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PAPER

Effects of Virtual Lab Experiences on Students' Achievement and Perceptions of Learning Physics

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ABSTRACT

In engineering education, laboratory experimentation is as significant as theoretical education. However, inadequate laboratory facilities affect students' abilities to learn. This study aimed to investigate the effect of virtual labs on students' learning achievements and their perceptions of virtual physics lab activities. The study was carried out with 240 first-year engineering students enrolled in a physics laboratory course at a private university. In the study, data on learning achievement were collected from quizzes completed by students after the experiments. The data on the perception of the students about the virtual laboratory were collected at the end of the term, with the Virtual Laboratory Perception Scale shared online. The research results indicated that simulation-based physics experiments could positively affect students' learning achievements. In addition, it was revealed that most students had very positive perceptions of virtual laboratory activities. The results obtained from this study can guide educators to prepare more effective laboratory environments.

KEYWORDS

learning achievement, physics lab, students' perceptions, virtual laboratory

1 INTRODUCTION

The enabling effect of technology in every field also manifests itself in education, where education systems develop and change in parallel with technology [1].

The technology is widely used in all areas of education, especially in science education. Science experiments are crucial for students' cognitive development [2]. Nevertheless, some problems are encountered in applying the laboratory method, a very significant method in science education. The most common of these problems is the insufficient number of school laboratories. To add to this, even if there is a laboratory, there might be a shortage of equipment due to high costs [3]. Lack of time for longer experiments—and therefore, the impossibility of completing them—are other problems faced by students. Additionally, due to time constraints,

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the experiments cannot be repeated [4]. A lack of equipment causes some laboratory sessions to be conducted by teachers, with students merely watching [5]. In such cases, students can only passively observe the experiment, which can be both boring and distracting [6].

Given these problems, it is clear that suitable alternatives must be sought. Students' understanding of scientific concepts can be increased if appropriate technological tools are selected for laboratory activities and an ideal learning environment is designed [7].

Virtual laboratories, or virtual labs, are physical laboratory simulations that provide objects that are virtual representations of real objects used in real laboratory environments. Thus, these virtual environments help students associate their theoretical knowledge with practice [8], [9]. Virtual labs provide students and instructors with a laboratory environment with neither time nor space restrictions, allowing them to experiment whenever and wherever they want. During lab work in real labs, students are limited in time and can perform only a limited number of experiments and tests [10]. Since there are no time or material constraints in virtual labs, students can perform experiments repeatedly [11].

In real labs, instructors have limited time to ensure that each student gains the necessary knowledge and experience in the lab session. It may not be possible for each student to practice one-on-one with the experimental tools, especially in large groups. The solution proposed to this issue is virtual labs [8].

Performing risky experiments in a real laboratory environment is difficult, but virtual labs allow for it. Virtual labs allow the visualization of abstract objects that cannot be displayed in real labs [12]. They provide better learning, greater student motivation [13], and increased self-responsibility [14]. It has been proven that simulation-based science learning improves students' conceptual understanding, strengthens information retention, and improves inquiry process skills [15]. While many studies state the advantages of virtual labs, there are also studies emphasizing their limitations. To illustrate, students might need clarification or elaboration on acquiring knowledge through simulation [16]. In addition, they might need help relating concepts of virtual representations to real-world situations [17]. This may negatively affect students with self-learning difficulties. Furthermore, it is thought that virtual labs do not contribute to students' skills in psychomotor and affective areas [18].

Virtual labs have been widely used in education, but few studies have examined student opinions about them. Since students' expectations may change after experiencing a virtual lab, they need to reveal their thoughts after the experience [19]. Consequently, some supportive strategies or practices should be introduced to work with simulation-based science learning to promote a more successful experience for students. Although many studies have reported positive effects of computer simulations on learning, there are very few studies on how university students understand basic physics concepts with simulations [20].

In this context, this study aimed to investigate the effect of the virtual laboratory on students' learning achievements and perceptions of virtual physics laboratory activities. For this purpose, the following research questions were examined:

- Is there a significant difference between the learning achievements of students who perform real and virtual laboratory activities?
- What are participants' perceptions toward virtual physics laboratory activities?

1.1 Simulations in teaching science

Virtual labs are environments simulated by computer programs, where students can access and conduct experiments [21], [22]. According to Alves [23], virtual labs are computer programs that provide flexibility, accessibility, reproducibility, and security, allowing students to work without time and place restrictions on their learning conditions.

Many empirical studies have reported the effects of using computer simulations in educational settings. For instance, Srisawasdi and Panjaburee [24] conducted a study to investigate simulation-based formative assessment effects on secondary school students. According to the study's results, the student's understanding of scientific concepts increased significantly when simulations were integrated into formative assessments. Kapilan [25] stated that most of the participants reported that they were satisfied with virtual labs after experiencing them during the pandemic period. Virtual laboratories should even be included in engineering curricula, according to students. Falloon [16] used simulations to teach children basic circuits. He concluded that with appropriate teacher support, simulations could effectively introduce young students to simple physical science concepts and provide them with opportunities to engage in higher-order thinking processes. Correia [26] used PhET simulation to investigate secondary school students' perceptions of the simulation-based learning system and its impact on their learning of science concepts. The findings showed that simulations could support students' conceptual change in the science-learning process.

2 METHODOLOGY

2.1 Participants

The study was conducted during the 2020–2021 fall term (N = 240 students). The control group (N = 120: 63% male; 37% female) was first-year engineering students enrolled in Physics Lab-1 in the spring 2019–2020 semester. The experimental group (N = 120: 67% male; 33% female) was first-year engineering students enrolled in Physics Lab-1 in the fall 2021–2022 semester.

Control group students performed their physics experiments in real laboratories, while the experimental group carried out the experiments using simulations supported by GeoGebra Software. Experimental-group students had no previous experience using the Virtual Physics Lab application. The physics instructors in both groups were the same, and the students attended a physics lab class once a week.

2.2 Data-collection tools

This section describes the data collection tools used to obtain data on students' learning achievement and perceptions of virtual labs.

Lab quiz. Data were obtained from the quizzes after each experiment to measure the achievements of both group of students in the lab course. Quizzes included questions on conceptual understanding and experimental tests for every experiment. The learning achievement was determined by calculating the mean of the results of the six quizzes.

The Virtual Laboratory Perception Scale. A Virtual Laboratory Perception Scale was used in this study, which was developed by Ekici [27] to get the experimental group students' perceptions of the virtual lab. After completing the 6-week experiments, the scale was shared with the students via Google Forms. Thus, data on students' virtual lab perceptions were collected. The scale consists of 16 items: nine positive and seven negative expressions and a five-point Likert scale (1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly Disagree). Cronbach's alpha reliability coefficient was calculated as 0.82.

2.3 Data analysis

The Likert scale data were analyzed using descriptive statistical techniques, mean, and standard deviation. The data obtained from the quizzes were analyzed with the t-test.

2.4 Instructional procedure

First-year engineering faculty students take the Physics Lab-I course. Seven different experiments were conducted over seven weeks, with a participation time of 2 hours for each experiment.

Control group activities. The experimental sessions took place weekly. Physics lab instructors shared a document containing theoretical information, a short video explaining how to experiment, and a table where students would save their data. These materials were shared two days before the experiment day on the Physics Lab course page opened on the Moodle platform. First of all, students logged into Moodle with their username and password to enter the course page. After watching the video and reading the document the day before, the students went to the laboratory. Experiments were conducted face-to-face in a real laboratory environment. After performing the experiments, a quiz was given by the instructors. Finally, the instructors checked the students' data and quiz answers.

Experimental group activities. In the first week, students were trained to conduct simulation-based experiments. Two days before each experiment session, instructors shared a document containing theoretical information about the experiment, a short video on how to do the experiment, and the e-table where they would save their data on the Physics Lab course page opened on the Moodle platform. Students watched the video and read the document before the experiment took place. On experiment day, the instructors uploaded the simulation to the Moodle platform and made it available to students. The simulations were created using the software GeoGebra (Figure 1).

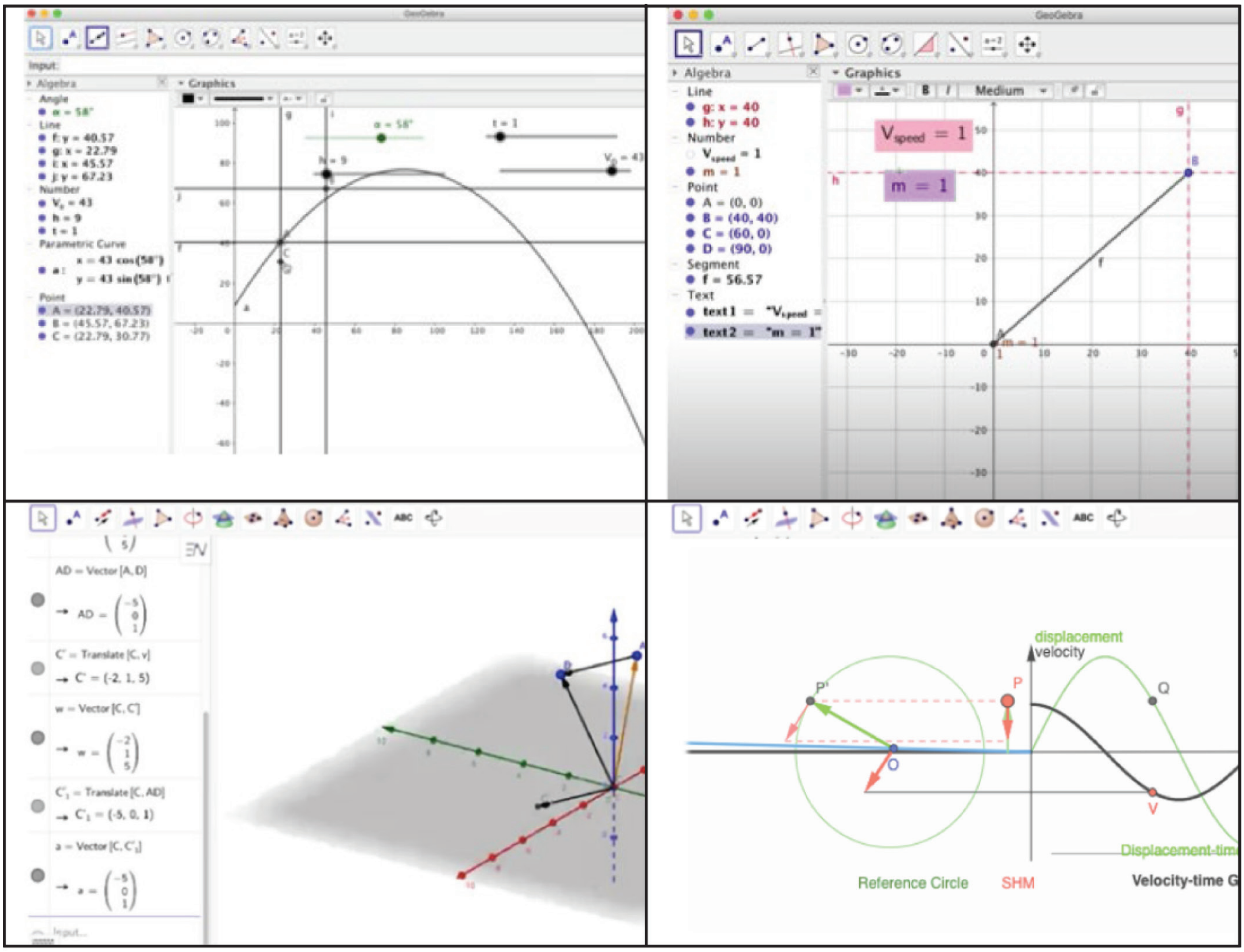

Fig. 1. Screenshots of simulation activity on physics lab course

On the days of the experiment, the students experimented on the Moodle platform and recorded their data in the spreadsheet. Finally, they answered the quiz questions. After seven weeks, the Virtual Lab Perception Scale on Google Forms was shared to determine the students' perceptions of the virtual physics lab (Figure 2).

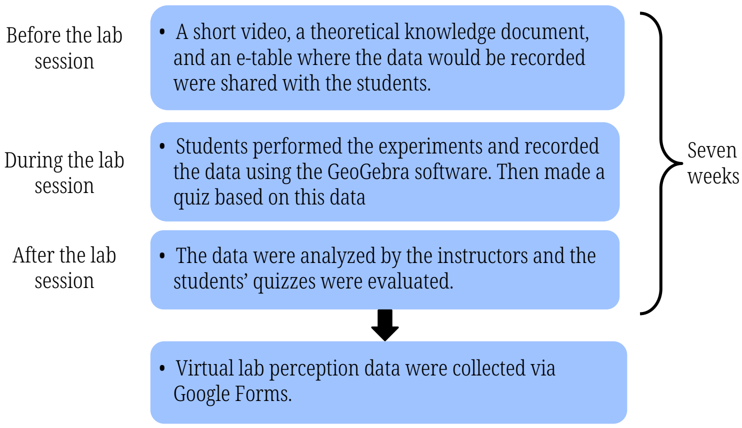

Fig. 2. The procedure of experimental group activities

3 RESULTS

3.1 Analysis of learning achievement data

The results obtained from the quizzes applied after each experiment showed the learning achievement of the students. The passing grade of the students was determined by the quizzes held after the experiments every week for six weeks. Based on the quiz results, an independent sample t-test was conducted (Table 1) to determine the conceptual understanding levels of both groups.

Table 1. Students' learning achievement

Group	N	Mean	SD	*t*	*p*
Control	120	66.369	16.475	1.970	0.047
Experimental	120	70.394	14.642		

Notes: N: sample size, Mean: average value, SD: standard deviation, *p*: probabilistic significance (0.05 level), *t*: ratio of the difference between the means to the variation within the samples.

The statistical data revealed that the results of the learning achievement test significantly differ between the control and the experiment groups ($t = 1.970$, $p < 0.05$). According to this outcome, simulation-based physics experiments can contribute positively to students' conceptual understanding.

3.2 Students' perceptions of the virtual physics lab

The study determined students' perceptions of the virtual laboratory application. The analysis of the data obtained through Google Forms is presented as the percentage mean (M) and standard deviation (SD) (Table 2).

Table 2. Students' perceptions of the virtual laboratory

Item No.	Survey Items	M	SD	Response
Positively expressed items				
3	All lab activities can be done virtually.	3.95	1.20	Agree
4	Virtual Lab activities increase my motivation.	3.85	1.25	Agree
6	Virtual Lab activities increase learning speed	3.96	1.20	Agree
7	Physics education curriculum is suitable for virtual lab applications in terms of the program.	3.37	1.26	Neutral
10	Virtual Lab activities provide a learning environment suitable for individual differences.	3.83	1.27	Agree
11	Virtual Lab activities provide flexible learning environments independent of time and space.	3.92	1.25	Agree
12	Virtual Lab activities allow repeating whenever I want.	4.33	0.94	Agree
15	Virtual Lab activities are more enjoyable than real experiments.	4.35	0.94	Agree
16	The Virtual Lab succeeds in Physics ed.	4.03	1.14	Agree
	Total	3.95	1.16	Agree

(Continued)

Table 2. Students' perceptions of the virtual laboratory *(Continued)*

Item No.	Survey Items	M	SD	Response
Negatively expressed items				
1	Not being able to do real lab activities makes me unhappy.	1.98	1.08	Disagree
2	Virtual Lab work wastes my time	2.13	1.25	Disagree
5	Virtual Lab experiments negatively affect my learning.	1.96	1.16	Disagree
8	Virtual Lab activities do not lead to thinking and research.	2.15	1.23	Disagree
9	Virtual Lab activities are insufficient to embody abstract concepts.	2.05	1.20	Disagree
13	Virtual Lab activities do not improve the ability to recognize and use experimental tools.	2.04	1.21	Disagree
14	The Virtual Lab method is technically challenging to implement.	2.09	1.21	Disagree
	Total	1.80	1.04	Disagree

Note: M: mean, SD: standard deviation.

As seen in Table 2, the total mean score of the positive expression items was 3.95 (SD = 1.16), which indicates that students have positive perceptions about simulation-based experiments. From the answers students gave to the positive items, it was revealed that they wanted all lab activities to be virtual (M = 3.95, SD = 1.20). They also stated that simulation-based experiments increased their motivation (M = 3.85, SD = 1.25) and learning speed (M = 3.96, SD = 1.20).

However, it was determined they were neutral about the expression "Physics education curriculum is suitable for virtual lab applications in terms of program" (M = 3.37, SD = 1.26), which means students could not decide whether the curriculum is suitable for virtual labs.

Students stated that virtual lab applications address individual differences (M = 3.83, SD = 1.27), provide a learning environment independent of time and space (M = 3.92, SD = 1.25), and provide the chance to do the experiments multiple times (M = 4.33, SD = 0.94).

In addition, it was determined that the students found the simulations enjoyable (M = 4.35, SD = 0.96) and agreed that it was a successful method in teaching physics (M = 0.03, SD = 1.14).

The overall mean score of the negative-expression items was M = 1.80 (SD = 1.20). The scores of the responses given by the students to the negative expressions were as follows: Item 1, "Not being able to do real lab activities makes me unhappy" M = 1.98 (SD = 1.08); Item 2, "Virtual Lab work wastes my time" M = 2.1, (SD = 1.25); Item 5, "Virtual Labs activities prevent me from learning by doing" M = 1.96, (SD = 1.16); Item 8, "Virtual Lab activities do not lead to thinking and research" M = 2.15, (SD = 1.23); Item 9 "Virtual Lab activities are insufficient to embody abstract concepts" M = 2.05, (SD = 1.20); Item 13 "Virtual Lab activities do not improve the ability to recognize and use experimental tools" M = 2.04, (SD = 1.21); and Item 14 "The Virtual Lab method is technically challenging to implement" M = 2.09, (SD = 1.21). These findings reveal that students do not perceive virtual labs.

4 DISCUSSION

The purpose of this study was to examine how virtual physics lab activities influence students' perceptions and conceptual understanding of science.

The study suggests that the conceptual understanding test results of the students who did physics experiments with simulations were significantly higher than those who did real lab experiments. This result was consistent with earlier research on nursing education [28], business education [29], chemistry education [30], science education [24], and mathematics education [31]. Similarly, Luo et al. [32] used a web-based interactive simulation tool in teaching physical geography laboratory courses in their study. They stated that students preferred simulations and performed better on higher-order thinking tasks. Correia et al. [26] reported PhET simulations could support students' conceptual change in the science-learning process. However, the difference between these studies is that our study is an online physics laboratory course.

According to another result of the current study, most students had positive perceptions of performing physics experiments in a virtual lab. In contrast to the limited number of experimental devices and the large number of students in real lab environments, this study clearly shows that students could repeat the experiments as much as they wanted in virtual labs, with no time limit, and with the visual-dynamic structure of simulations, students were drawn in.

In addition, the current study highlights that students find that virtual lab activities are enjoyable, increase their motivation, and support personalized learning. These results are consistent with the studies exploring students' perceptions of virtual lab experiences [8], [33], [34], [35]. Therefore, the results of these previous studies support the results of the current study.

5 CONCLUSIONS

Laboratory courses are essential in engineering education to improve student skills and validate theoretical concepts. The use of simulation technology for learning helps students grasp complex concepts more quickly.

The findings of this study showed that the virtual physics laboratory had a positive effect on the learning achievements of the students and that the students' perceptions of the virtual experiments were positive. Thus, it is recommended to develop and use different simulations for other laboratory courses based on the results of this study.

There are a few limitations to this study. First, physics experiments were performed with GeoGebra software. Using other simulation software in addition to GeoGebra is recommended for future studies. The second limitation of the study was that the number of experiments was limited to six. To investigate their long-term effects on learning, additional research and experiments are needed.

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