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The Influence of a Virtual Physics Experiment Learning Environment on Grade 9 Students' Motivation Towards Physics Learning: A Mixed Method Research

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Experiments are essential in learning physics to help students comprehend abstract concepts, and scientific inquiry is a key learning process when students conduct physics experiments. However, the outdatedness and inadequacies of experimental equipment could negatively affect the learning effectiveness of real physics experiments. Recent research has pointed out that virtual physics experiments could compensate for the insufficiencies of real experiment equipment. Although studies had explored whether virtual physics experiments could affect students' learning motivation, they showed inconclusive results. Therefore, this research aimed to investigate the influence of a virtual physics experiment learning environment on the physics learning motivation of Grade 9 students, using quantitative (embedded quasi-experimental design) and qualitative (student interviews) research methods. Participants of this research were two Grade 9 classes divided into an experimental group (n = 37) and a control group (n = 37). The intervention lasted for three weeks, with one 45-minute physics experiment class per week. Learning motivation was measured by the Physics Learning Motivation Test (McAuley, Duncan, & Tammen, 1989; Yin, Goh, & Yang, 2020), which includes dimensions like interest-enjoyment, tension-pressure, perceived choice, perceived competence, and perceived value. Based on the data analysis from the pre-test, post-test, and interview, we found that the virtual experiment learning environment significantly increased students' learning motivation, especially for the perceived value dimension. Moreover, students who perceived a higher level of competence in the virtual environment were more likely to appreciate its value and utilize virtual experiments again, as evidenced by student interviews. We hope that the implications of this study and intervention design can be a reference for researchers, learning designers and teachers in incorporating virtual experiments in future physics education and provide a possible solution for conducting physics lessons when it is difficult to conduct the face-to-face lesson. More in-depth teacher interviews are recommended to investigate the issues from their angles, especially the pedagogical perspectives.

Keywords: physics learning, virtual experiment learning environment, students' motivation

Introduction

Physics could be abstract and complex, reducing learners' motivation (Awan, Sarwar, Naz, & Noreen, 2011). Experiments are essential in physics because they are considered an effective learning approach to help students

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grasp abstract concepts and acquire hands-on skills (Hamed & Aljanazrah, 2020). However, the outdatedness and inadequacies of experimental equipment could negatively affect the learning effectiveness of real physics instruction (Huo, 2015; Kaptingei & Rutto, 2014), which dampened students' enthusiasm to learn physics because they did not have enough opportunities to experience and study physics experiments. Research pointed out that the insufficiencies of real physics experiments could be compensated by virtual physics experiments (Hamed & Aljanazrah, 2020). Virtual physics experiments could simulate real experiments by visualising some difficult-to-observe experiment phenomena and providing a flexible learning environment (Li, 2015), thus boosting student achievement (Al-Amri, Osman, & Musawi, 2020), learning motivation, and engagement (Ogbuanya & Onele, 2018). Although studies had explored whether the virtual physics experiment learning environment could influence students' learning motivation, they showed inconclusive results, with an increase (Gunawan, Nisrina, Suranti, Herayanti, & Rahmatiah, 2018; Maksoud, 2018), a decrease (Aliane, Pastor, & Mariscal, 2010), and no significant effect (Aslan & Duruhan, 2021). Therefore, this study aimed to explore whether the virtual physics experiment learning environment could shape the motivation of Grade 9 students in a middle school in Mainland China. This study investigated two research questions as follows:

(1) Does the virtual physics experiment learning environment affect Grade 9 students' motivation towards physics learning?

(2) If so, how does the virtual physics experiment learning environment affect Grade 9 students' motivation towards physics learning?

Literature Review

Virtual Experiments to Create Physical Learning Environments

The virtual physics experiment is the product of virtual technology applied to physics education, allowing students to complete physics experiments online without considering time and space (Carnevale, 2003). The effectiveness of using virtual experiments to create learning environments has received considerable attention in education research (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014; Glava & Glava, 2010; Gunawan et al., 2018; Hamed & Aljanazrah, 2020; Zacharia, 2007). For instance, Zacharia (2007) conducted a pre-post comparison study in a university and found that combining virtual and real experiments could improve students' understanding of circuit concepts. Hamed and Aljanazrah (2020) found that flexible virtual experiment learning environments helped undergraduate students better prepare for real experiments. Although many studies have examined the impact of virtual experiments in teaching and learning, most focused on higher education, and little research investigated the effectiveness of secondary education. Thus, this research aimed to investigate whether Grade 9 students' motivation would be influenced in the virtual physics learning environment and to see if the virtual physics learning environment could be exploited to promote secondary school students' physics learning.

Virtual Physics Experiment and Learning Motivation

Motivation is the automatic response that inspires and sustains learners to engage in learning activities and directs the learner's efforts toward the goal (Li & Yan, 1993). Of the research that examined the impact of virtual physics experiments on students' learning motivation, many studies demonstrated that they could increase students' motivation (Gunawan et al., 2018; Maksoud, 2018), while other studies showed different results. For instance, Gunawan et al. (2018) found that students who utilised virtual experiments had higher levels of conceptual understanding because the enjoyment of using virtual experiments increased their motivation.

However, Aliane et al. (2010) described the limitations of virtual laboratories based on their teaching experience, such as negatively affecting student motivation because of the lack of hands-on activities. Aslan and Duruhan (2021) found no significant difference in motivation between virtual and real learning environments. The above review of studies revealed different findings on the impact of virtual physics experiments on students' motivation. To better stimulate students' learning motivation in physics, it is necessary to conduct this research to explore how the virtual physics experiment learning environment may influence learning motivation.

Scientific Inquiry in Virtual Physics Experiment Education

The physics curriculum should emphasise the participation of students in the scientific inquiry process when it comes to conduct physics experiments (Ministry of Education of the People's Republic of China, 2012). Therefore, this study used the scientific inquiry model proposed by Wang (2013) as the theoretical basis for designing the intervention. It includes five phases: question, hypothesis, experiment, conclusion, communication, and reflection (Wang, 2013). In the virtual experimental environment, students could simulate the real inquiry process and complete each step of the scientific inquiry process. Many researchers had used a virtual laboratory to support students in their scientific inquiry activities. For instance, Wang, Guo, and Jou (2015) found that introducing virtual experiments in STEM education could improve students' scientific inquiry skills. Based on the previous studies, this study designed virtual experiment physics courses based on the scientific inquiry process.

Methodology

Research Design

This research was conducted in Grade 9 physics experiment classes in a middle school in southern China. Using mixed methods with quantitative (embedded quasi-experimental design) and qualitative (student interviews) approaches, this research investigated the influence of the virtual physics experiment learning environment on Grade 9 students' motivation toward physics learning. The two groups came from two classes and were taught by the same teacher to minimize the possible related impact on the research findings. Figure 1 provides an overview of the research design.

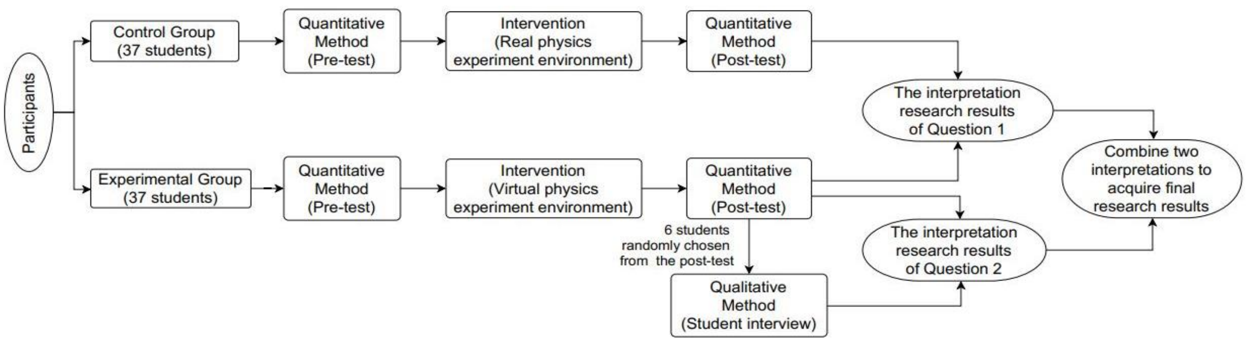

Figure 1. Overview of the research design: a sequential explanatory mixed method research.

Virtual Physics Experiment Platform: Guangdong Virtual Learning Platform

The Guangdong Virtual Learning Platform (2018) is an innovative digital learning platform widely used by secondary schools in Guangdong Province, a province in southern China. Figure 2 shows the translated screenshot of the virtual physics experiment platform. It provides high-quality virtual physics experiments for students and teachers for learning and teaching online, especially through stimulation, avoiding wasting time restarting experiments due to errors in the real laboratory. Each virtual experiment will provide buttons for students to participate in learning about the purposes, steps, and operation tips, so students can better use the virtual platform to complete the experiment. They can record and perform data processing directly on the platform. The platform also allows students to repeat the experiment multiple times by resetting the design.

In this study, the virtual environment could help students learn knowledge and skills by allowing them to complete online circuit-related experiments through interaction with the virtual physics experiment platform. For instance, one of the experiments for Ohm's Law was to investigate the relationship between current and voltage. Students were required to select the appropriate range of ammeter, voltmeter, and other experimental instruments, measure the current through the resistor several times by changing the voltage, record and analyse the current law in the virtual platform, and draw conclusions.

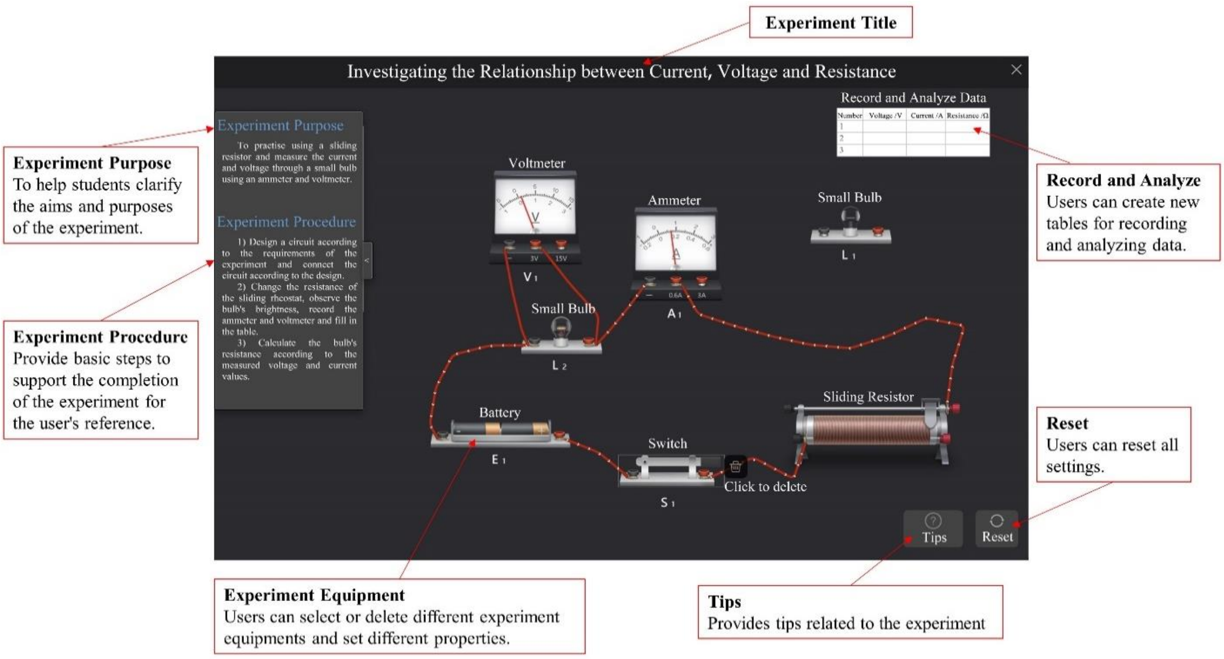

Figure 2. The translated screenshot of the virtual physics experiment platform.

Data Collection and Analysis

Questionnaires and student interviews were adopted to collect data in this study. Students' learning motivation was measured by the Physics Learning Motivation Test (PLMT), adapted from the Intrinsic Motivation Inventory (McAuley et al., 1989; Yin, Goh, & Yang, 2020). The PLMT includes five areas: interest-enjoyment, tension-pressure, perceived choice, perceived competence, and perceived value. Additionally, six students from the experimental group were randomly selected for interviews. We first tested the reliability of the questionnaire and conducted a descriptive analysis to know background information. Then, ANOVA was used to compare the two groups' motivation and examine how the intervention influenced motivation. Finally, the interview data were analysed to explain the findings in the quantitative analysis.

Participants

The research participants were Grade 9 students in a middle school in Mainland China. They came from two classes and were divided into an experimental group (n = 37) and a control group (n = 37). The intervention was completed in a virtual experimental environment for the experimental group, while the control group conducted real experiments. The same physics teacher taught both classes separately to guarantee they learned very similar material in different learning environments. Both groups had a similar academic background before the intervention. All the participants involved finished the pre-test and post-test. Six students from the experimental group were randomly selected for interview after the intervention.

Intervention

The intervention lasted for three weeks, with one 45-min physics experiment class per week. The virtual experimental platform created the virtual experimental environment provided in this study. An experienced physics teacher who joined this study designed the experimental content according to the Grade 9 physics textbook. The entire intervention consisted of three physics experiment sessions on electrical experiments. The first lesson introduced series and parallel circuit current laws. The second session discussed circuit troubleshooting. The third lesson explained Ohm's Law. Figure 3 shows alignment with the theoretical framework and the process of intervention.

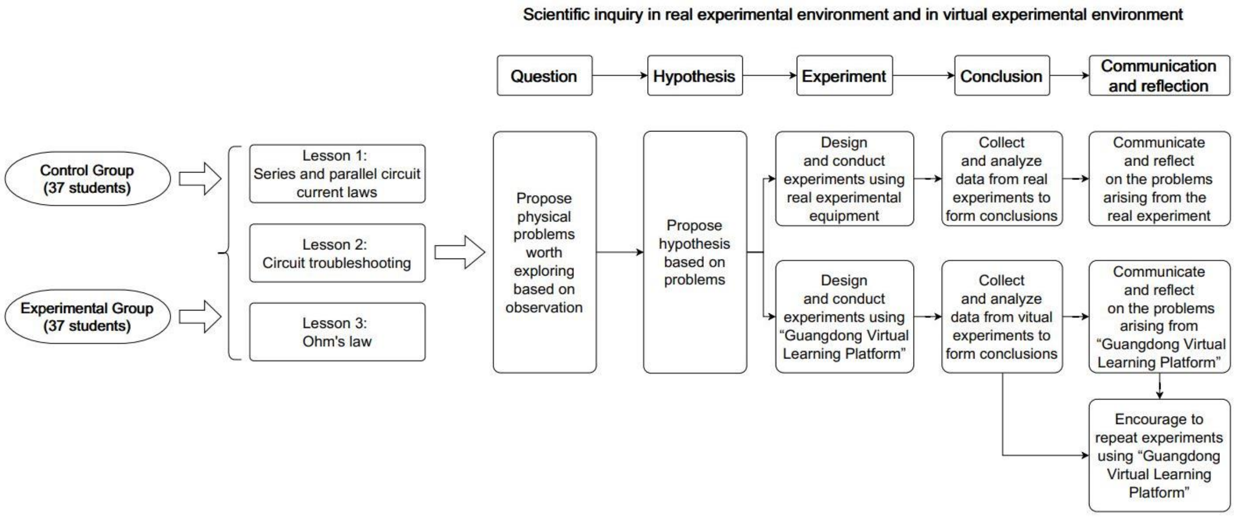

Figure 3. The process of intervention and its alignment with the adopted theoretical framework.

Results and Findings

Background Information

The internal reliability of the PLMT was investigated based on Cronbach's alpha. Table 1 shows the reliability of the questionnaire. The Cronbach's α for each dimension ranged from 0.780 to 0.936. The overall α for the questionnaire was 0.908, indicating that the questionnaire's data was reliable enough to evaluate the learning motivation.

Table 1

Reliability of Five Dimensions of Physics Learning Motivation Test

Dimensions	M	SD	α of each dimension	α
Interest-enjoyment (IE)	4.375	1.317	0.920	
Tension-pressure (TP)	3.168	1.091	0.780	
Perceived choice (PCh)	4.118	1.567	0.819	0.908
Perceived competence (PCo)	3.886	1.084	0.908	
Perceived value (PV)	4.449	1.291	0.936	

To check that the experimental group and control group had similar learning motivation levels before the intervention, we utilised ANOVA. The pre-test score was set as the dependent variable, and two learning environments were set as independent variables. Table 2 shows the result. Statistical analysis showed no significant difference in the pre-test between the control and experimental groups ($p = 0.292 > 0.05$), indicating that these two groups did not significantly differ in learning motivation levels before the intervention.

Impact of the Virtual Experiment Environment on Students' Physics Learning Motivation

The ANOVA was conducted to examine whether significant differences in learning motivation existed in the two learning environments after the intervention. The learning environments were set as independent variables, and the five dimensions of the PLMT were set as the dependent variables: interest-enjoyment (IE), tension-pressure (TP), perceived choice (PCh), perceived competence (PCo), and perceived value (PV). All the consequences of the tests of Homogeneity of Variances of the five independent variables were $p > 0.05$, so all the dimensions could use *F*-test. Table 2 shows the result.

Statistical analysis showed that there was no significant difference in IE ($F = 1.653$, $p = 0.203 > 0.05$), TP ($F = 0.060$, $p = 0.807 > 0.05$), PCh ($F = 3.023$, $p = 0.086 > 0.05$) and PCo ($F = 1.816$, $p = 0.182 > 0.05$), indicating that the virtual experimental environment could produce the similar learning effect (e.g., learning interest, learning pressure) in these four dimensions as the real experimental environment. Moreover, the means of IE ($M_E = 4.927 > M_C = 4.517$), PCh ($M_E = 4.439 > M_C = 3.946$), and PCo ($M_E = 4.378 > M_C = 3.930$) in the experimental group were higher than in the control group, reflecting a sign after the intervention, students might have higher motivation in these three dimensions in the physics learning. It sounds that students enjoy the virtual environment more, are more likely to choose the virtual experiment environment if possible and believe that the virtual experiment is more capable of helping them improve their competence in learning physics. The mean of TP ($M_C = 2.773 > M_E = 2.692$) in the control group was higher than in the experimental group, which might indicate that students were slightly less stressed and nervous in the virtual environment. Nevertheless, there was a significant difference in PV ($F = 6.543$, $p = 0.013 < 0.05$), suggesting that the intervention significantly affected students' perceived value. In addition, based on the mean of PV post-test scores ($M_C = 4.345 < M_E = 5.196$), students perceived a higher value in using the virtual physics experiment.

Table 2

ANOVA of the Pre-test and Post-test Learning Motivation

Test	Dependent variables	Groups	M	SD	*F*-value	*p*-value
Pre-test	Total learning motivation	Control	3.906	0.998	6.097	0.292
		Experimental	4.107	0.575		
Post-test	Interest-enjoyment (IE)	Control	4.517	1.509	1.653	0.203
		Experimental	4.927	1.213		
	Tension-pressure (TP)	Control	2.773	1.309	0.060	0.807
		Experimental	2.692	1.525		
	Perceived choice (PCh)	Control	3.946	1.403	3.023	0.086
		Experimental	4.439	1.004		
	Perceived competence (PCo)	Control	3.930	1.452	1.816	0.182
		Experimental	4.378	1.411		
	Perceived value (PV)	Control	4.345	1.500	6.543	0.013
		Experimental	5.196	1.359		

The first research question can be answered based on the previous findings: the virtual physics experiment environment did increase students' physics learning motivation, especially in terms of the perceived value dimension as the results of ANOVA found that there was a significant difference. This reflected that the students in the experimental group perceived the value of using the virtual physics experiment, which boosted their motivation.

Students' Perceptions of Virtual Physics Learning Environment

Student interviews were conducted to investigate how the virtual physics experiment learning environment affects Grade 9 Students' motivation toward physics. Six participants from the experimental group were randomly invited. The interview data were examined according to five dimensions of the PLMT (interest-enjoyment, tension-pressure, perceived choice, perceived competence, and perceived value). To protect privacy, we coded students from ST1 to ST6. For example, ST1 is the first student participating in the interview.

Through the individual interviews, it was found that the great majority of students ($n = 5$) agreed that the virtual physics experiment improved their interest and enjoyment of physics learning, which aligned with the previous quantitative results of this study. For instance, ST1 stated that he felt good about the learning experience because the virtual platform provided many physics experiments for him to try and allowed him to observe experimental phenomena (e.g., the direction of current flow) that could not be visible in real experiments. ST2 and ST3 also stated that using virtual platforms to experiment was a fresh and interesting learning experience, so they were motivated to use it during non-class time.

Regarding whether students felt tension and pressure when doing experiments in the virtual environment, most students (ST1, ST2, ST4, and ST6) stated that the stress in the virtual environment differed from what they had felt in the past, echoing the quantitative data analysis results. For example, ST1 and ST2 shared the same idea that their task in the virtual environment was still to prepare for future examinations so that no matter what environment they were in, they still felt nervous. However, ST3 explained that completing experiments in a virtual environment did not require consideration of instrument damage and disorder steps, which were not allowed in a traditional physics experiment class, thus reducing the learning pressure.

Although the results of the quantitative analysis showed a higher level of perceived choice in the experimental group than in the control group, when asked whether they would choose a real or a virtual laboratory, only one student (ST4) stated that he would choose the virtual laboratory. ST4 stated that virtual experiments were easy to use and saved him time. Traditionally, he must spend much time listening to the instructor and preparing the equipment. However, in the virtual environment, he could develop his learning path based on his learning needs, helping to save time. Other respondents (ST1, ST2, ST3, ST5, and ST6) explained that the virtual experiments would be selected to complement real experiments to accomplish what cannot be done in the real laboratory and deepen their understanding of physics.

Most students ($n = 5$) thought they were more motivated to learn physics because they perceived improved competence in the virtual learning environment. For instance, ST1 and ST3 believed that the virtual platform had improved their problem-solving ability. ST2 improved experimental ability by repeatedly performing experimental procedures in the virtual platform. ST4 and ST5 believed their concept-understanding ability had improved because the virtual platform helped them understand the knowledge better and made physics less complicated and abstract.

The students felt that their competence had improved in the virtual environment also recognised its value. The students perceived the increased competence as the most significant value that the virtual environment brought them (ST1, ST2, ST4, and ST6), which likely motivated them to choose the virtual environment again. For example, ST2 said, "after using the virtual experiment, I felt my experimental ability and knowledge improved. This made me more courageous to challenge difficult physics problems because I can use virtual experiments to simulate the scenes and help me understand the problems." This indicated that once the students perceived good experimental competence in the virtual environment, they would choose the virtual environment again to challenge difficult problems.

In general, based on the above, it seemed that the flexible virtual experimental environment could provide students with a good learning experience, help them improve their abilities and solve physics challenges, and therefore have a higher potential to increase their motivation, especially students with higher perceptual competence as they felt a higher value in using virtual experiments to learn physics and thus were more motivated.

Discussion: Virtual Physics Experiment Environment Could Increase Motivation

This study aimed to investigate the impact of a virtual experimental learning environment on Grade 9 students' physics learning motivation by conducting a quasi-experiment research with interviews in Mainland China. Although the results demonstrated that students' motivation rose in both learning environments, the experimental group showed significant changes after the intervention, suggesting that students perceived higher motivation in the virtual environment. It was consistent with the findings of Maksoud (2018) and De Vries and May (2019). As a novel teaching tool, virtual experiments have considerable potential to motivate students to learn physics. Based on the findings from student interviews, this is mainly attributed to the flexibility of the virtual environment. It respected students' autonomy and provided opportunities for repetitive practice, significantly increasing participants' motivation in the experimental group. When students were provided with choices to do what they wanted, it positively affected their intrinsic motivation (Deci & Ryan, 1987). In addition, findings from student interviews also confirmed that those who perceived increased experimental ability in the virtual environment were more self-motivated, which explained why the experimental group witnessed a higher level of interest-enjoyment, perceived choice, and perceived competence than the control group. Such qualities are of immense significance to students' academic development. Thus, there are potentials for virtual physics experiments as an effective and efficient learning tool to motivate students to remain tapped to a greater extent.

The Influence of Virtual Physics Experiment Environment on Interest-Enjoyment

According to this research, the great convenience and various choices offered by virtual physics experiments can arouse students' enthusiasm for learning. By interacting with just a tablet, students could complete experiments at any time with deeper immersion when doing experiments in the virtual environment than in the real experiment environment, which matches the findings of Hamed and Aljanazrah (2020). Besides, the great variety of experimental resources incorporated in the virtual physics experiment environment allowed students to choose whatever they needed based on individual learning objectives. This kind of student-centred learning in the virtual environment increased students' motivation, which in turn motivated them to learn (Gunawan et al., 2018). In other words, students in a virtual environment tended to enjoy learning more than those in real experiment setting. The use of virtual physics experiments thus would be a practical tool to make up for the weaknesses of the real experiments and promote integrating information technology into education (Li, 2015).

The Influence of Virtual Physics Experiment Environment on Tension-Pressure

There was no significant difference in pressure in the two distinct learning environments, indicating that students' pressure in both environments might be mainly rooted in exam-oriented education. Under examination pressure, students' curiosity might be stifled (Archer et al., 2017). Despite that, there was still a slight difference between the pressure in the virtual and real experiment environment. According to this research, students felt more stressed in the real learning environment. This might be mainly because students were concerned they would not have the opportunity to try the experiment again after class. What is more, teachers require that students carefully follow strict rules and experimental procedures to avoid damage to the equipment, which could also cause tension in students' minds. Therefore, in such a learning environment, students' learning pressure might be heightened, possibly leading to learning burnout (Stoliker & Lafreniere, 2015). In contrast, in the virtual environment, students could repeatedly work without fear of making mistakes because the procedures could be reset (Li, 2015). Therefore, learning in a virtual environment is likely to reduce students' pressure and tension.

The Influence of Virtual Physics Experiment Environment on Perceived Choice

This study reported a higher level of perceived choice for participants in the experimental group. It suggested that the flexibility of the virtual experimental environment provided learners with autonomy, allowing them to design how to learn at their own pace. In contrast, in a real learning environment, it was the teacher who controlled the pace of learning and teaching (Gao, Wang, & Zhong, 2018). The teacher-centred learning scenario may harm students' learning autonomy, and students are likely to feel forced to learn, which may decrease their motivation. Additionally, findings from interviews reflected that combining virtual experiments with real laboratories helped to deepen their knowledge of circuits. This is in line with the study conducted by Hamed and Aljanazrah (2020), which reported that combining virtual with real experiments could facilitate students' learning process and conceptual understanding. Therefore, students would actively choose to repeatedly do physical experiments in the virtual environment to prepare for the real experiment operation and consolidate their knowledge base.

The Influence of Virtual Physics Experiment Environment on Perceived Competence

Based on the quantitative analysis results, there was no significant difference in students' perceived competence in the two environments, suggesting that Grade 9 students acquired knowledge and skills regardless of the environment. This is consistent with previous findings that the virtual experimental environment provided the same scientific inquiry skills that students could develop in the real experimental environment (Darrah et al., 2014; Hamed & Aljanazrah, 2020), which was the essential learning outcome of physics experiment courses. Nonetheless, this research demonstrated that students had slightly higher perceived competence in the virtual environment, which indicated that they had different levels of development in the two learning environments. The findings from student interviews also confirmed that they could improve their experimental skills through repetitive practice in the virtual environment. Thus, virtual learning environments could achieve similar learning outcomes as traditional instruction but provide additional opportunities to promote higher perceived competence.

The Influence of Virtual Physics Experiment Environment on Perceived Value

This research shows that the virtual experimental environment significantly increased perceived value. Further research found that students with high perceived competence had higher perceived value, and thus were more motivated to learn physics. One possible interpretation was that students perceived increased competency in the flexible virtual learning environment, thus recognising the value of virtual learning and gaining confidence to challenge difficulties (Rodriguez et al., 2021), so they may choose to use it again as a learning tool. Based on the findings from student interviews, their perceived value included repeating the experiment and simulating difficult physical situations. Therefore, if learning designers aim to increase students' motivation to learn physics, they are recommended to design instructional strategies that would enhance students' perceived competence to increase their recognition of the value of the virtual physics experiment environment.

Conclusion

This study used a mixed methods design with quantitative (embedded quasi-experimental design) and qualitative approach (student interviews) to explore whether virtual physics experiments could affect Grade 9 students' learning motivation. The results showed that the virtual physics experiment learning environment could significantly increase participants' motivation, especially in the perceived value dimension. The findings from student interviews also aligned with the those of the quantitative analysis that students with a high perceived competence were more likely to increase their motivation through the virtual physical experiment environment. This research has contributed to filling the gap left by current findings on using virtual physics experiments to motivate students to learn sciences. Furthermore, the intervention in this study created a virtual physics experiment-based instructional design based on the scientific inquiry approach, which can be a reference for learning designers and teachers in incorporating virtual experiments in future physics education and provide a possible solution for conducting physics lessons when it is difficult to conduct the face-to-face lesson.

The limitation of this study is that the intervention lasted only three weeks due to resources constraint. If the duration could be extended, it might cause a more profound impact, especially in increasing other dimensions of students' motivation. In addition, teacher perspectives could be investigated, especially the pedagogical perspectives.

References

Al-Amri, A., Osman, M. E., & Musawi, A. (2020). The effectiveness of a 3D-virtual reality learning environment (3D-VRLE) on the Omani eighth grade students' achievement and motivation towards physics learning. *International Journal of Emerging Technologies in Learning, 15*(5), 4-16.

Aliane, N., Pastor, R., & Mariscal, G. (2010). Limitations of remote laboratories in control engineering education. *International Journal of Online Engineering, 6*(1), 31-33.

Archer, L., Dawson, E., DeWitt, J., Godec, S., King, H., Mau, A., Nomikou, E., & Seakins, A. (2017). Killing curiosity? An analysis of celebrated identity performances among teachers and students in nine London secondary science classrooms. *Science Education, 101*(5), 741-764.

Aslan, S. A., & Duruhan, K. (2021). The effect of virtual learning environments designed according to problem-based learning approach to students' success, problem-solving skills, and motivations. *Education and Information Technologies, 26*(2), 2253-2283.

Awan, R.-U.-N., Sarwar, M., Naz, A., & Noreen, G. (2011). Attitudes toward science among school students of different nations: A review study. *Journal of College Teaching & Learning (TLC), 8*(2), 43-50.

Carnevale, D. (2003). The virtual lab experiment: Some colleges use computer simulations to expand science offerings online. *The Chronicle of Higher Education, 49*(21), A30.

Darrah, M., Humbert, R., Finstein, J., Simon, M., & Hopkins, J. (2014). Are virtual labs as effective as hands-on labs for undergraduate physics? A comparative study at two major universities. *Journal of Science Education and Technology, 23*(6), 803-814.

De Vries, L. E., & May, M. (2019). Virtual laboratory simulation in the education of laboratory technicians-motivation and study intensity. *Biochemistry and Molecular Biology Education, 47*(3), 257-262.

Deci, E. L., & Ryan, R. M. (1987). The support of autonomy and the control of behavior. *Journal of Personality and Social Psychology, 53*(6), 1024-1037.

Gao, S., Wang, J., & Zhong, Z. Y. (2018). Influence of science instruction reform on academic performance of eighth grade students in Chinese inner-Mongolia autonomous region. *Journal of Comparative and International Education, 48*(6), 879-895.

Glava, C. C., & Glava, A. E. (2010). Student's voices on science teaching and learning based on virtual instrumentations. An international comparative view. *Innovation and Creativity in Education, 2*(2), 2594-2598.

Guangdong Virtual Learning Platform. (2018). Guangdong virtual learning platform website. Retrieved July 31, 2022 from https://www.gdtextbook.com/

Gunawan, G., Nisrina, N. Y., Suranti, N. M., Herayanti, L., & Rahmatiah, R. (2018). Virtual laboratory to improve students' conceptual understanding in physics learning. *Journal of Physics. Conference Series, 1108*(1), 12049.

Hamed, G., & Aljanazrah, A. (2020). The effectiveness of using virtual experiments on students' learning in the general physics lab. *Journal of Information Technology Education: Research, 19*, 977-996.

Huo, D. Y. (2015). The design of teaching experiment system based on virtual instrument technology. *Proceedings of the 2015 International Conference on Management, Education, Information and Control, 125*, 53-57.

Kaptingei, P., & Rutto, D. K. (2014). Challenges facing laboratory practical approach in physics instruction in Kenyan District secondary schools. *International Journal of Advancements in Research & Technology, 3*(8), 13-17.

Li, B., & Yan, G. (1993). *Educational psychology*. Wuhan: Central China Normal University Press.

Li, Y. F. (2015). The application of the virtual experiment in physics teaching. *Proceedings of the 2015 International Conference on Education Technology, Management and Humanities Science (Etmhs 2015), 27*, 1225-1228.

Maksoud, N. F. A. (2018). When virtual becomes better than real: Investigating the impact of a networking simulation on learning and motivation. *International Journal of Education and Practice*, *6*(4), 253-270.

McAuley, E., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the intrinsic motivation inventory in a competitive sport setting: A confirmatory factor analysis. *Research Quarterly for Exercise and Sport*, *60*(1), 48-58.

Ministry of Education of the People's Republic of China. (2012). *Physics curriculum standards for compulsory education* (2011 Ed.). Beijing: Beijing Normal University Press.

Ogbuanya, T. C., & Onele, N. O. (2018). Investigating the effectiveness of desktop virtual reality for teaching and learning of electrical/electronics technology in universities. *Computers in the Schools, 35*(3), 226-248.

Rodriguez, S., Estevez, I., Pineiro, I., Valle, A., Vieites, T., & Regueiro, B. (2021). Perceived competence and intrinsic motivation in mathematics: Exploring latent profiles. *Sustainability, 13*(16), 8707.

Stoliker, B. E., & Lafreniere, K. D. (2015). The influence of perceived stress loneliness and learning burnout on university students' educational experience. *College Student Journal, 49*(1), 146-160.

Wang, H. (2013). Scientific inquiry teaching design: Basis, implementation, and evaluation. *China Educational Technology, 28*(9), 102-106, 126.

Wang, J. Y., Guo, D. H., & Jou, M. (2015). A study on the effects of model-based inquiry pedagogy on students' inquiry skills in a virtual physics lab. *Computers in Human Behavior, 49*, 658-669.

Yin, J., Goh, T.-T., & Yang, B. (2020). Conversation technology with micro-learning: The impact of chatbot-based learning on students' learning motivation and performance. *Journal of Educational Computing Research, 59*(1), 154-177.

Zacharia, Z. C. (2007). Comparing land combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning*, *23*(2), 120-132.