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EFFECTIVENESS OF VIRTUAL LABORATORY ON GRADE EIGHT STUDENTS' SPATIAL ABILITY

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Abstract:

This study examines how virtual laboratory improves and enhances 8th grade students' spatial ability to learn electricity-related subjects in the Sultanate of Oman. As for the instrument a quasi-experimental pre-test and post-test were used to analyse the data obtained from forty school girls aged 14-15. The findings demonstrate that the virtual lab, as opposed to the physical one, developed students' mental turning, spatial imagining and spatial skills. The results emphasise that by using the virtual laboratory, pupils are able to visualise non-perceptible phenomena and processes, and that the virtual lab, unlike the physical lab, develops higher level thinking skills, self-confidence and imagination of primary school students. The results are statistically significant for the experimental group, who actually learned and performed more quickly than the control group. The study recommends that a future study be conducted on how virtual laboratory effects 8th grade students' cognitive and conceptual abilities in physics and electricity.

Keywords:

Physical Laboratory, Virtual Laboratory, Spatial Ability, Mental Rotation, Spatial Visualization

Introduction

Physics, a core area of the natural sciences, is the study of universal laws of various behaviours and relationships between a wide range of physical concepts and phenomena (Bajpai, 2013).

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The basic concepts of electricity, such as electric current, voltage and resistance, are taught at all three levels of education: basic, intermediate and higher (Stavrinides, Taramopoulos, Hatzikraniotis, & Psillos, 2015).

Of course, the concepts of electricity are still abstract and difficult to understand. As a result, students are likely to have misconceptions about the behavioural nature of electrical circuits (Kollöffel & de Jong, 2013).

In the Omani education system, little attention is paid to the improvement of students' spatial skills. This could be due to the fact that the educational system still uses traditional methods not effectively integrating technology to help students understand classroom exercises and activities of science subjects (Vosniadou, 2019).

This study may be valuable in recommending some techniques and strategies to develop students' spatial skills. This could positively influence their academic performance.

The present study can add some valuable insights to the literature by: a- emphasising the importance of using the virtual laboratory to help students learn the physical concepts of electricity and magnetism, b- emphasising the importance of the virtual laboratory to improve student spatial skills, and c- concisely describing the unique features and components of the virtual laboratory to improve student spatial skills.

This study aims to explore the effectiveness of students' spatial ability using a specially designed virtual Laboratory on learning about electricity.
The study was further guided by the following research questions:

1. Is there any significant mean difference in mental rotation between 8th graders who learn using Virtual Lab and those who learn using Physical Lab in learning electricity?
2. Is there any significant mean difference in spatial orientation between 8th graders who learn using Virtual Lab and those who learn using Physical Lab in learning electricity?
3. Is there any significant mean difference in spatial visualisation between 8th graders who learn using Virtual Lab and those who learn using Physical Lab in learning electricity?
4. Is there any significant mean difference in spatial ability overall score between 8th graders who learn using Virtual Lab and those who learn using Physical Lab in learning electricity?

Literature Review
Some studies (Engelhardt, 1997; Engelhardt & Beichner, 2004; Afra, Osta, & Zoubeir, 2009; Bilal & Erol, 2009; Küçüközer & Kocakülah, 2007) argue that science students do not easily understand electrical concepts. The general inability of learners to grasp complex electrical concepts is highlighted by Kirschener and Meester (1988). An important source of abstraction is the spatial nature of many scientific concepts. The spatial abilities and experiences of the learners have an impact on their mental images (Al-balushi & Al-Battashi, 2013).

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A number of studies argue that science students do not find it easy to understand electrical concepts (Engelhardt, 1997; Engelhardt & Beichner, 2004; Afra, Osta, & Zoubeir, 2009; Bilal & Erol, 2009; Küçüközer & Kocakülah, 2007). Kirschener and Meester (1988) stress that students in general cannot understand the complex electrical concepts. The spatial nature of many science concepts is a central source of abstraction. Learners' spatial abilities and experiences influence their mental images (Al-balushi & Al-Battashi, 2013).

Lohman (1979) defined spatial ability as "the ability to generate, retain, retrieve, and transform well-structured visual images" (p.126). Turgut (2014) points out that spatial ability is a collection of skills. It includes integrating and decomposing objects in the mind, mentally moving objects, and visualising objects from different perspectives.

A heated debate has arisen as researchers have attempted to disaggregate spatial ability into more than one component (Tarng, et al., 2021). Some scholars argue (Barratt, 1953; Lohman, 1979; Roca-González, Martín Gutiérrez, García-Dominguez, & Mato Carrodeguas, 2017) that the components of spatial ability may overlap with each other by using cognitive processing strategies categorised into three domains. These domains are: spatial orientation, spatial visualisation and mental rotation. These three domains are mainly used in the present experiment.

Russell et al. (2022) define spatial imagery as the ability of an individual to perform mental and cognitive rotations, manipulations and rotations of two or more dimensional objects. Spatial visualisation could be thought of as an umbrella term that covers a wide range of spatial manoeuvres. Mental rotation is considered a type of spatial visualisation by a number of researchers (Rogers et al., 2021).

Rogers et al. (2021 define spatial ability as the skill of seeing or observing the spatial relationships between dynamic objects, spatial relationships that require imagining that the object or objects are moving through space. Yilmaz (2009) emphasised that spatial orientation is "the ability to imagine the appearance of an object from different perspectives" (p.2).

Roca-González et al., (2017) argues that it is awkward to separate spatial orientation from spatial visualisation, provided that both require thinking skills and materials. This may help to move objects by mental rotation rather than moving an image of oneself to the preferred perspective. The difference between the former and the latter is that the former assists in imagining the motion of an object, while the latter assists in changing the perspective of an object.

Mental rotation, the third component, involves some features of imagining the rotations of 2D and 3D objects as a whole body (Olkun, 2003a). Mental rotation, as defined by Roca-González et al., (2017) is the ability to turn mental representations of 2D and 3D objects as it relates to the visual representation of such rotation in the human mind. In a similar vein, Barratt (1953) defined mental rotation as 'the ability of turning or rotating a particular figure or part of a figure in a plane (or about imaginary axes) and seeing whether the figure or part of the figure corresponds with another figure in the same plane' (p. 20).

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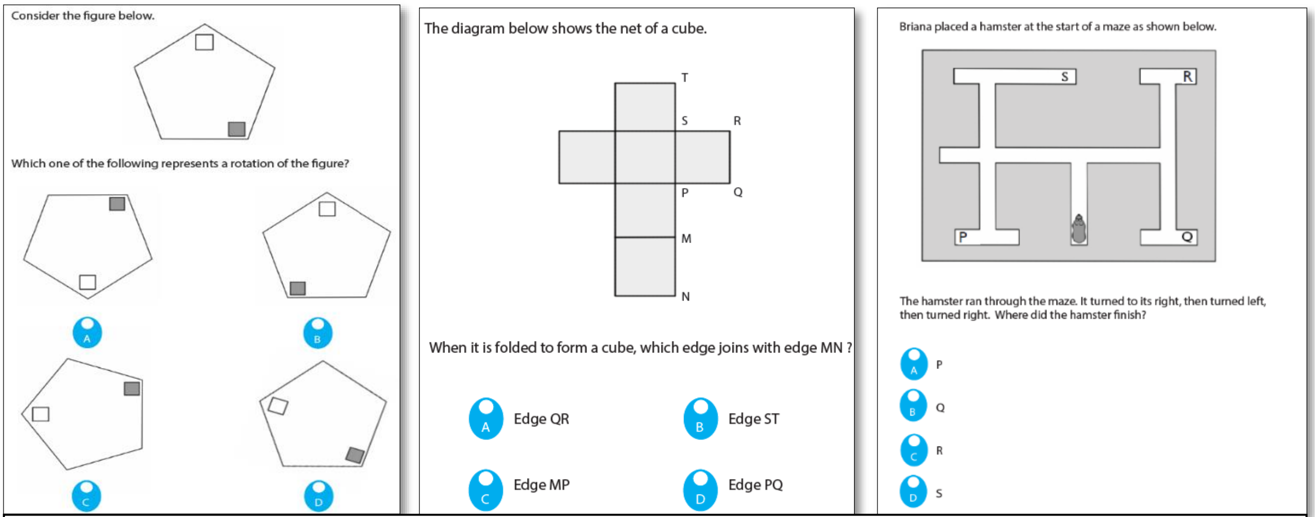
It is suggested that the most important feature of spatial ability is not the speed or efficiency of the different mental transformations of the image, but the internal mental images. Figure 1 shows examples of items relating to the most important components of spatial ability.

Figure 1
Item Samples For Some Of The Major Components Of Spatial Ability



Mental rotation	Spatial Visualisation	Spatial Orientation

Recent research has identified spatial skills as a key determinant of success in engineering (Olkun, 2003b), geography education (Likouri, Klonari, & Flouris, 2017), and science learning (Chen, Yang, & Chang, 2020). Science, engineering, and mathematics prominently and heavily rely on spatial ability to help students obtain outstanding results (Benzer & Yildiz, 2019). Some research emphasises that there is a robust connection between spatial ability and one's academic achievement in science.

Pedrosa et al., (2014) conducted a study to investigate the relationship between students' spatial skills and their academic performance when assessed in science. Their research was concerned with the knowledge and skills of students in some aspects of biology, chemistry and physics. They concluded that the better students' spatial skills, the better their conceptual and scientific thinking, and that students' good mastery of spatial skills significantly improves their academic performance in challenging subjects such as physics and mathematics.

Another study by (Duffy et al., 2016) shows a significant correlation between student performance on an electrical circuit concept test and their performance on a spatial visualisation test.

Another study by (Al-Balushi & Al-Battashi, 2013) aimed to compare low and highperforming Omani ninth grade students on their working memory (WMC) and spatial ability in science. The results showed that high achievers in both maths and science significantly outperformed low achievers in terms of WMC and spatial abilities.

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Virtual Technologies for Spatial Ability Enhancement

In science education, visualisation involves the use of specific images or representations in the instruction of science to assist the students' learning of science concepts (Oh et al., 2012). In addition, the interaction of two- or three-dimensional simulations and animations support the conceptualisation of abstract concepts, which may be difficult to grasp while using static visual representations and enhances students' visualisation and spatial abilities (Al-Balushi, Al-Musawi, Ambusaidi, & Al-Hajri, 2017). Moreover, simulations are supposed to help learners imagine processes properly and thus to be able to build adequate mental representations (Höffler, 2010).

However, various interactive web-based tools have been developed to enhance students' facility in understanding these invisible processes making use of animations and simulations based on constructivist learning designs, while taking care to avoid overloading the working memory of students (Oh et al., 2012; Yurt & Tünkler, 2016). According to previous research, there are some courses and activities based on virtual technologies have been developed to enhance learners' spatial abilities (Al-Balushi & Al-Hajri, 2014; Al-Balushi et al., 2017; Höffler, 2010; Kline, 2012; Wang, Wu, & Hsu, 2017). For example, Al-Balushi, Al-Musawi, Ambusaidi, and Al-Hajri (2017) conducted a quasi-experimental approach study to investigate the effectiveness of interacting with animations using mobile devices on the Omani 12^{th}-grade students' spatial ability and scientific reasoning skills. The findings showed significant statistical differences between the two groups in terms of spatial ability in favour of the experimental group, and there were no differences between the two groups in terms of reasoning ability. Kline (2012), in his study, suggested that learners with lower spatial ability might need other forms of assistance for mental model generation, such as animated instructions.

Virtual Laboratory is one of the recent advances in Information and Communication Technologies (ICT)-based learning besides traditional laboratories. It is a virtual studying and learning environment that stimulates the real laboratory. It provides the students with materials, tools, and lab sets on the computer to perform experiments subjectively or within a group anytime and anywhere (Babateen, 2011, P. 101). These experiments are saved on CDS or web site. In the present study, the authors used a virtual laboratory to improve students' spatial abilities. Researchers have observed that it is possible to develop spatial abilities in virtual worlds and there are a few studies indicated that the experience that individuals acquire in using virtual laboratory led them to have similar behaviour in the physical laboratory and similar circumstances.

Research Methodology

Participants

The participants in this study are eighth grade students in schools in Al-Batinah South region of Oman. The sample is made up of the eighth-grade students in one of the schools of the Basic Education School in the Al-Batinah South Region. To select the control and treatment groups, the school was randomly selected from the population and existing classes. The sample consists of forty female students aged 14-15 who participated in the study, twenty treatment and twenty control students.

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The school is equipped with a computer room with a good internet connection for learning. All of the students do not have any previous experience of using the virtual lab. Informed consent to participate in this study was obtained from the students and their parents by the researcher prior to the study. All students were in agreement with the participation in this study.

Research Approach

The present study is based on a non-equivalent (pretest-posttest) control-group design. In this design, the treatment and control groups are selected without random assignment. However, random selection was conducted to select the school from the population and on existing classes to choose the control group and treatment group. Both groups take pre-test and post-test. Only the treatment group (VL) receives the treatment (Creswell, 2006).

Instrument to Measure the Components of Spatial Ability

Students' Spatial Ability was measured using the Spatial Reasoning Instrument (SRI), developed by Ramful, Lowrie and Logan (2017). It was based on three constructs (mental rotation, spatial orientation, and spatial visualisation) with 30 items, as demonstrated in Table1.

Table 1
Constructs of Spatial Reasoning Instrument

Number of Items	Spatial Ability	Items
10	Mental rotation	1,4,7,10,13,16,19,22,25,28
10	Spatial Orientation	2,5,8,11,14,17,20,23,26,29
10	Spatial Visualization	3,6,9,12,15,18,21,24,27,30

The purpose of the SRI is to assess students' spatial ability in middle school (11-14 years old). The items are represented in multiple-choice format, with 27 of the 30 items involving four choices of answers and three items offering two choices only. The three items, with only two answer choices, are designed to test students' understanding of left and right directions as well as clockwise and anticlockwise, leaving only two options as appropriate. A correct item is scored as 1, whereas an incorrect item is 0. This makes the minimum score 0, and the maximum score 30.

Spatial Reasoning Instrument (SRI) is adapted and translated to Arabic by back-to-back translation. The questions were only slightly modified to fit the Omani content and culture. Twelve (12) subject matter experts have determined the content validity of the research instrument. They are requested to review the items and make a judgment about how well these items represent the intended content area. Furthermore, many items are modified based on the experts' feedback. Then, a pilot study of the Spatial Reasoning Instrument was conducted on 67 students of the 8^{th} grade from Omani public schools, which is used firstly to examine the internal consistency of the instruments. The data obtained were calculated using the SPSS to determine the reliability coefficient of the three components of spatial ability (mental rotation, spatial orientation, and spatial visualisation). The Cronbach alpha reliability coefficient ranges from 0.72-0.75, which is considered acceptable as it is greater than the minimum reliability level (<0.60) (Hair et al., 2006), meaning that the items in the instrument are internally

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consistent and can be used for measuring the same content universe (Churchill, 1979; Ellis & Levy, 2009).

Intervention
Prior to the treatment, the researcher went to the sampled school in order to obtain permission from the school authorities to carry out the research. The research lasted nine (9) weeks after permission was obtained. Due to the Covid 19 pandemic in Oman, a strict SOP was followed during data collection. The mode of teaching followed by the school at the time was blended learning. For example, a group of students were physically present at the school for one week (face-to-face teaching).

And the following week, the same students were taught at a distance (synchronous and asynchronous online classes) using the Google Classroom platform. For example, the treatment group (VL) was taught remotely (synchronous online classes) using the Google Classroom platform while the control group (PL) was taught physically at school (face-to-face classes) for one week. And the following week, the opposite was the case.

During the first week, the students and the teacher were oriented and trained on how to use the virtual lab and the lesson plans prepared by the researchers. At the end of the first week, the spatial reasoning instrument pretest was administered to the treatment group (virtual lab group). The control group (physical lab group) was given the test the following week. It was a lucky coincidence that the treatment group went to school one week and the control group went to school the next week.

In the second week, the treatment commenced and lasted for eight (8) weeks. A total of 3 hours (180 minutes) per week was used for class interaction. The researcher observed the treatment for the virtual lab group (VL) and the physical lab group (PL) throughout the period.

The virtual laboratory has been linked with the Google Classroom platform to facilitate the process of communicating with treatment group (VL) students during synchronised online classes. After the intervention, Spatial Reasoning Instrument (SRI) was administered as a post-test for both groups.

Virtual Laboratory
The Virtual Laboratory is specially designed and developed to provide an optimal user experience using the local language. For instance, simple and intuitive graphic interfaces were created to help students understand the concepts and guide them smoothly through each experiment. Another example is the home page that includes topics of the practical experiments supported by graphical icons to attract students' attention and facilitate access to the experiment to be carried out (see Figure2).

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Figure 2
Virtual Lab Homepage

The content of the Virtual Laboratory was divided into 15 parts according to grade eight science curriculum “Magnetism and Electricity Unit” topics (see Figure 2). Each part consists of:

- **Simulation:** the learners conduct the experiments by using its components. The simulation’s features allowed students to manipulate different variables, predict and visualise the results. The simulations managed to serve as a mini virtual laboratory, particularly when participants manipulated the variables and predicted the results.
- **Learning Activities:** to guide students to do the experiment, record the data, and record their findings and explanations.
- **2D and 3D Animation Videos:** illustrate the unit's topics to support the students' understanding.
- **Online Self-assessment**: students can evaluate their understanding a number of times and at any time.
- **Communication Tools:** to allow students to communicate with the teacher or classmates via virtual classroom meetings, chat, and email which are embedded within the virtual laboratory.

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The virtual lab components for each topic are as shown in Figure 3

Figure 3
The Virtual Lab Components

The virtual lab was available to the treatment group students at any time, and they were able to access the website of the virtual lab from home and at school. They can use it either synchronously or asynchronously with their teacher and classmates.

Data Analysis

To determine the significant difference between the pre-test and the post-test of spatial ability for both groups, a paired samples t-test was performed. Then, to determine the significant differences in spatial ability between the two groups, multivariate analysis of variance (MANOVA) was used. For all statistical analyses, the 0.05 alpha level was used as the level of significance.

Hypotheses for paired samples t-test and MANOVA were checked. Prior to the analysis, a normality check was carried out on the pre-test and post-test data. Skewness and Kurtosis values ranging from -2 to +2 indicate that the data were normally distributed (George & Mallery, 2019).

To determine the magnitude of the learning gains between groups, Cohen's d was used to calculate the effect size. The learning gain results were interpreted as 0.2 small effect size, 0.5 medium effect size and 0.8 large effect size (Cohen, 1988).

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Results

First, descriptive statistics were used to determine the mean difference between the virtual laboratory and the physical laboratory in the improvement of spatial ability. The data obtained were analysed to compare the mean and standard deviation of the treatment and control groups in terms of the overall score and the three components of spatial ability: mental rotation, spatial orientation and spatial imagination. The results are shown in Table 2.

Table 2
Mean and Standard Deviation Comparison of Pre-test and Post-test Result for The Spatial Ability of Treatment Group and Control Group

Spatial Ability Components	Group	Pre-test		Post-test		Mean Gain
		Mean	SD	Mean	SD	
Mental Rotation	Treatment	2.75	1.251	3.350	1.785	0.6
	Control	3.15	1.268	4.050	2.064	0.9
Spatial Orientation	Treatment	5.40	1.875	6.550	1.356	1.15
	Control	5.95	2.139	7.000	2.052	1.05
Spatial Visualisation	Treatment	3.35	1.694	3.650	2.134	0.3
	Control	3.00	1.973	5.450	1.877	2.45
Overall	Treatment	11.50	3.900	13.55	3.873	2.05
	Control	12.10	4.424	16.50	4.628	4.4

The results show that both groups improved in all components of spatial ability compared to pre-test. The differences in mean gains between the treatment and control groups were in favour of the treatment group in mental rotation, spatial visualisation and overall spatial ability. In other words, the virtual laboratory had a greater effect on mental rotation, spatial visualisation and overall spatial ability than the control group's teaching method. This is shown graphically in Figure 4.

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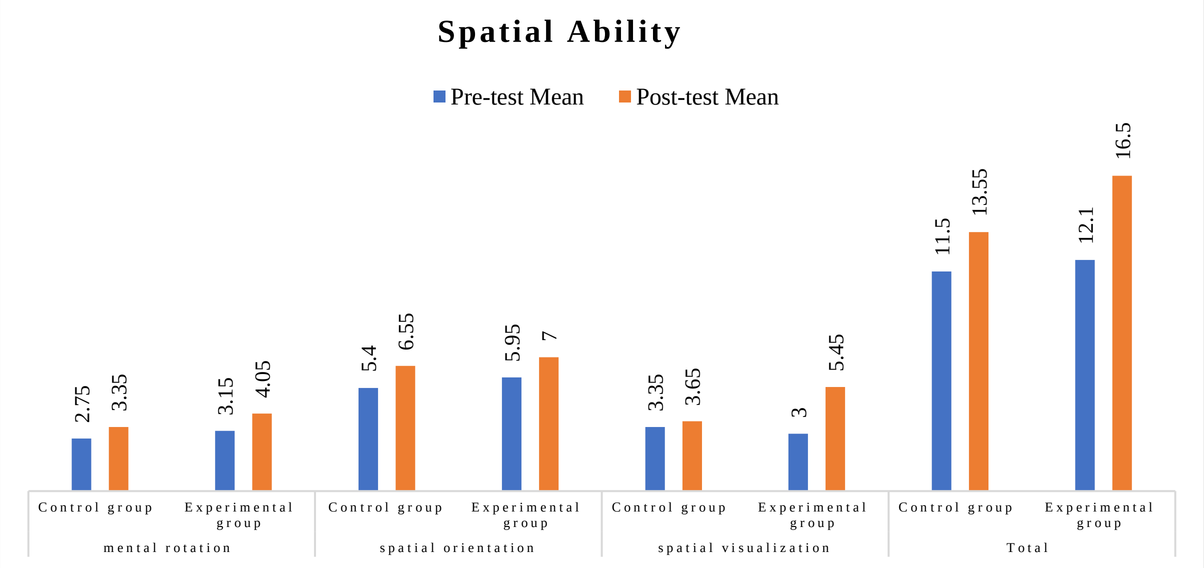
Figure 4
Pre-test and Post-test Comparison of Treatment Group and Control Groups in Spatial Ability



The significant differences between pre-test and post-test of overall and three components of spatial ability for both groups were calculated using Paired-Samples *t*-Test. Findings are shown in Table 3.

Table 3
Means, Standard Deviations, and (t) of The Mean Scores of The Treatment and Control Groups Pre and Post-test in The Spatial Ability Test

Dependent Variable	Group	Pre-test Mean (SD)	Post-test Mean (SD)	t-value	sig	d^2
Mental Rotation	Treatment	3.15 (1.268)	4.05 (2.064)	1.147	.259	0.53
	Control	2.75 (1.25)	3.35 (1.785)	1.004	.322	0.39
Spatial Orientation	Treatment	5.95 (2.14)	7 (2.052)	.818	.418	0.50
	Control	5.4 (1.88)	6.55 (1.36)	.865	.393	0.70
Spatial Visualisation	Treatment	3 (1.97)	5.45 (1.88)	2.832	.007*	1.3
	Control	3.35 (1.69)	3.65 (2.134)	-.602	.551	0.16
Overall	Treatment	12.1 (4.42)	16.5 (4.63)	2.186	.035*	0.97
	Control	11.5 (3.9)	13.55 (3.87)	.455	.652	0.53

*Significance at ($\alpha \leq 0.05$)

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Table 3 indicates that there are statistically significant differences in the overall pre- and post-test scores for the Spatial Ability and Spatial Imagination components in the treatment group. However, for both the treatment and control groups, there are no statistically significant differences for the mental rotation and spatial orientation components before and after the test. The effect size of using a virtual lab for the study sample is also large, as shown in Table 3. 97% of the total variation in the dependent variable (level of improvement in acquiring spatial skills) is accounted for by the effect of the independent variable (using the virtual lab).

To investigate the significance of the differences between the two groups, one-way MANOVA was applied. Findings are presented in Table 4.

Table 4
Tests of Between-Subjects Effects of Treatment Group and Control Group in Spatial Ability

Source	Dependent Variable	Type III Sum of Squares	Mean Square	F	Sig.	Partial η^2
Group	Mental rotation	4.9	4.900	1.32	.259	.033
	Spatial Orientation	2.03	2.03	.67	.418	.017
	Spatial Visualisation	32.4	32.4	8.02	.007*	.174
	Overall	87.03	87.03	4.78	.035*	.112

*Significance at ($\alpha \leq 0.05$)

These results show that the spatial visualisation components and the overall spatial ability score are significantly different between the treatment and control groups. Table 4 indicates that the effect size of the use of a virtual lab for the study sample was high. The effect of the independent variable (use of VL) accounts for 17.4% of the total variation in the dependent variable (level of improvement in spatial visualisation). This percentage is higher than the one established by Cohen (15% or more) in order to consider the size of the effect of the independent variable on the dependent variable to be large. The η2 indicates that approximately 11.2% of the variance in spatial ability can be explained by the treatment. It is worth noting that although both groups improved in Mental Rotation and Spatial Orientation, they did not show significant improvement.

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The overall spatial ability estimated means is highlighted as in Figure 5.

Figure 5
Estimated Marginal Means of Spatial Ability for Control and Treatment Groups in Post-test

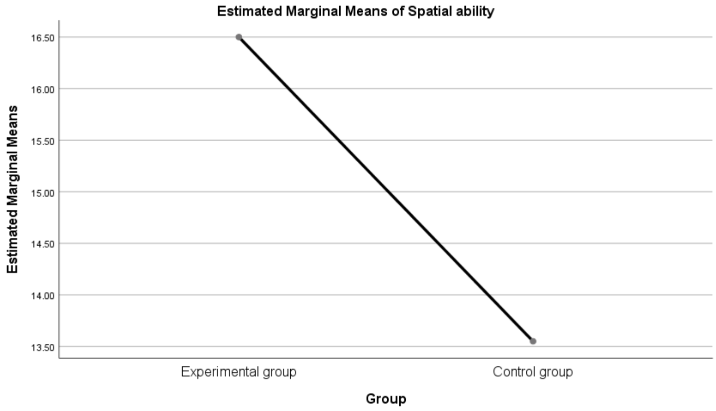

Figure 5 Overall estimated marginal means of the treatment group and control group post-test scores on the Spatial Reasoning Instrument (SRI) indicates that the virtual laboratory was more effective than the control group in improving students' spatial ability among eighth-grade students.

Discussion and Conclusion

This study has shown an improvement in the spatial ability of the students in both groups compared to the pre-test in all dimensions of spatial ability. However, the overall spatial ability and visualisation skills of the treatment group were significantly better than those of the control group, showing that the students benefited from the treatment.

The average gain differences in mental rotation, spatial imagination and overall spatial ability between the virtual and physical laboratory groups were in favour of the virtual laboratory group. This result indicates that virtual lab improved mental rotation, spatial visualisation and overall spatial ability more than physical lab.

This finding is in line with previous literature reporting that virtual technology can enhance spatial ability (Benzer & Yildiz, 2019; Hartatiana, 2017; Latif, Yuliardi, & Tamur, 2020; S. A. Sorby, 2009; Toptas, Celik, & Karaca, 2012). For example, Toptas, Celik, and Karaca (2012) reported a study that investigated the effect of a 3D modelling programme on the spatial ability of 8th grade students using an experimental research design. The results of the study indicated that the use of computer programs improved spatial ability.

However, this study is inconsistent with the findings of Philleo (1997) and Collins (2018). While Collins (2018) found that students in both media showed an increase in spatial ability, the paper media was slightly better than the digital media in terms of students' spatial ability. First, virtual laboratories allow students to make visible phenomena and processes, such as electric or magnetic field lines or electric current, as they carry out hands-on activities related to electricity and magnetism. The animations and simulations could also help to conceptualise abstract concepts that may be difficult for learners to grasp and understand. The spatial features

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of the simulated and animated materials used in the current study may have helped to develop the spatial abilities of the participants.

These findings concur with Al-Balushi et al. (2016), who reported that the interaction of two- to three-dimensional animations and simulations boosts the visualisation and spatial abilities of the students. Moreover, in his study, Levy (2013) suggests that students ought to be given a chance to watch and follow what is otherwise regarded as too small to be seen or too fast to be tracked to improve their ability to explain related phenomena.

Secondly, according to Potter and van der Merwe (2001), mental imagery develops through action and can be developed through activities that involve imitation. In addition, constructivist learning theory suggests that by reflecting on experiences, students construct their own understanding of the world. In this study, the virtual lab makes it possible for the students to be involved, in an active manner, through having complete control; for example, the students can start, stop, and play again the information as needed (Wichmann & Timpe, 2015).

In addition, in the present research, the participants can control inputs by changing variables, such as the number of batteries, with immediate feedback on the effect of changes on the experiment set-up. Therefore, students in the current study not only acquire knowledge but do the practical part, carry out experiments and observe the results directly facilitating active student involvement and enhancing students' spatial abilities. This finding is in line with Rafi et al. (2005), who reported that students might find opportunities to develop spatial ability skills via informal methods such as exploration, manipulation, and interaction in the virtual environment.

Thirdly, according to Mayer’s cognitive theory (2003), knowledge is presented and manipulated through two cognitive channels, i.e., visual-pictorial and audio channels, to keep cognitive load low. Therefore, the current study displays the virtual lab content in various forms, such as text, animations, figures, pictures, and videos. Thus, this virtual lab can help learners to get a deeper understanding. This result agrees with scholars who reported that multimedia software programs were found to be good facilitators for enhancing students’ spatial ability (Al-Balushi & Al-Hajri, 2014; Sorby et al. 2005). Therefore, built on what has been aforementioned, designers need to consider spatial ability as one of the main factors to design a good virtual lab.

Regarding research limitations, the current study encountered a relatively short period of time for the implementation phase. In other words, the 9-week period was not enough to make the expected significant impact on all spatial ability skills components. Hence, further future research could consider extending a similar study for the entire semester, 16 weeks, or even the entire school year. In this way, spatial ability components of the participants would have enough time to develop during the course of the study. Moreover, these findings can be further investigated by using think-aloud interviews. According to this study’s findings, it is recommended to employ virtual labs in the development of the current teaching programs in various educational stages.

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