

The Effect of Virtual Laboratory Combination With Hands-On Laboratory on Students' Learning

Yan Zhao, Xi'an Jiaotong-Liverpool University, China

Gang Liu, Xi'an Jiaotong-Liverpool University, China

M.B.N. Kouwenhoven, Xi'an Jiaotong-Liverpool University, China

Hao Yu, Xi'an Jiaotong-Liverpool University, China

The European Conference on Education 2025
Official Conference Proceedings

Abstract

In physics education, laboratory experiments are a key component of the learning process, as they enable students to apply scientific theories in practice. However, traditional hands-on laboratories face great challenges due to large student enrollment and lack of class time and lab space. To address these challenges, this study implemented a blended learning approach that combines hands-on labs with virtual labs. The lab instruments and environment used in the virtual laboratory were created using 3D Unity WebGL. Participants in this study were first-year undergraduate students in China, divided into two groups. Students in the experimental group conducted the experiment in the virtual laboratory prior to their hands-on lab session, while the control group performed the same experiment in a traditional teaching laboratory without the participation in virtual laboratory. To assess the impact of the virtual laboratory in combination with the hands-on laboratory, we evaluated student engagement, lab scores, and attitudes toward the virtual learning experience. Our findings indicate that students in a blended learning environment were more engaged and achieved higher scores compared to those in a traditional setting. This supports previous research suggesting that virtual laboratories can effectively supplement traditional hands-on labs, providing students with greater flexibility and access to learning resources. The results of this study underscore the role of virtual laboratories in enhancing student motivation and overall learning experience.

Keywords: virtual laboratory, blended learning, physics education

iafor

The International Academic Forum
www.iafor.org

Introduction

In physics education, laboratory experiments are a key element of learning (Lunetta et al., 2007; Ma & Nickerson, 2006; Satterthwait, 2010; Singer et al., 2006), as they allow students to apply the scientific theories studied in lecture courses to practical situations. These laboratory experiences equip students with the skills to make predictions and test their hypotheses through experimentation, thereby enhancing their understanding of scientific facts and concepts while also boosting their motivation to learn science. Furthermore, hands-on laboratory work helps students develop essential practical skills, such as using laboratory equipment, making observations, taking measurements, and interpreting experimental results. Therefore, effective design and implementation of laboratory activities in physics are vital for creating meaningful learning experiences.

In traditional hands-on laboratories, students conduct experiments under the guidance of a lab instructor, who explains the theoretical background and procedures before they begin their work. Following these instructions, students collect and analyze experimental data, and report their findings in a lab report. This conventional laboratory practice offers students valuable hands-on experience in the use of laboratory equipment, and allows students to have face-to-face interactions with the lab instructor. However, traditional labs are often constrained by safety concerns, physical space, equipment, or budget, which can limit the types of experiments students can carry out.

The rapid development of internet technology has provided additional teaching strategies for laboratory experiments, with online education being one of the most exciting enhancements (Chen et al., 2010). Evidence from literature shows that the integration of online instructional technologies, such as simulations, animation, videos, and visualizations, with real practical work is very promising (Hofstein & Kind, 2012). Currently, there are two approaches to conduct the experiments online: virtual labs and remote labs. Virtual labs utilize software to simulate the lab processes and actions in physical laboratories. The adoption of virtual labs increased significantly during the global pandemic. Remote labs, on the other hand, enable students to control the lab equipment remotely through the Internet. Therefore, online laboratories provide students the opportunity to conduct experiments without the traditional constraints of time and location.

In this study, we assess the effectiveness of blended physics laboratory experiments in enhancing students' achievement levels compared to the traditional hands-on approach. Through a comparative analysis, our goal is to explore the role of virtual laboratories in physics education. The findings of this study will contribute to the ongoing discussion on the integration of virtual reality technology in teaching and learning activities.

Methodology

This study employed a quasi-experimental research design to investigate the effects of blended laboratory experiments on teaching physics. A total of 214 students participated in the laboratory experiments. The learning outcomes of two groups were compared based on their lab report scores: one group of 98 students served as the control group, completing the laboratory tasks in a traditional hands-on format, while the other group consisted of 116 students in the experimental group, who were taught through a combination of hands-on and virtual labs. After the experimental group completed all laboratory activities, a satisfaction survey was administered to gather their perceptions regarding the use of the virtual laboratory.

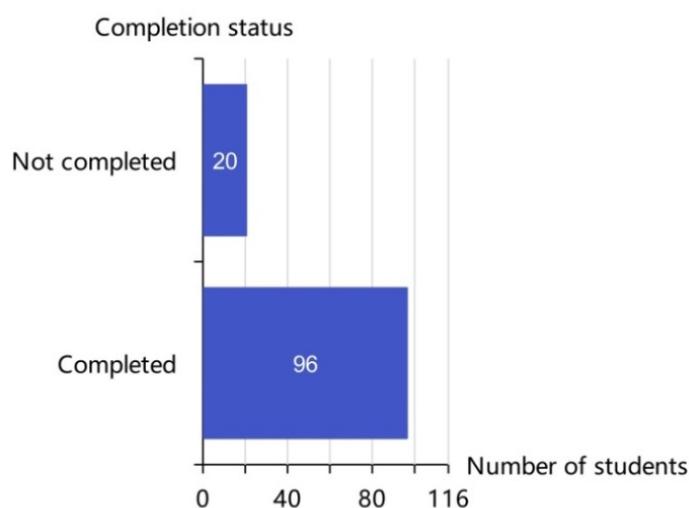
Results

Lab Engagement

According to the activity completion report from the virtual laboratory platform, as shown in Figure 1, 96 students from the experimental group completed the virtual experiment, while 20 students did not. Thus, the virtual lab completion rate is approximately 83%. One possible reason for students not completing the virtual lab could be that the virtual lab was not mandatory and students' performance in the virtual lab did not contribute to their final lab scores.

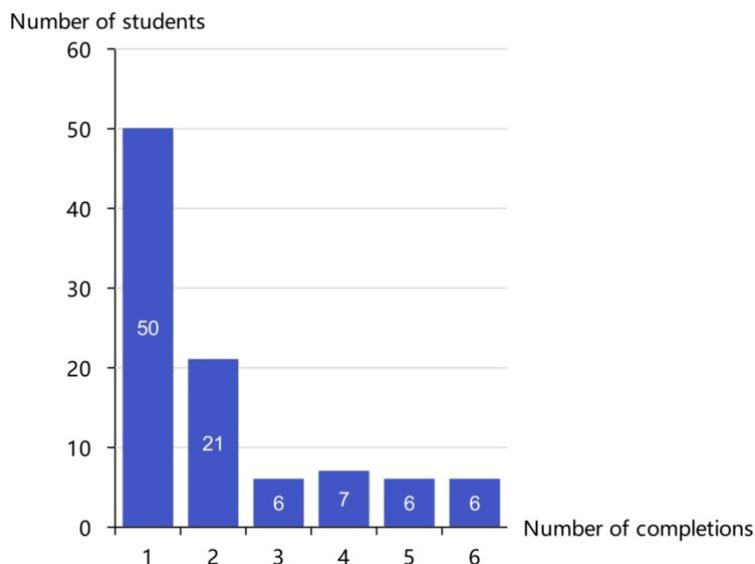
Figure 1

Virtual Lab Completion Status



As shown in Figure 2, among the students who completed the virtual experiments, 50 students completed the experimental work once, while 49 students completed the experiments multiple times. The results revealed that over 40% of students in the experimental group were highly engaged with the virtual learning platform, completing labs multiple times.

Figure 2
Virtual Lab Completion Counts



Lab Performance

Students' lab performance was evaluated based on their lab report scores. After removing all students who scored 0, Table 1 presents the results of lab scores for students in the blended learning mode compared to those in the traditional hands-on lab mode. The mean score in the traditional lab format was 54, while the mean score in the blended format was 63. And the standard deviation of scores was 16.53 for the blended labs and 15.42 for the traditional labs. This indicates that although the mean score in the experimental group (blended format) was higher than that in the control group (traditional format), the experimental group had greater variability in their lab scores, reflecting a wider range of student performance.

Table 1
Student Lab Scores in Different Learning Modes

Laboratory Format	Statistics				
	Mean	Median	Min	Max	Standard deviation
Blended Laboratory Format	62.51	63	16	95	16.53
Traditional Laboratory Format	54.39	51.5	14	94	15.42

The following charts illustrate the frequency distribution of students' lab scores in both blended and hand-on laboratory formats. The range of scores was divided into intervals of width 4, and the number of scores falling into each interval was counted to determine the frequency. A normal distribution curve was plotted on top of each histogram to assess how closely the scores follow a normal distribution. The data revealed that in traditional hands-on lab, scores below 60 occurred frequently while scores higher than 80 were rare, suggesting a skewed distribution. However, in blended labs, the scores are approximately normally distributed, despite a high frequency of scores between 80 and 84. Furthermore, when comparing the score distribution in the traditional hands-on mode, it is evident that a higher percentage of students scored above 60 in the blended mode.

Figure 3
Student Lab Score Distribution in Hands-On Lab Mode

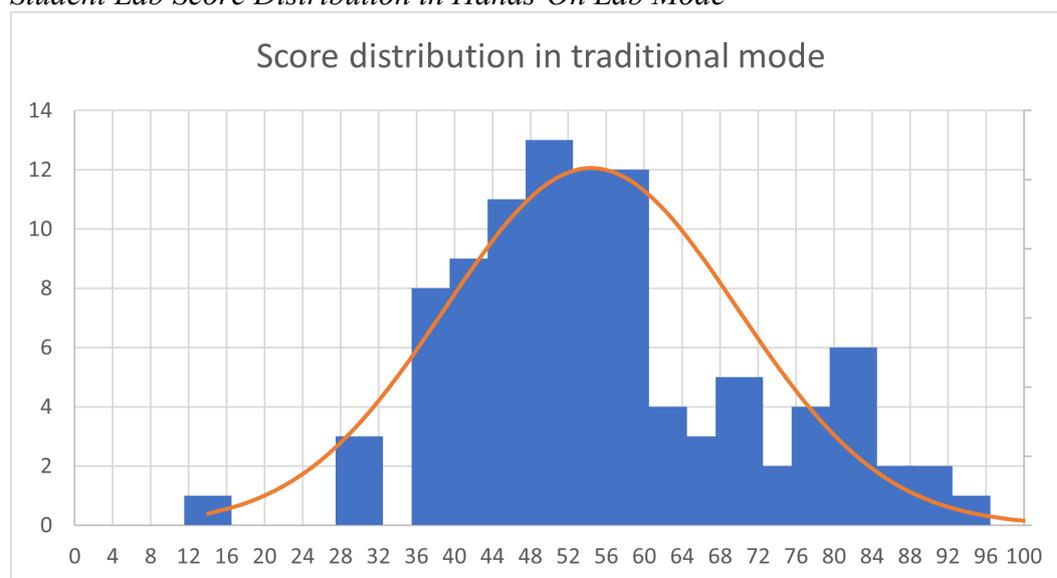
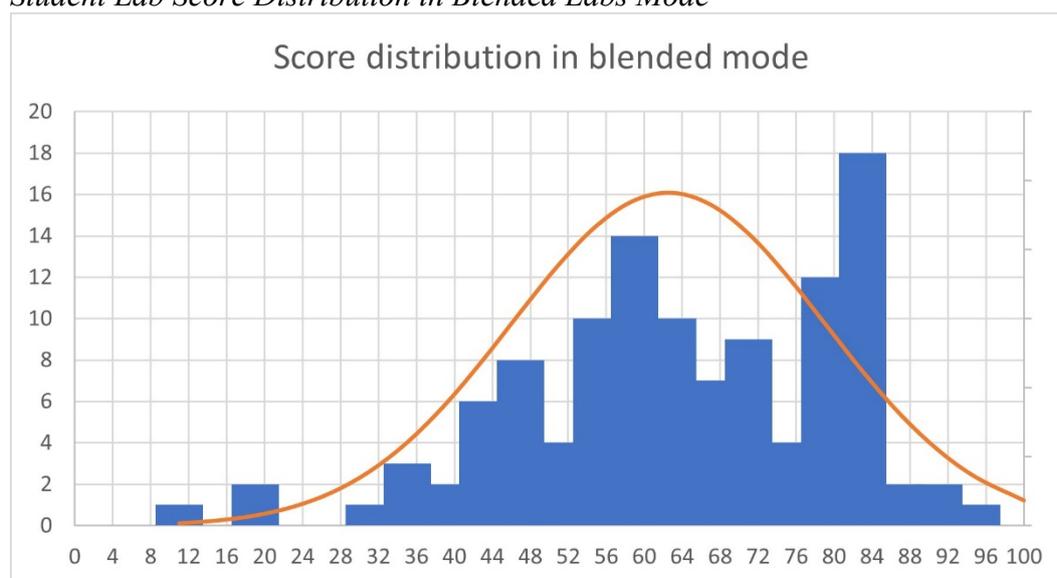


Figure 4
Student Lab Score Distribution in Blended Labs Mode



Since the lab scores from the control group are not normally distributed, a nonparametric Mann-Whitney U test was conducted to identify any significant differences in lab scores between the experimental and control groups. A significance level of $p = 0.05$ was chosen for the test. The results indicated a significant difference between the two groups ($U = 7758$, $p = 0.000007 < 0.05$).

Student Attitudes Towards the Use of Virtual Laboratory

At the end of the semester, a laboratory evaluation survey was given to students in the experimental group to collect their feedback on the virtual laboratory learning experience. There were ten Likert scale questions in the survey and students were asked to respond to each question using a four-point scale (e.g., 2 = Strongly Agree, 1 = Agree, 0 = Neutral, -1 = Disagree). A total of 58 students participated in the survey, and their responses were converted

into percentages for the evaluation of the virtual lab activities. Below are the students' answers to the survey questions.

Table 2

Student Responses Towards the Virtual Learning Experience

1. The virtual experiment helped me to learn physics concepts.			
Strongly Agree: 60%	Agree: 31%	Neutral: 7%	Disagree: 2%
2. The virtual experiment enabled me to work at my own pace.			
Strongly Agree: 59%	Agree: 34%	Neutral: 7%	Disagree: 0%
3. The virtual experiment was clear and easy to follow.			
Strongly Agree: 57%	Agree: 33%	Neutral: 10%	Disagree: 0%
4. Virtually performing an experiment helped me better understand the physics laws/principles behind the experiment.			
Strongly Agree: 62%	Agree: 26%	Neutral: 9%	Disagree: 3%
5. The virtual experiment stimulated my curiosity about physics.			
Strongly Agree: 55%	Agree: 31%	Neutral: 12%	Disagree: 2%
6. The virtual experiment helped me to become more confident in carrying out the real experiment.			
Strongly Agree: 57%	Agree: 33%	Neutral: 7%	Disagree: 3%
7. The quality of experimental learning is increased using virtual experiment.			
Strongly Agree: 55%	Agree: 31%	Neutral: 9%	Disagree: 5%
8. My knowledge and skills are enhanced after conducting the virtual experiment.			
Strongly Agree: 54%	Agree: 34%	Neutral: 10%	Disagree: 2%
9. I am satisfied with my learning experiences in the virtual lab.			
Strongly Agree: 48%	Agree: 36%	Neutral: 14%	Disagree: 2%
10. I prefer to participate in virtual lab compared to traditional lab.			
Strongly Agree: 42%	Agree: 28%	Neutral: 21%	Disagree: 9%

In general, Table 2 shows that the virtual laboratory learning experiences was evaluated positively by students. For all questions, an average of over 85% responded positively toward the use of virtual laboratory. Many of students were satisfied with the virtual experiment design and contents and they believed that the work carried out in the virtual laboratory improved their knowledge, skills and attitudes. Over 80% of students stated that practice in the virtual laboratory increased their confidence when performing real experiments.

The survey also included several open-ended questions to collect students' feedback regarding their preferences, challenges and suggestions on the virtual learning experience. Below are some representative comments from the students: "What I like best is the pleasure of discovering new things while performing the virtual experiments." "I think the virtual experiment is interesting and it is helpful to understand the theories in physics." "The main challenge for me is to understand the process of doing an experiment, so I performed the virtual experiment before real lab to overcome the challenge." "I hope the virtual laboratory experiments could be more interactive."

Discussion

When comparing students' lab scores in two different learning modes, as shown in Table 1, the mean score of the experimental group was higher than that of the control group. The Mann-Whitney U test confirmed a significant difference in lab scores between the two groups. This difference may be attributed to the fact that students who did not practice the experiments before entering the physical lab lacked experience and prior knowledge, so they need longer time and more attention to comprehend but are limited by classroom teaching time and interaction frequency, their learning efficiency is lower. In contrast, students in the experimental group had the opportunity to conduct experiments in a virtual laboratory prior to their real lab sessions, allowing them to gain a deeper understanding of the underlying physics concepts and successfully complete their laboratory tasks. These findings align with the previous studies that integrating virtual labs with physical labs improved students' conceptual understanding, leading to enhanced learning outcomes (Aldosari & Ghita, 2022; Arista & Kuswanto, 2018; Bhatti et al., 2018; Sriadhi et al., 2019).

Furthermore, the distribution of student lab scores between the two groups highlights the effectiveness of the virtual laboratory on students' achievement. The proportion of high scores in the experimental group was greater than that in the control group, particularly for scores in the 76-84 range. 26% of students in the experimental group scored between 76 and 84, compared to only 11% of participants in the control group. This indicates that the combination of virtual and hands-on laboratory environments significantly enhanced students learning outcomes compared to using hands-on environment alone. This result confirms the findings of several earlier studies (Anam et al., 2019; Bortnik et al., 2017; Sari et al., 2019; Sugiharti & Limbong, 2018). In addition, results from the activity completion report indicate that students in the experimental group were highly engaged with the virtual laboratory experiments. 80% of the students completed the virtual laboratory experiments, and 40% of them completed the experiments multiple times.

Results from the student survey show that the virtual learning experience had a good level of appreciation by students. Most students from the experiment group were actively engaged with the virtual experiment and satisfied with their virtual learning experiences. They appreciated the self-paced learning environment which allows them to do experiments at their own pace. In addition, they felt the virtual laboratory was helpful to learn physics concepts and gain practical skills, which confirms the results from previous studies conducted by Darrah et al. (2014), Roblyer and Hughes (2019), and Sypsas et al. (2019).

Furthermore, students in the experiment group mentioned that performing the experiment virtually increased their interests toward the topics and their confidence and motivations for learning physics. This might be due to the virtual laboratory increased students' knowledge about the lab content and techniques, making the learning experience more interesting and fulfilling. Many studies have shown that students' motivation is positively and significantly related to their academic achievement (Skinner et al., 2017; Steinmayr et al., 2019; Taylor et al., 2014). Our study confirmed that the virtual laboratory effectively motivated students to learn, resulting in improved learning outcomes. Additionally, survey results indicate that the majority of students felt the virtual laboratory facilitated a deeper understanding of physics concepts and ideas, thereby enhancing the quality of their laboratory learning. Thus, the virtual laboratory can serve as an effective tool to better prepare students before they enter traditional labs by increasing their knowledge and confidence.

In general, the combination of virtual and hands-on laboratories has positively impacted students' learning outcomes in practical physics. Students can access the virtual laboratory multiple times to deepen their understanding and have more time and opportunities to complete the lab activities. However, in virtual laboratory, students lack the hands-on experiences with real equipment and collaborations with other students. Therefore, virtual laboratories could not replace hands-on laboratories but can be used as valuable supplements to hands-on learning process to improve students' learning outcomes in physics. In this study, we examined student engagement, lab scores, and attitudes to explore the effects of blended lab activities on learning physics. However, other factors such as student attendance, laboratory performance, and learning efficiency may also be influenced by the blended learning environment. Future research should investigate the impact of blended labs on these factors. Additionally, more studies, including pre-lab and post-lab quizzes or tests, are needed to assess students' learning performance and achievement due to the use of virtual laboratories.

Conclusions

In conclusion, this study provides strong evidence for the effectiveness of combining hands-on and virtual laboratory experiments to learn physics concepts. Analysis of lab report scores revealed that the mean score in the blended learning group was higher than that of the traditional learning group. Furthermore, the Mann-Whitney U-test indicated that the difference in means between the two groups was statistically significant. Regarding students' perceptions of the virtual laboratory, the findings showed a very high level of satisfaction among participants. The majority of students appreciated the flexibility to learn at their own pace and felt that the virtual laboratory enhanced their motivation, understanding, and mastery of knowledge and skills. These results confirm previous studies indicating that the integration of hands-on and virtual laboratory environments gives significantly better outcomes for student achievement compared to using hands-on laboratories alone. In terms of the limitations of this study, although lab report scores can reflect students' achievement, further research is needed to explore the impact of blended labs on other factors that contribute to student success.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The authors declare that no AI or AI-assisted technologies have been used in the writing of this manuscript. The ideas, design, procedures, findings, analyses, and discussion are originally written and derived from careful and systematic conduct of the research.

References

- Aldosari, S., & Ghita, B. (2022). A Gesture-Based Educational System that Integrates Simulation and Molecular Visualization to Teach Chemistry. *International Journal of Emerging Technologies in Learning (iJET)*, 17, 194–211. <http://doi.org/10.3991/ijet.17i04.26503>
- Anam, A. C., Wiyanto, W., & Alimah, S. (2019). The analysis of students' conceptual understanding and motivation in guided inquiry science learning model assisted by android virtual laboratory. *Journal of Innovative Science Education*, 8(2), 163–172. <https://doi.org/10.15294/jise.v0i0.27712>
- Arista, F. S., & Kuswanto, H. (2018). Virtual physics laboratory application based on the android smartphone to improve learning independence and conceptual understanding. *International Journal of Instruction*, 11(1), 1–16. <https://doi.org/10.12973/iji.2018.1111a>
- Bhatti, Z., Abro, A., Gillal, A. R., & Karbasi, M. (2018). Be-educated: Multimedia learning through 3D animation. *International Journal of Computer Science and Emerging Technologies (IJCET)*, 1(1), 13–22. <https://doi.org/10.48550/arXiv.1802.06852>
- Bortnik, B., Stozhko, N., Pervukhina, I., Tchernysheva, A., & Belysheva, G. (2017). Effect of virtual analytical chemistry laboratory on enhancing student research skills and practices. *Research in Learning Technology*, 25, 1–20. <https://doi.org/10.25304/rlt.v25.1968>
- Chen, X., Song, G., & Zhang, Y. (2010). Virtual and remote laboratory development: A review. In *Earth and Space 2010: Engineering, Science, Construction, and Operations in Challenging Environments - Proceedings of the 12th International Conference* (pp. 3843–3852). [https://doi.org/10.1061/41096\(366\)368](https://doi.org/10.1061/41096(366)368)
- 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), 803–813. <https://doi.org/10.1007/s10956-014-9513-9>
- Hofstein, A., & Kind, P. M. (2012). Learning in and from science laboratories. In B. Fraser, K. Tobin, & J. M. Campbell (Eds.), *Second international handbook of science education* (pp. 189–207). Springer. https://doi.org/10.1007/978-1-4020-9041-7_15
- Lunetta, V. N., Hofstein, A., & Clough, M. (2007). Learning and teaching in the school science laboratory: an analysis of research, theory, and practice. In N. Lederman, & S. Abel (Eds.), *Handbook of research on science education* (pp. 393e441). Lawrence Erlbaum.
- Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: a comparative literature review. *ACM Computing Surveys*, 38(3), 1.
- Roblyer, M. D., & Hughes, J. E. (2019). *Integrating educational technology into teaching: Transforming learning across disciplines*. Pearson Education.

- Sari, U., Pektaş, H. M., Çelik, H., & Kirindi, T. (2019). The effects of virtual and computer based real laboratory applications on the attitude, motivation and graphic interpretation skills of university students. *International Journal of Innovation in Science and Mathematics Education*, 27(1), 1–17. <https://doi.org/10.30722/IJISME.27.01.001>
- Satterthwait, D. (2010). Why are 'hands-on' science activities so effective for student learning?. *Teaching Science*, 56, 7–10.
- Singer, S. R., Hilton, M. L., & Schweingruber, H. A. (Eds.). (2006). *America's laboratory report: Investigations in high school science*. National Research Council.
- Skinner, E., Saxton, E., Currie, C., & Shusterman, G. (2017). A motivational account of the undergraduate experience in science: brief measures of students' self-system appraisals, engagement in coursework, and identity as a scientist. *International Journal of Science Education*, 39(17), 2433–2459. <https://doi.org/10.1080/09500693.2017.1387946>
- Sriadhi, S., Restu, R., Sitompul, H., & Manurung, J. (2019). Development of web-virtual laboratory to improve the effectiveness and efficiency of remedial learning. *Journal of Physics: Conference Series PAPER*. <https://doi.org/10.1088/1742-6596/1402/7/077059>
- Steinmayr, R., & Weidinger, A., & Schwinger, M., & Spinath, B. (2019). The Importance of Students' Motivation for Their Academic Achievement – Replicating and Extending Previous Findings. *Frontiers in Psychology*. <http://doi.org/10.10389/fpsyg.2019.01730>
- Sugiharti, G., & Limbong, E. R. (2018). Application of learning model with virtual lab and motivation in learning chemistry. *Jurnal Pendidikan Kimia*, 10(1), 362–366. <https://doi.org/10.24114/jpkim.v10i1.9676>
- Sypsas, A., Paxinou, E., & Kalles, D. (2019). Reviewing inquiry-based learning approaches in virtual laboratory environment for science education. *Proceedings of the 10th International Conference in Open & Distance Learning* (pp. 74–89). Athens, Greece. <https://doi.org/10.12681/icodl.2288>
- Taylor, G., Jungert, T., Mageau, G. A., Schattke, K., Dedic, H., Rosenfeld, S., & Koestner, R. (2014). A self-determination theory approach to predicting school achievement over time: The unique role of intrinsic motivation. *Contemporary Educational Psychology*, 39(4), 342–358. <https://doi.org/10.1016/j.cedpsych.2014.08.002>

Contact email: yan.zhao@xjtlu.edu.cn