2004), Goldberg F (1997), McAteer, E. et. al. (1996), Zacharia Z. et. al (2003), Wong et.al. (2020)]. Most of the recent studies have used virtual labs as a supplement to the conventional labs rather than a replacement. Some of the Virtual labs simulate real life activities/experiments, or it simulates non seen interactions or behavior of the microscopic world (atoms/molecules/ elementary particles) specially in the three-dimensional world [PheT simulations]. The tools, equipment and the different tests procedures are simulated in virtual labs, where the sense of performing the experiments is implemented in the student's mind [Alsharif (2022), Chang K. E. et. al (2008), Eylon B.S. (1996), Lewis E. et. al (1993). The students can also perform experiments simulating dangerous unsafe environments (radiation/high temperatures, etc.).

The main concerns regarding using virtual labs, is that virtual labs are not the best method to improve the hand -on skills when it comes to measurement, use of tools, and any activity that requires hands-on skills. We all know, one of the major objectives behind the lab portion in any course, is to develop the hand -on skills on students. Which is not achievable in virtual labs. In comparison to conventional labs, virtual labs might be more exciting to students due to the similarity between these labs and the computer games and the ability to perform these labs with high accuracy and precision. The excitement that the students may find in virtual labs will make it easier for them to understand and verify the theoretical principles of the course.

Besides the scientific advantages of using virtual labs, cost wise considerations are a very important factor for schools with limited lab budgets. Limiting the number of lab sections per course in many cases increases the number of students in lab sections which affects the student's gain from the labs. In conventional labs, students are grouped in groups of three or more based on the equipment availability and this again affects the student's gain from these labs, especially for students with limited knowledge about the experiment. Virtual labs allow the universities/colleges/schools to expand the lab-based courses to students by offering more sections allowing more students to enroll in these sections. One more advantage to using virtual labs is the ability to transfer to these lab forms during emergencies/disasters or pandemics as happened during the COVID-19 pandemic.

Simulation labs are worked individually and this, as all educators believe, is more effective for students to get a better understanding of the theory. All that is required is a computer able to perform the simulations following a well-prepared handout/instruction to perform the experiment. This handout must contain several conceptual questions that measure how much the students gained by performing the simulation.

In Physics, the lab portion is a crucial part in most physics' courses. Physics is a pure and applied science, where both the theory and its applications are usually studied in parallel for most physics' courses. Many researchers investigated the effectiveness of using virtual labs in teaching physics [Asiksoy G (2023), Guangyang Xu et. al (2018), Xiulin, Ma (2008)].

An intensive study must be done to reach a conclusion whether the conventional or the virtual labs are more efficient in teaching labs and which teaching delivery method is more suitable to achieve most of the goals behind teaching labs in science and engineering courses.

2. Aim of This Work

Our aim in this work is to investigate which is more effective in teaching physics laboratory, the conventional or the virtual – simulation labs. This goal cannot be achieved without the help of the students. Collecting the student's opinions about this issue by conducting surveys will help the educator to get an in-field insight about which is more acceptable to students, and which is more effective to achieve the main goals of learning. We hope after analyzing the student's responses to the survey questions (some of its questions is essay questions), to be able to give the educators the conclusions that help in giving them more insight about the more effective delivery method to teach physics laboratory for general physics courses.

3. PhET Interactive Simulation

"PhET Interactive Simulations were used in our online virtual labs. These well designed and prepared simulations were founded and created in 2002 by Nobel Laureate Carl Wieman, at the University of Colorado – Boulder. These simulations create free interactive math and science simulations. The simulations are based on extensive education research and engage students through an intuitive, game-like environment where students learn through

exploration and discovery" [https://phet.colorado.edu/en/]

4. Methodology

To study and determine which is more effective in physics laboratory teaching, a survey was prepared focusing on collecting student's opinion regarding the effectiveness of teaching laboratory for both laboratory teaching methods, the conventional (in -lab) method and the virtual (simulation) method. One physics course was chosen for this study, Physics I-2425 (Mechanics). The survey was made available to the students online after the students finished working and running all the experiments. Half of the experiments were conventional, and the other half were virtual. Two experiments were chosen, and our students worked on it with both methods, conventional and virtual.

Our students performed six different conventional experiments following the lab manual, Table 1. For simulation experiments, lab handouts were distributed for all the experiments. These lab handouts contain the instructions to perform the simulation with several questions (conceptual and based on the simulation). The questions are prepared in a way to test the student's understanding. The students performed six different virtual labs (simulations). Table 2 shows the experiments performed by the students with its links. The two experiments that the students worked on with both methods (conventional and virtual) are Hook's Law and the Balancing Act (Torque and Equilibrium).

Table 1. The Conventional Experiments Performed by Phys-2425 Students.

Experiment	Physics
Velocity and acceleration	Motion
The force Table	Vectors
Conservation of momentum	Momentum
Hook's Law and SHM	SHM
Torques and equilibrium	Equilibrium
Centripetal force	Circular motion

Table 2. The Simulation Experiments Performed by the Students in Phys-2425

Experiment	Physics	Link
The Moving Man	Motion in 1-D	https://phet.colorado.edu/en/simulations/moving-man
Projectile Motion	Motion in 2-D	https://phet.colorado.edu/en/simulations/projectile-motion.
Force and Motion	Newton's Laws	https://phet.colorado.edu/en/simulations/forces-and-motion.
Balancing Act	Equilibrium	https://phet.colorado.edu/en/simulations/balancing-act
Energy Skate	Conservation of Energy	https://phet.colorado.edu/en/simulations/energy-skate-park.
Hook's Law	Spring stiffness	https://phet.colorado.edu/en/simulations/hookes-law

5. Results and Analysis

The results of the survey are shown in Table 3 and in Figure 1. The main findings of the survey are summarized by the following points:

• 46 % of the surveyed students agreed that virtual experiments enhanced their knowledge about the material covered in the class more than the conventional experiments (33% neutral, 11% disagree).

• 83 % of the students agreed that the large-scale events of the simulation experiments improve their understanding more than the conventional experiments (17 % neutral).

• 33% of the students agreed that the simulation experiments are more interesting and attracted their attention more than the conventional ones (39% neutral, 28% disagree).

• 66% of the students agreed that the resemblance of the simulation experiments to real life scenarios makes it more exciting than the conventional experiments.

• 39 % of the students agreed that the simulation experiments make them feel they are part of the experiment compared to the conventional ones (17 % neutral, 43% disagree).

• 88 % of the students indicated that simulation experiments are easier to follow and operate when compared to conventional experiments (6 % neutral, 6 % disagree).

• 61 % of the students agreed that virtual simulation experiments encouraged them to create other scenarios, besides those in lab handouts (creativity) (17 % neutral, 6% disagree).

• 88 % of the students indicated that the most noticeable advantage for virtual simulation experiments is allowing them to repeat any part of the simulation to get more understanding and to verify the obtained results (6 % neutral, 6% disagree).

• 61% of the students agreed that virtual experiments must be used more in teaching (13 % neutral, 16 % disagree).

• 56% of the students agreed that virtual labs must be part of the conventional labs (39 neutral, 5% disagree).

The student's answers indicate that they prefer virtual-simulation experiments for many reasons:

• More understanding achieved due to the ability of students to investigate many of the theoretical concepts covered in lectures in a short time with easy simulation performance.

• Virtual/simulation experiments are more exciting to work on due to the resemblance in its scenarios to real life experience, especially for experiments require extended large-scale space. This can be emphasized by encouraging the students to create their own addition to the simulations.

• The ability of the students to repeat the simulation till they get more understanding.

• The results obtained by using simulations have less errors due to the accurate virtual tools the students use (meters, scales, ..).

• The simulations are easy to follow and perform due to its resemblance to the video games most of the students play.

• Exceptional students started thinking about new scenarios to be added to the simulations and this resulted from the more understanding of the theory.

Table 3. The Survey Result for Phys-2425

Q	Question	Agree %	Strongly Agree%	Neutral %	Disagree %	Strongly Disagree %
1	Comparing the virtual simulation experiments with the conventional ones, simulations experiments enhanced my knowledge of the concepts covered in the lectures more than the conventional ones.	39	17	33	11	0
2	Comparing the simulation experiments with the conventional ones, the large-scale simulation events enhanced my understanding of the theory.	61	22	17	0	0
3	Virtual experiments are more interesting than the conventional ones and attracted my attention throughout the simulation.	16.5	16.5	39	28	0
4	Working with simulations resembling real-life scenarios makes the simulation labs more exciting than the conventional ones.	33	33	17	17	0
5	Performing the simulation experiments gives me the feeling of being part of the experiment compared to the conventional labs.	28	11	17	33	11
6	Virtual simulation labs are easier to follow and operate than the conventional labs.	44	44	6	6	0
7	The virtual simulation lab encouraged me to create other scenarios than conventional lab (creativity).	33	28	17	22	0
8	One important advantage of virtual simulation experiments compared to conventional experiments is allowing me to repeat the lab (or part of it) several times easily to verify my results.	31	56	6	6	0
9	Virtual laboratories must be used more in teaching.	28	33	33	16	0
10	Virtual labs should be part of the conventional labs.	28	28	39	5	0

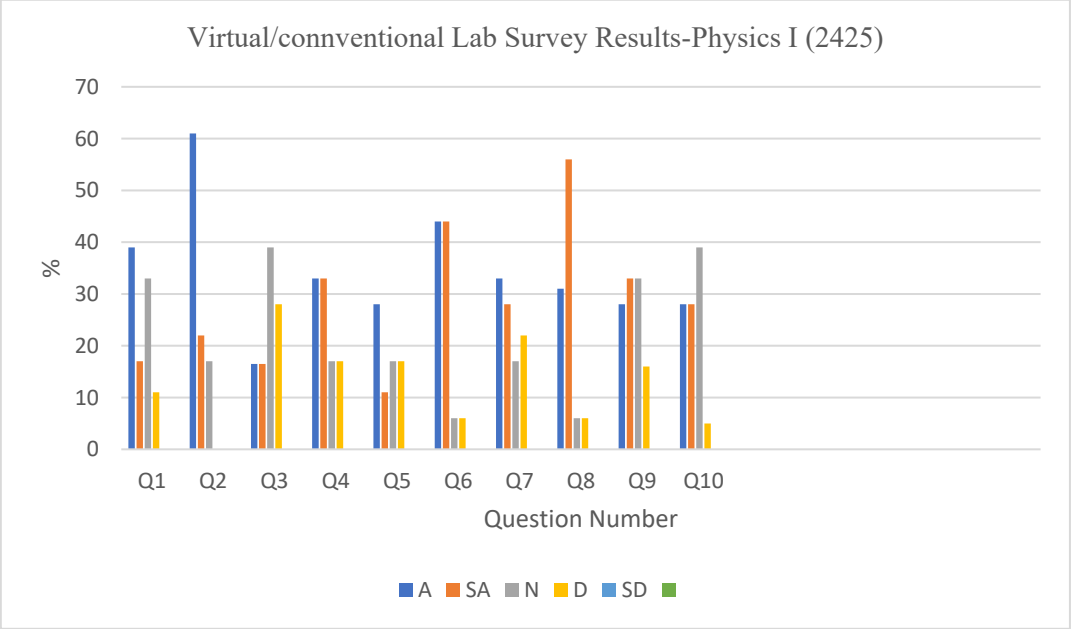

Figure 1. The Bar Diagram for the Survey Results for Phys2425

Part of the survey were three essay questions (the questions and the most common answers are given below):

Question 1: Give the advantages of using virtual simulation labs over conventional labs.

The most common answers are:

Answer1: The students can be more interactive in virtual labs because everyone can run the simulation individually on their own laptop.

Answer 2: The students can repeat the experiment or part of it till they get more understanding. Conventional labs need more time to repeat it, which is not achievable for most experiments.

Answer 3: The high accuracy of the results obtained from simulation labs compared to the conventional ones.

Answer 4: The ability of the students to repeat the experiment outside the lab time to get more understanding of the theory of the experiment.

Answer 5: The simulations have more options to get more information such as bar graphs, value indicators. These different options enhance the student's knowledge and understanding. Conventional labs are performed with limited options.

Answer 6: Ability to perform experiments that are usually not available in conventional labs (big objects, wide space experiment – projectile motion).

Question 2: Give the disadvantages of using virtual simulation labs over conventional labs.

The most common answers:

Answer 1: Students are less interactive with each other in virtual labs compared to conventional ones. This will affect students' team building component usually developed in conventional labs.

Answer 2: Very small chance to account for human error in virtual labs. This will affect the development of hand-on skills for students to avoid human errors (trial/error component usually practiced in most conventional labs).

Answer 3: Conventional labs are usually well explained, and less intervening required by the instructors. This will minimize the knowledge gained from the instructor/student interactions presented in conventional labs.

Answer 4: Virtual labs require technology access provided by the students (laptops), which is not all students can provide. Internet access is sometimes disturbed, and the simulation cannot be performed.

Answer 5: Students in many cases learn better by being able to handle things physically, which is achievable in conventional labs and not in virtual labs.

Question 3: Which of the two lab teaching methods (virtual simulation lab/conventional lab helped you more to link the experiment to the theory? Explain why?

Most of the students indicate that virtual simulation labs help them more to link the theory to the experiments and this was due to less distraction when working the simulation experiments than when working conventional labs. This distraction in most cases resulted from the technical issues (e.g. Wrong set-up, tools/devices not working) the students usually encounter when working in the conventional labs.

6. Discussion

Our results show a considerable acceptance of our students to the virtual labs. Their interactive performance with these labs enables them to get a deeper understanding of the theory and the physical concepts. This works well in constructing and enhancing their knowledge and understanding to be more prepared for the exams. This is very clear from their responses. Similar results were obtained by another research group [Sypsas A, (2019)]. Combining both virtual and conventional labs were highly recommended and preferred by the students. Virtual labs provide a more flexible environment for students and allow them to work on and verify most of the physical principles in adequate time. The ability of the students to repeat the simulation or part of it several times allows the students to get more understanding of the physical principles covered by the simulations and verify the accuracy of their results.

The educators believe that hand skills developed in conventional labs are one of the important goals behind working it to develop these skills. This will lead us to think of adopting an effective and acceptable model of combining virtual and conventional labs and get the

objectives of both teaching delivery method, more understanding of the theory and the physical concepts and improving the hand skills of our students. The answers of our students support the idea of mixing virtual and conventional labs to achieve all the goals behind the lab portion of physics courses, or in science courses in general.

The space/time issue is a very important factor that in many cases limits working on the conventional labs effectively. In conventional labs, more time is needed to perform the experiment and collect data in comparison with the virtual labs (simulations). The two hours conventional lab can be performed in about half of this time when working the same experiment virtually. The extra time can be used to work on more options usually presented in simulations. The space limitation existing in conventional experiments is not an issue in virtual labs, where the student can perform, for example the projectile motion experiment in an extended space reaching to few miles [Muthuprasad et. al. (2021)]. The outcome of the survey revealed this, and our students managed to get a more understanding of physical concepts without being affected by space/time limitations.

Virtual labs make learning enjoyable, enhances student-content interaction, and this affects much the student's collective achievements from every experiment. Virtual labs make Physics principles more connected to the real world due to the very close scenarios of the experiments to real life examples. Virtual labs motivated and created interest in students. It enhances the creativity of several students to think about adding other options to the simulation which will improve the learning outcome from it.

7. Conclusions

Careful analysis of the survey results indicates that virtual labs have a positive effect on student learning when compared with the conventional labs. Virtual (simulation) labs visualize the scientific concepts covered in the lectures, and this will enable the student to understand more what is discussed in lectures than just using the concepts/theories/equations in working classical and traditional examples.

The large (extended) space scale of many simulations' events/environment enables the students to understand the theory of the experiment and work more options that need large space provided in simulations (e.g. projectile motion experiment).

Conventional lab experiments require much more time to perform than the simulation experiments, and this enables the students to investigate many parameters, which are not investigated or verified when working conventional labs due to the limited time (and space for some experiments) to perform the experiments.

The effect of simulations scenarios on the creativity of our students is well noticed by many students where many suggestions were received by the students to improve the simulations and add more scenarios to it.

Most students agreed that virtual labs must be used more in teaching-when applicable- and at least to be part of the conventional labs.

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Data sharing statement

No additional data are available.