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RESEARCH ARTICLE

Investigating the Effects of Virtual Laboratories on Students' Motivation and Attitudes Toward Science

Dareen Shukri A. Alnaser, Sufian Forawi

Department of Science Education, Faculty of Education, The British University, Dubai, United Arab Emirates

***Corresponding Author:** 21000864@student.buid.ac.ae

ABSTRACT

Allowing students to practice science inquiry in the classroom is fundamental for science education. Students should master investigation skills, promoting their understanding of science concepts. Virtual laboratories have emerged as a powerful interactive tool that can be a suitable alternative to real laboratories, especially when lacking enough equipment and safety measures. This mixed approach study investigates the effects of virtual science laboratories on students' motivation and attitude toward science (ATS). Students (n = 237) from grades (7, 8, 9, 10, and 11) were surveyed to evaluate their virtual laboratory experience in an American curriculum private school in Dubai with the theoretical basis of motivation theories. The study reported that virtual laboratories positively impact students' overall motivation in terms of intrinsic motivation, perceived usefulness (U), effort (E), perceived self-efficacy (SE), and ATS. Students, perceived SE and U significantly impact student attitudes toward science ($p < 0.001$). Students' perceived SE is a predictor of their E in the laboratory by 6.1%. Students with high SE put more E into completing a virtual laboratory task than students with low SE.

KEY WORDS: Attitudes toward science; self-efficacy; students' motivation; virtual laboratories

INTRODUCTION

Technology nowadays is part of every aspect of our lives and this also applies to the educational field. The use of technology in classrooms has been a subject of study in past years, which caused a shift in teaching methods and educational processes, as well as reforming curriculum to have more technology integration (Siyam et al., 2022). The UAE Ministry of Education sanctioned the importance of technology and had plans for proper implementation and use of technology in schools (Siyam and Hussain, 2021). Virtual laboratories, for example, are one of the many advancements in learning media as a practical implementation of technology in science education (Anam et al., 2019).

What makes science different from other subjects is its practical nature that involves conducting experiments to explore phenomena, so doing proper experiments can increase students' motivation toward science (Ayesh, 2004; Siyam, 2017). Learning science cannot be isolated from experiments due to the peculiarities of science subjects, which need mastering knowledge and including discovery. Experiments, often known as practicums, are vital tools and strategies for better understanding scientific phenomena and delving deeper into scientific ideas (Liu et al., 2015). Computer simulations can enhance students' inquiry skills, especially during the COVID-19 pandemic. It becomes necessary to incorporate virtual laboratories to teach complex science concepts (Koehler, 2021). Virtual laboratories have design features that allow students to critically investigate science phenomena, such as graphing tools, manipulating variables, collecting data, and moving interactive models and images (Sari et al., 2019). Laboratory work, computer simulations, and virtual laboratories are interconnected tools in the scientific toolkit. They offer a spectrum of options for conducting experiments, learning, and advancing our understanding of the natural world.

Virtual laboratories and computer simulations have been investigated and studied as a learning environment over the years (Ambusaidi et al., 2018; Irwanto, 2018; Reeves et al., 2021). Many of these researchers evaluated the impact of virtual laboratories on students' conceptual understanding and learning outcomes to that real laboratories (Chang et al., 2008; Faour and Ayoubi, 2018; and Rutten et al., 2012; Son, 2016). There have only been a few attempts to investigate the impact of virtual laboratories on students' motivation and attitude toward science (ATS).(Ambusaidi et al., 2018; Koehler, 2021).

We must be concerned with inquiries that explore how students engage in laboratory work and continue at such activities since motivation is an essential variable for academic learning and accomplishment (Dohn et al., 2016a). In this study, we investigate the impact of virtual laboratories on students' intrinsic motivation (IM), perceived usefulness (U), self-efficacy (SE), and attitude toward science (ATS). This study also investigates the impacts of students' SE and perceived U on students' attitudes toward science. Moreover, it investigates the effect of students' SE on the amount of effort (E) they put into the virtual laboratory tasks. Thus, this paper aims to answer the following questions:

- RS1: What effects do virtual laboratories have on students' motivations, SE, and attitudes toward science?
- RS2: What is the impact of students' perceived SE on their attitudes toward science?
- RS3: What is the impact of students' perceived U of virtual laboratories on their attitudes toward science?
- RS4: What is the impact of students' perceived SE on the amount of E they put in when conducting a virtual laboratory?

Theoretical Framework

Inquiry in forms of laboratory work is an integral part of science education. It allows students to practice scientific processes and master investigation skills (Ernita et al., 2021). Virtual laboratories (e.g., Labster, PhET, and Gizmos) are commonly used in schools as a substitutional and support inquiry tool. For this reason, studying the effectiveness of this type of laboratory environment is essential. Motivational effects on virtual laboratories are less commonly studied and measured. Hence, this study aims to investigate the effectiveness of virtual laboratories on students' motivation and ATS. "Motivation has been defined as the process whereby goal-directed activities are initiated and sustained. In expectancy-value theory, motivation is a function of the expectation of success and perceived value" (Cook and Artino Jr., 2016, p. 997).

According to motivational theories such as social cognitive theory developed by Bandura (1977) and expectation value theory developed by Wigfield and Eccles (2002), motivation to learn consists of many components such as SE, outcome expectations, value, task interest, and goal setting. This study will focus on IM, utility (or U), E invested, SE, and attitudes toward science. IM refers to interest and enjoyment in doing a task (Cook and Artino Jr., 2016). There is a close relationship between interest and learning. More interest in doing an activity such as virtual laboratories increases students' conceptual understanding of the science topic (Dohn et al., 2016a). Both E and U are essential parts of motivation because students are motivated when they feel that the task or activity is valuable to their learning (Davis, 1989; Dohn et al., 2016a). SE is the perceived capability to learn or perform at a certain level and expectancy of success (Glynn et al., 2011). Students with high SE are willing to work harder on their tasks and achieve their goals. SE is important because it measures how students think of their learning outcome and act on it (Dohn et al., 2016a). ATS is defined as students' feelings about science in which they take an interest in science education (Hitlin and Pinkston, 2013). Attitude is based on internal beliefs; however, it can be changed when encountered with a new approach (Hitlin and Pinkston, 2013). This study hypothesizes that virtual laboratories increase students' attitudes toward science.

LITERATURE REVIEW

Virtual Laboratory in Science Education

In recent years, there has been an increase in the use of virtual laboratories in science education, especially during the pandemic of COVID-19 (Sari et al., 2019). Virtual laboratories are a computer-programmed manipulative tool that allows students to explore science phenomena and connect science concepts and science skills (Keller and Keller, 2005). Several studies have documented the effectiveness of technology-based laboratories as simulation. Chang et al. (2008) suggested no difference between traditional laboratories and simulations regarding abstract reasoning abilities. Studies reviewed by Rutten et al. (2012) provided evidence that using computer simulation can be a tool to upgrade standard instructions and promote the conceptual understanding of students. Faour and Ayoubi (2018) found that using virtual laboratories increased content knowledge for physics students. In another study, Son (2016) compared physical laboratories and two courses of virtual laboratories in their ability to encourage inquiry-based learning, a positive attitude toward biology, and financial commitment. They concluded that students who performed a hybrid version of virtual laboratories (including in-person help every week) scored better grades and had a more positive attitude toward learning biology. However, they did not detect any changes in learning new concepts among the three models. Virtual laboratories decreased the cost and allowed more students to enroll in the course than in the physical laboratory. Virtual laboratories can be used as a supportive instructional tool to train students before doing the actual laboratory experiment (Bortnik et al., 2017). Their study found that students in a blended environment (combined hands-on and virtual lab) were more engaged and performed better than students in a traditional (hands-on only) setting. They recommended that virtual laboratories be used as a supplementary tool to improve students' research and studying skills.

Implementing virtual laboratories in schools has many advantages: Using technology in classrooms has changed the way students, teachers, and curricula interact and, therefore, changed the learning environment (Wu et al., 2007), so integration technology in virtual laboratories can boost students' learning and motivation toward learning science. Virtual laboratories can be used when performing physical laboratories is impossible, such as insufficient resources (Koehler, 2021). Virtual simulations allow students to repeat experiments without consequences or risk (Aljuhani et al., 2018). The need for using virtual laboratory simulations emerged mainly during the COVID-19 pandemic as schools shifted to online learning. The use of virtual laboratories allows students to see science in action (Koehler, 2021). Technology-based laboratories can also save time for scientific inquiry, such as data collection, analysis, and evaluation (Husnaini and Chen, 2019). Virtual simulations can provide simplified interactive models of phenomena or science processes and allow students to explore the effect of different variables. They can give the students feedback on their work. They can be used individually or collaboratively as a classroom application, provide a safer environment, and promote cognitive development through visual interactions (McDonald, 2016).

Moreover, it can be an effective solution for distance learning because of lousy weather situations such as heavy rains (Koehler, 2021). According to Martínez et al. (2011), using simulations can be very useful in applied science as it provides realistic models that effectively teach abstract concepts of science. In Saudi Arabia, a recent study examined the need for virtual laboratories in middle school as a learning environment that will allow students to access various resources for practical experimenting for science concepts. This study concluded that virtual laboratories improved the learning experience and students' understanding of experiment objectives and results. It enabled them to conduct investigations individually, which enhanced their ability to remember information given. Furthermore, the system tested provided feedback that allowed teachers to monitor students' progress effectively (Aljuhani et al., 2018).

However, virtual laboratories have some disadvantages; Students are discouraged from learning physical instruments and genuine devices. Direct collaboration and engagement between students and teachers are limited by remote access. Assessments are at a higher risk of plagiarism (Chan and Fok, 2009).

Virtual Laboratories and Student's Motivation

One of the keys to student involvement and academic performance is motivation. The most significant issue teachers, particularly at the middle and secondary level, confront is motivating individuals and overcoming student apathy. As instructors, we all want to motivate our students because we know that engaged classrooms and improved academic accomplishment result from motivated students (Llewellyn, 2010). We must be concerned with inquiries that explore how students engage in laboratory work and continue with such activities since motivation is an important variable for academic learning and accomplishment (Dohn et al., 2016a).

Motivation is a person's desire and willingness to participate in and accomplish a task. Motivation stimulates goal-oriented behavior by providing a cause and path to achieve a task. The work usually involves a specific area of the learning process for teachers. While people may be equally and publicly motivated to complete a task, the source of their internal motivation may differ from person to person (Lumsden, 1994).

Motivation to learn science is understood as a state that motivates, directs, and sustains science-learning behavior. Students who are motivated achieve academically by engaging in behaviors such as asking questions, asking for advice, studying, and actively participating in classes and laboratories. Students motivated to learn science have multiple components that are not captured by a single factor in social cognitive theory. That is because the motivation to learn is a multidimensional construct. These components contribute to the overall motivation of students (Glynn et al., 2011). These components are IM, perceived U, E, and SE. Science education researchers aim to understand why students struggle to study science, what feelings they experience while doing a task, how intensely they conduct an E, and how long they strive when measuring motivation to learn science. Measuring the desire to learn science is complex because a construct and its components are not immediately observable variables (Glynn et al., 2011).

As many studies have documented and experimented with the effect of virtual laboratories on conceptual understanding and cognitive abilities, compared to real-life laboratories, few have linked virtual laboratories as an instructional tool to students' motivation and attitude toward learning science. In their study, Sari et al. (2019) reported that the virtual and computer-based real laboratory had increased students' motivation and attitude toward learning physics. They also concluded that computer-based laboratories are a more effective tool in teaching physics classes as they improve students' motivation to do collaborative work and communication. Several searchers have compared virtual and physical or face-to-face laboratories on students' motivation and enjoyment and found no significant differences between the two approaches (Martínez et al., 2011; Reece and Butler, 2017). Ernita et al. (2021) compared the effect of inquiry models (real and virtual) and achievement motivation on learning outcomes in physics. They measured high school students' achievement motivation using a motivation scale and a test to measure their learning outcomes. Their results conclude that there was no interaction between the inquiry learning model (virtual or real) with the achievement motivation (high and low) on the students' learning outcomes. Students with high achievement motivation and low achievement motivation had no significant difference in their learning outcomes. Sugiharti and Limbong (2018) concluded that there is a relationship between the learning model and learning motivation in terms of chemistry learning outcomes, with students who have high learning motivation being taught by the PBL model using virtual laboratory achieving a higher mean, whereas students with low learning motivation being taught by PBL model using virtual laboratory achieving a lower average learning outcome. Similar to these findings, Anam et al. (2019) concluded that learning the motion of things content through a guided inquiry paradigm aided by an android virtual laboratory application is beneficial in improving students' conceptual understanding and motivation. Nolen and Koretsky (2018) reported that virtual laboratory projects had a more significant effect on end-of-course interest in engineering problem-solving and positively impacted task-E orientation than the physical laboratory. Students were more engaged in virtual laboratory projects. They had higher chances of transferring prior knowledge from coursework and could contribute more to group learning.

However, Dyrberg et al. (2017a) concluded that virtual laboratories could not replace real laboratories as virtual laboratories' perceived value of engagement was less than real ones. Students found virtual cases to be less effective and exciting. They also reported that students' confidence after forming virtual laboratories improved their practical work. They suggested that virtual laboratories can be used as a pre-step to prepare students for practical laboratory instructions, reducing cognitive load and helping students understand the introduced topic. Reeves et al. (2021) examined the undergraduate students' experience using virtual reality laboratories in their chemistry classes. These students reported that virtual reality laboratories promoted their learning, yet these laboratories were not always practical, especially when the way the laboratories were designed did not allow them to move forward unless they completed every step of the task.

Students' SE and Attitudes Toward Science

SE or a person's view about his or her capacity to perform effectively on a particular activity is a primary factor of whether or not a person would undertake the task, how much E will be wasted, and how much perseverance will be demonstrated while pursuing the task (Kurbanoglu and Akin, 2010). Perceived SE impacts and is impacted by cognitive patterns, emotional arousal, decision behavior, and task performance, according to SE theory. SE influences perseverance, engagement, and success in the classroom, and students perceive complexity and performance (Bandura, 1977).

When students are confident of their abilities, they will surely put more E into a given task, such as virtual laboratories. Therefore, this will increase their positive feeling about the topic given. Moreover, students with high SE had a more assertive ATS. They also will grow positive feelings toward science when they feel the importance and U of the virtual laboratory and how it can add and promote their learning (Dohn et al., 2016a).

For this reason, it is essential to use a method that promotes positive attitudes and makes students more engaged in their learning (Sarı et al., 2017). These studies can provide teachers with a guide on choosing a laboratory that improves students' conceptual understanding and enjoyment; significantly, those virtual laboratories can help students improve complex and abstract concepts (Husnaini and Chen, 2019). In conclusion, the study of variables related to the use of virtual laboratories in education is necessary as it provides valuable insights into promoting positive attitudes, enhancing student engagement, and improving conceptual understanding. By understanding the impact of virtual laboratories on student engagement and learning outcomes, educators can make informed decisions regarding the integration of virtual laboratories into their teaching practices.

Examples of Virtual Laboratories Evaluated in the Study

PhET simulations

PhET simulations are a project at the University of Colorado (PhET, 2022). They provide an interactive fun way for learning science from grades K-12. These simulations include manipulatives, intuitive controls, graphics, measurement instruments, a ruler, and a stopwatch for more accurate data analysis. PhET is designed to develop students' inquiry skills. There are around a hundred interactive simulations found on the website free to use. One of the primary goals of PhET is to provide students with an open experiment environment where they can engage with the science content like a scientist. Students can manipulate different variables to study phenomena not easily observed in real laboratories. PhET is widely used in schools across UAE in physics, chemistry, and biology classes.

PhET simulations were shown to be beneficial in assisting students in visualizing the motion of a string while learning the wave concept (Perkins et al., 2006). Ndihokubwayo (2020) studied the effect of using PhET simulations to promote learning optics. They reported that students achieved better post-test scores when using PhET than those who did not. Yuliati et al. (2018) concluded that using active learning methods of teaching such as PhET can improve students' problem-solving skills and allow them to think scientifically. Figure 1 shows a virtual laboratory (state of matter) students can manipulate several variables such as heat and pressure to study their effect on the movement of particles, as well they can also choose the type of matter they are studying (water, oxygen, and argon).

Gizmos

Gizmos are virtual laboratories and simulations in math and science for students in grades 3–12 (Gizmos, 2022). Over 400 Gizmos tied to the most recent standards assist instructors in bringing innovative STEM learning experiences to the classroom. With interactive visual models, the Gizmos in the Explore Learning Library cover hundreds of topics in math and science. Gizmos, for example, can assist students in visualizing the flow of current in an electrical circuit they have created, studying the process of triangulation in establishing an earthquake's epicenter, and identifying the role of the Sun and Moon in ocean tide variation.

There are a variety of innovative interactive simulations and animations throughout the Gizmo library that assist students in grasping subjects that are difficult to articulate or envision. Figure 2 shows a natural selection virtual laboratory in which students can observe the effect of natural selection on peppered moths over time. They can change the type of environment to detect changes in the number of moths, as well they can also analyze a graph to deepen their understanding of the concept. Gizmos use an inquiry-based learning strategy that has been proven to be a very effective technique to improve conceptual understanding through considerable study. Smith (2012) reported the positive effect of using explore learning (Gizmos) on 5th graders' engagement in science.

METHODOLOGY

This quantitative study evaluated the virtual laboratory effectiveness using a student questionnaire. This questionnaire was adapted from the IM inventory, a multidimensional measurement device intended to assess participants' subjective experience related to target activity in laboratory experiments. McAuley et al. (1989) strongly supported the validity of this scale. The questionnaire was coded using a 5-point Likert scale ranging from strongly disagree (=1) to agree (=5) (Appendix

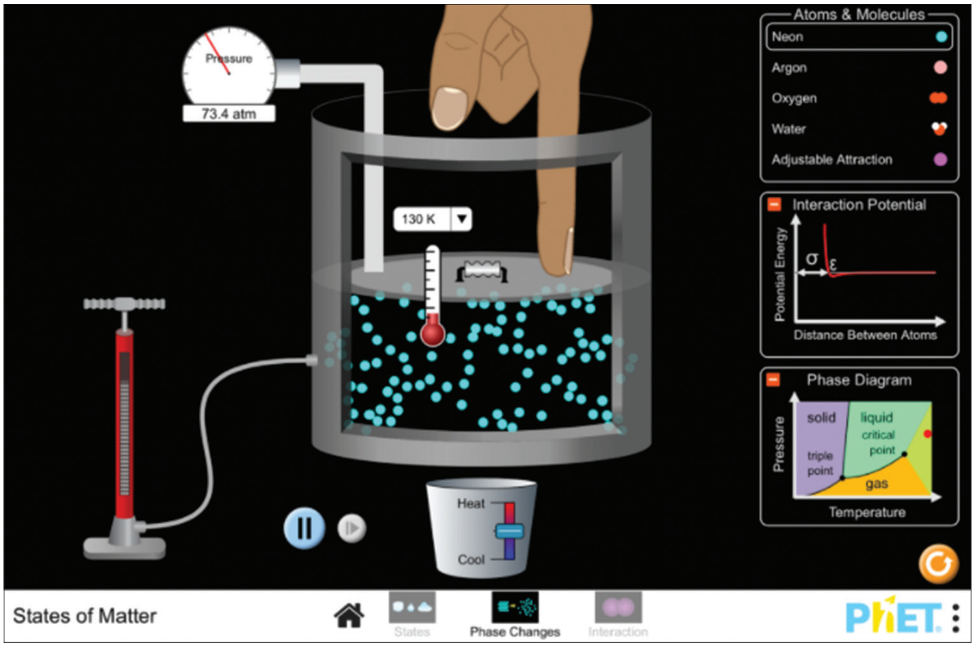

Figure 1: State of matter is an example of an interactive feature associated with PhET

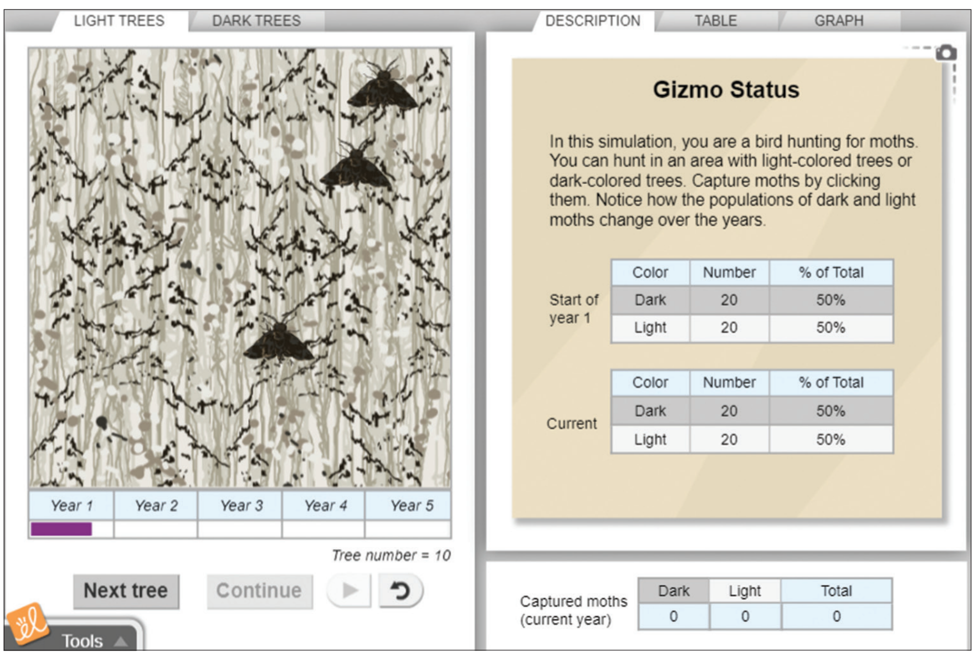

Figure 2: Natural selection virtual laboratory on Gizmos

1) strongly. A' do not know option was added to avoid a mean skew caused by uncertain students. Another methodological consideration was not to overwhelm the students with too many questions, leading them to abandon the survey before it was completed. During science class, the students freely completed the questionnaire. The questionnaire consisted of background questions such as gender, nationality, grade, and 19 question statements divided into five subscales: Intrinsic interest (three items, one is negatively worded), U (three items, one is negatively worded), E (three items, one is negatively worded), SE (five items), and ATS (four items). A total of three items were negative, and 16 items were positive. The questionnaire was distributed to 237 students (grades 7, 8, 9, 10, and 11) during their science classes. The study took place in an American curriculum private school in Dubai where students evaluated virtual laboratories used in the school, such as (PhET) and (Gizmos).

ETHICAL CONSIDERATION

A letter was sent and signed by the school vice principal to grant permission to conduct the questionnaire. Furthermore, another letter was sent to parents to seek their permission. We also made sure the teachers would not influence the students' answers. Moreover, teachers did the questionnaire in their classes voluntarily and were informed about the study's aim and how to conduct it with students. Students who did the questionnaire were randomly selected.

DATA ANALYSIS

A total of 237 students participated in this questionnaire. Some of them did not respond fully to the questionnaire, so a varying number of respondents (n) is included when reporting the results. The missing values are reported in Table 1. The participants' demographic data are shown in Table 1. About 63% are males, 36.7% are females, and 75% of the students are Emirati.

The reliability of subscales was done using a Cronbach's α test, and the results for each item are shown in Table 2.

As seen above, (IM) value is 0.845, (U) is 0.891, (E) is 0.920, SE is 0.839, and (ATS) is 0.839. All values subscales showed internal consistency; all subscales are >0.7, suggesting solid reliability (>0.7).

Table 1: Demographic data of the participants

	Male	Female	UAE	Others
(n) frequency	150	87	180	57
Valid percent	63.3	36.7	75.9	24.1

Note: The valid percentage is based on a total number of 267 as there were 30 (11.2%) missing systems

Table 2: Cronbach's alpha test results

Subscale	Cronbach's Alpha	N of Items
Intrinsic motivation	0.845	3
Usefulness	0.891	3
Effort	0.920	3
Self-efficacy	0.839	5
Attitude toward science	0.839	4

FINDINGS

Testing for research hypotheses

H1: There is a significant relationship between the use of virtual laboratories, students' motivation, and ATS.

Table 3 shows the mean for each of the subscales and standard deviations. We determined that strongly disagree and disagree (coded as 1 and 2) will be considered a negative response to each subscale item, whereas agreeing and strongly disagree (coded as 4 and 5) will be a positive response, and do not know (coded as 3) will be neutral. As well, negatively worded items were reversely coded. It was determined that if the mean score for each of the subscales is >2 (coded as disagree) on the measurement scale for each of the subscales (IM, U, E, SE, and ATS), it shows positive results.

By examining the means of each subscale in Table 3, we notice that the average scores for all subscales; IM (3.932), U (3.993), SE (3.836), and ATS (3.836), are positive (higher than 3), which means that most of them enjoyed working with it. Most students found the virtual laboratory valuable and essential to improving their learning. Most were confident about using the virtual laboratory.

Moreover, most understood science better and had a positive feeling about it. However, when looking at the mean average of the E (3.1), it is evident that students are indecisive about the amount of E put into the virtual laboratories.

A one-sample t-test was conducted using Statistical Package for the Social Sciences software to test a significant difference among the subscales measured (IM, U, E, perceived SE, and ATS). The results of the t-test are shown in Table 4.

Table 3: Means and standard deviation of independent variables

Dependent variable	Mean	Effect	Standard deviation	95% confidence interval	
				Lower bound	Upper bound
Intrinsic motivation	3.932	Positive	0.82518	3.826	4.038
Usefulness	3.993	Positive	97459	3.868	4.118
Effort	3.140	Neutral	1.18730	2.988	3.292
Self-efficacy	3.953	Positive	0.80505	3.850	4.057
Attitude toward science	3.8369	Positive	0.82518	3.7076	3.9682

*Scales from 1 to 5 with higher numbers being positive (>3). n=236–237, n=30 excluded cases

Table 4 presented that all subscales were statistically significant (<0.001) for the one- and two-tailed t-test, indicating that the hypothesis is accepted. From this table and comparison of the means above, we can conclude that virtual laboratories positively affect students' motivation and ATS-based perceptions of participating students. However, students might put some E into doing the virtual laboratories task and reading laboratory instructions.

H2: There is a significant impact of students' perceived SE on their ATS.

A regression test was conducted to test the impact of perceived SE and U on students' attitudes toward science and measured the effect of SE on the amount of E students put into virtual laboratories. The results are shown in Table 5.

To test if students' SE impacts their ATS. The dependent variable ATS was regressed on predicting variable SE. The findings shown in Table 5 revealed that students' SE significantly predicted students' ATS, $F(1,235) = 233.287$, $p < 0.001$, which indicated that SE could play a significant role in shaping (ATS). These results direct the positive effect of SE. Moreover, the R square ($R^2 = 0.496$) depicts that the model explains 49.6 %of the variance in ATS.

Table 4: One sample t-test results

One-sample test

	Test value=2						
	T	df	Significance		Mean difference	95% confidence interval of the difference	
			One-sided p	Two-sided p		Lower	Upper
Usefulness	31.414	235	<0.001	<0.001	1.99294	1.8680	2.1179
Effort	14.748	235	<0.001	<0.001	1.13983	0.9876	1.2921
Self-efficacy	37.310	236	<0.001	<0.001	1.95105	1.8480	2.0541
Attitude toward science	29.431	236	<0.001	<0.001	1.83966	1.7165	1.9628
Intrinsic motivation	36.053	236	<0.001	<0.001	1.93249	1.8269	2.0381

Table 5: Regression test findings

Hypothesis	Regression weight	Beta coefficient	R square	F	p-value	Hypothesis supported
H2	SE→ATS	0.706	0.496	233.287	<0.001*	Yes
H3	U→ATS	0.676	0.454	196.485	<0.001*	Yes
H4	SE→E	0.093	0.061	16.352	<0.001*	Yes

*p<0.05. SE: Self-efficacy, U: Usefulness, ATS: Attitude toward science, E: Effort

H3: There is a significant impact on student's perceived U of the virtual laboratories on their ATS.

To test if U impacts students' ATS. The dependent variable ATS was regressed on predicting variable U. The findings shown in Table 5 revealed that students' SE significantly predicted students' ATS, $F(1,234) = 196.485$, $p < 0.001$, which indicated that (U) could play a significant role in shaping (ATS). These results direct the positive effect of SE. Moreover, the R square ($R^2 = 0.454$) depicts that the model explains 45.4% of the variance in ATS.

H4: There is a significant impact of students' SE on the amount of E they add when conducting a virtual laboratory.

To test if students' SE impacts the E when conducting a virtual laboratory (E). The dependent variable E was regressed on predicting variable SE. The findings shown in Table 5 revealed that students' SE significantly predicted students' E, $F(1,234) = 16.352$, $p < 0.001$, which indicated that SE could play a significant role in shaping (E). These results direct the positive effect of SE. Moreover, the R square ($R^2 = 0.061$) depicts that the model explains only 6.1% of the variance in the E.

DISCUSSION AND CONCLUSION

The main aim of this study is to investigate the effect of using virtual laboratories on students' motivation and ATS. Two hundred thirty-seven participants from grades 7 to 11 were involved in this study. Students reported their responses using a questionnaire. The findings from this study show that using virtual laboratories positively affects students' motivation and ATS. These findings match several studies (Dohn et al., 2016a; Ernita et al., 2021; Koehler, 2021; Sari et al., 2019; Son, 2016). All these studies reported a positive effect of virtual laboratories on students' motivation. The findings are incongruent with existing research that suggests students exhibit higher motivation when engaging in physical laboratory activities (Puntambekar et al., 2021). The examination of the data demonstrates positive evaluations of innovation, effectiveness, benefits, and the presentation of procedures, juxtaposed with negative perceptions regarding motivational aspects. Consequently, this investigation indicates that the utilization of PhET-based virtual laboratories is characterized by innovation and effectiveness; yet, its capacity to motivate students is impeded by essential tasks (Putra et al., 2021).

This study also investigated the relationship between perceived SE and U on students' attitudes toward science. The findings revealed that SE and U were dominant predictors of students' attitudes toward learning science. As well, SE has a significant impact on the E applied. In their results, Dohn et al. (2016b) explained that students had high perceived SE while doing the laboratory work, which positively affected their academic performance; yet, no correlation was found between E and academic performance.

When students are confident of their abilities, they will surely put more E into a given task, such as virtual laboratories. Therefore, this will increase their positive feeling about the topic given. Moreover, students with high SE had a more assertive ATS. They also will grow positive feelings toward science when they feel the importance and U of virtual laboratories and how it can add and promote their learning (Dyrberg et al., 2017a).

To sum it up, it is essential to integrate virtual laboratories in the classroom as a supportive tool that allows students to explore abstract science concepts safely. We suggest that teachers include virtual laboratories as a tool classroom tool to explore a science concept and prepare ahead of the class, which will increase students' motivation. Virtual laboratories can also be given homework to all students to elaborate on a scientific phenomenon further. Moreover, we believe that a blended approach in which the teacher can integrate virtual and traditional laboratories will ensure full access to science inquiry skills and promote students' overall learning experience. Considering the available resources, safety measures, and time required to cover a science concept, the teacher can design and choose the appropriate learning activities (virtual or real laboratories) for students, making them more motivated to learn and increase their conceptual understanding.

Limitation to the Study

There are limitations to these findings. Using a questionnaire is an effective way to measure students' motivation. However, other measures should be taken, such as conducting interviews. Interviews with students and teachers will allow us to understand students' behavior in virtual laboratories fully. Additionally, relying on self-reported data in questionnaires can introduce bias, as students may overestimate or underestimate their motivation levels due to social desirability or misunderstanding of the questions. Furthermore, the study's sample size and diversity might not be representative of the broader student population, which limits the generalizability of the findings.

Suggestions for Further Studies

As these emerging technologies in science education are increasing in the Arab region, more studies should be conducted to investigate the effect of virtual laboratory design on students' understanding and engagement. These studies should be done on a large scale more systematically to provide teachers with a map on the best way to implement virtual laboratories in their teaching and what type of virtual laboratories is best for each level. Moreover, future studies should focus on developing a general framework of design principles for virtual labs. Studies should examine how virtual laboratory designs influence inquiry strategies and how it affect student's learning experience. Furthermore, More studies longitudinal studies should be conducted to track changes in student motivation and attitudes toward science over time as they engage with virtual laboratories. This could provide insights into the long-term impact of virtual laboratories on student motivation and attitudes.

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