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The Effect of Virtual Laboratory on Students' Computational Thinking on Half-Life Concepts

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Abstract
This study investigated the impact of virtual laboratories on enhancing students' computational thinking skills, focusing on the half-life concept in radiochemistry. Using a quantitative research approach, a quasi-experimental design with a one-group pretest-posttest model was employed. Thirteen students enrolled in a Radiochemistry course participated in the study. The intervention involved the use of PhET simulations as a virtual laboratory, designed to facilitate a structured and interactive learning environment. Pretest and posttest assessments were conducted to measure the students' computational thinking skills. The results showed significant improvement in computational thinking post-intervention, with notable gains in decomposition, pattern recognition, abstraction, and algorithm design. Statistical analysis using paired-sample t-test and normalized gain scores confirmed the effectiveness of the virtual laboratory in enhancing these skills. The study concluded that virtual laboratories, such as PhET simulations, were effective in developing computational thinking abilities, providing a valuable tool for modern educational practices. These findings suggested that integrating virtual laboratories into the curriculum could significantly improve students' problem-solving and critical thinking skills, preparing them for future academic and professional challenges.

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INTRODUCTION

The concept of half-life was inherently abstract, posing significant challenges for students to grasp and internalize. Traditionally, students tackled chemistry problems in an unstructured manner, which compounded the difficulties in understanding complex topics like half-life. Practical experiments on half-life were often impractical due to the constraints of laboratory equipment and materials. These limitations were effectively addressed through the use of virtual laboratories, which simulated the practical experience without the need for physical resources.

Virtual laboratories, such as PhET simulations, emerged as powerful tools in chemistry education, enhancing students' learning experiences by providing interactive and realistic experimental environments (Herlika, 2022). Research indicated that these simulations not only helped students understand and achieve better results in chemistry but also fostered positive attitudes towards learning (Aliyu & Talib, 2019; Salame & Makki, 2021). They proved particularly beneficial in making abstract concepts more tangible and comprehensible (Clark & Chamberlain, 2014; Mashami et al., 2023).

Despite the recognized benefits of virtual laboratories, their integration into educational practices was still limited. Many educational institutions lacked the infrastructure or the pedagogical frameworks necessary to effectively implement these technologies. The main research problem, therefore, was to investigate whether virtual laboratories could significantly enhance students' computational thinking skills when learning about half-life concepts. The general solution proposed involved the use of PhET simulations, which were designed to provide an immersive and interactive learning environment. These simulations replicated real laboratory conditions, thereby allowing students to engage in experiments that would otherwise have been impossible due to logistical constraints. By using PhET simulations, students could learn in a structured manner, which was expected to improve their problem-solving and computational thinking abilities (Inayah & Masruroh, 2021; Ismalia et al., 2022).

PhET simulations were specifically highlighted in the literature as effective tools for teaching complex scientific concepts. For example, studies showed that these simulations could effectively substitute traditional laboratory tools, making abstract concepts like static electricity more understandable (Mashami et al., 2023). The simulations' interactive nature facilitated a deeper understanding of scientific principles by providing visual and practical experiences that were difficult to achieve through traditional teaching methods alone (Clark & Chamberlain, 2014). Moreover, the use of virtual laboratories during the pandemic underscored their effectiveness in maintaining educational continuity and enhancing learning outcomes. Research during this period demonstrated significant improvements in students' conceptual understanding and engagement when using PhET simulations for laboratory practices (Inayah & Masruroh, 2021). This indicated that virtual laboratories were not only a viable alternative but also an enhancement to conventional educational practices.

Further studies established that virtual simulations could bridge the gap between theoretical knowledge and practical application. This was particularly important in fields like radiochemistry, where students often faced difficulties in conducting experiments due to the hazardous nature of the materials involved. By employing virtual simulations, educators provided a safe and effective learning environment that mirrored real-world conditions without the associated risks (Aliyu & Talib, 2019; Salame & Makki, 2021).

Despite the promising results associated with the use of virtual laboratories, there remained a gap in the research concerning their impact on computational thinking skills specifically in the context of half-life concepts. Previous studies primarily focused on general science education and overall academic achievement without delving deeply into specific cognitive skills like computational thinking (Herlika, 2022; Ismalia et al., 2022). Additionally, while there was evidence supporting the effectiveness of virtual laboratories in enhancing conceptual understanding and practical skills, there was limited research on how these tools influenced the structured problem-solving approach inherent in computational thinking. The studies conducted so far had not systematically investigated the step-by-step processes involved in computational thinking, such as decomposition, pattern recognition, abstraction, and algorithm design (Belmar, 2022; Chakraborty & Yadav, 2023).

This gap highlighted the need for targeted research that examined how virtual laboratories could be used to foster computational thinking skills in chemistry education. Such research would provide valuable insights into the specific educational strategies and tools that could enhance students' abilities to apply computational methods to solve complex scientific problems (Guggemos et al., 2022; Rafli, 2024).

The objective of this study was to investigate the effect of virtual laboratories on students' computational thinking skills, specifically in the context of learning half-life concepts. This study aimed to provide empirical evidence on the effectiveness of PhET simulations in enhancing students' structured problem-solving abilities. The novelty of this research lay in its focus on computational thinking, a crucial skill set for solving complex problems in various disciplines, particularly within the realm of chemistry education.

The scope of this study involved the use of PhET simulations as the virtual laboratory platform. Computational thinking was assessed through its core components: decomposition, pattern recognition, abstraction, and algorithms. These components were used as indicators to measure the improvement in students' computational thinking skills. This research was expected to contribute to the growing body of knowledge on the use of virtual laboratories in education, offering practical insights for educators and policymakers on how to integrate these tools to enhance learning outcomes (Chakraborty & Yadav, 2023; Herlika, 2022; Rafli, 2024).

METHOD

This study adopted a quantitative research approach to evaluate the impact of virtual laboratories on students' computational thinking skills in the context of half-life concepts. A quasi-experimental design was employed, utilizing a one-group pretest-posttest model. This design allowed for the assessment of students' computational thinking before and after the intervention with the virtual laboratory.

The research subjects comprised 13 students enrolled in a Radiochemistry course. Initially, a pretest was administered to gauge the baseline computational thinking skills of the participants. This was followed by a series of instructional sessions using PhET Simulations as the virtual laboratory platform. Upon completion of the treatment, a posttest was conducted to measure any improvements in computational thinking. Both the pretest and posttest were in the form of written essay tests, designed to evaluate the various components of computational thinking, including decomposition, pattern recognition, abstraction, and algorithms.

The collected data were analyzed using statistical methods. A paired-sample t-test was conducted to determine the significance of the differences in computational thinking skills before and after the use of the virtual laboratory. Additionally, the normalized gain score was calculated to assess the magnitude of improvement in students' computational thinking abilities.

RESULTS AND DISCUSSION

Students' Computational Thinking after Virtual Laboratory Learning

The results of this study highlighted significant improvements in students' computational thinking skills following the use of PhET simulations as a virtual laboratory. Specifically, the data from Table 1 illustrated the scores of students' computational thinking skills before and after the intervention, with scores ranging from 0 to 4. Notably, the posttest scores showed a marked increase compared to the pretest scores, with the average posttest score being significantly higher. This suggested that the intervention had a positive effect on enhancing students' computational thinking skills.

Table 1. Computational Thinking Data

Criteria	**Computational Thinking**	
	Pretest	**Posttest**
Highest score	7	16

Lowest score	3	7
Average score	5.23	12.08

The normality test results using the Kolmogorov-Smirnov test indicated that both pretest and posttest data were normally distributed, with significance values of 0.100 and 0.200, respectively (Table 2). The paired-sample t-test results revealed a significant value of 0.000, demonstrating a significant difference between the pretest and posttest computational thinking scores. These findings supported the hypothesis that the use of the PhET virtual laboratory positively impacted students' computational thinking skills.

Table 2. Data from paired sample t-test results

	Paired Differences					**t**	**df**	**Sig. (2-tailed)**
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
				Lower	**Upper**			
Pair 1 Pretest-Posttest	-6.846	2.115	0.587	-8.124	-5.568	-11.670	12	0.000

Studying the half-life concept through PhET simulations made it easier for students to understand and remember the abstract concepts by visualizing them in a more tangible manner. The improvement observed aligned with previous research emphasizing the effectiveness of virtual laboratories in enhancing computational thinking and related skills. Virtual laboratories provided interactive and immersive environments conducive to better understanding complex concepts (Herlika, 2022). Aliyu & Talib (2019) found that virtual labs overcame practical challenges in traditional settings, enhancing both understanding and achievement in chemistry education. This interactive learning approach not only facilitated a deeper understanding but also made the learning experience more meaningful and lasting. PhET simulations specifically contributed to students' conceptual understanding and positive attitudes towards learning (Salame & Makki, 2021).

Furthermore, the present study's results corroborated these findings by demonstrating significant improvements in computational thinking, likely due to the structured and interactive nature of the virtual lab activities. Ismalia et al. (2022) reported that virtual simulations effectively substituted for practical tools, providing accessible and efficient alternatives for understanding abstract topics. Similarly, Mashami et al. (2023) emphasized the role of PhET simulations in teaching complex chemistry concepts, enhancing students' learning experiences through visualization and interaction.

The significant improvement in students' computational thinking skills observed in this study had both scientific and practical implications. Scientifically, the findings contributed to the growing body of evidence supporting the use of virtual laboratories as effective educational tools. The positive impact on computational thinking skills highlighted the potential of virtual labs to facilitate the understanding of specific subject matter and develop essential problem-solving abilities applicable across various disciplines (Rafli, 2024). This underscored the broader educational value of integrating computational thinking into curricula (Ezeamuzie et al., 2022; Li et al., 2020).

Practically, the improved computational thinking skills suggested that students were better equipped to approach and solve complex problems in a structured manner, crucial in the technologically advanced world. The interactive and engaging nature of virtual labs led to more meaningful learning experiences, as students could visualize and experiment with otherwise abstract and difficult-to-grasp concepts. This experiential learning approach, facilitated by tools like PhET simulations, enhanced retention and application of knowledge, preparing students for future academic and professional challenges (Inayah & Masruroh, 2021).

Moreover, the findings indicated that virtual laboratories could serve as valuable resources in situations where traditional labs were not feasible, such as during pandemics or in institutions with limited resources. This flexibility and accessibility could democratize science education, providing all students the opportunity to develop critical thinking and problem-solving skills essential for their academic and career success (Kharki et al., 2021; Torre et al., 2015).

Computational Thinking Improvement for each Indicator

The analysis of computational thinking skills across different indicators revealed significant improvements following the use of PhET simulations. Table 3 presented the computational thinking scores for various indicators, ranging from 0 to 4. In the pretest, students' initial abilities across these indicators scored between 0 and 2, indicating nascent computational thinking skills. Posttest scores, however, ranged from 1 to 4, reflecting a significant development in computational thinking. The increase in scores across these indicators suggested that the use of PhET virtual laboratories effectively supported the development of computational thinking skills among students, facilitating their ability to abstract, decompose, recognize patterns, and design algorithms.

Table 3. Computational Thinking Data for each Indicator

Indicators	Average Score	
	Pretest	**Posttest**
Decomposition	1.62	3.38
Recognition of pattern	1.62	3.31
Abstraction	1.15	3.08
Algorithm design	0.85	2.31

The increase in computational thinking abilities was further highlighted by the normalized gain scores, as depicted in Figure 1. The progression from the lowest to the highest improvement was observed in the following order: algorithm design, abstraction, recognition of pattern, and decomposition. This sequence suggested that while all areas of computational thinking improved, algorithm design showed the most significant gains, indicating that students developed a stronger ability to create systematic procedures for problem-solving.

The positive impact of PhET simulations on computational thinking aligned with findings that interactive and engaging activities in virtual laboratories enhanced students' problem-solving, critical thinking, and decision-making skills (Hasyim et al., 2020). The hands-on experience provided by these simulations allowed students to manipulate objects and variables in a virtual environment, fostering skills in abstraction, decomposition, and algorithmization (Taibu et al., 2021). This experiential learning approach supported the development of expert thinking and improved conceptual understanding (Banda & Nzabahimana, 2022). The dynamic visual environment of PhET simulations made learning more meaningful by contextualizing complex scientific concepts. This interactive learning platform supported higher-order thinking skills and advanced cognitive processes (Srikan et al., 2021). Verawati et al. (2022)also demonstrated that PhET simulations improved students' critical thinking and conceptual understanding, making learning more engaging and effective.

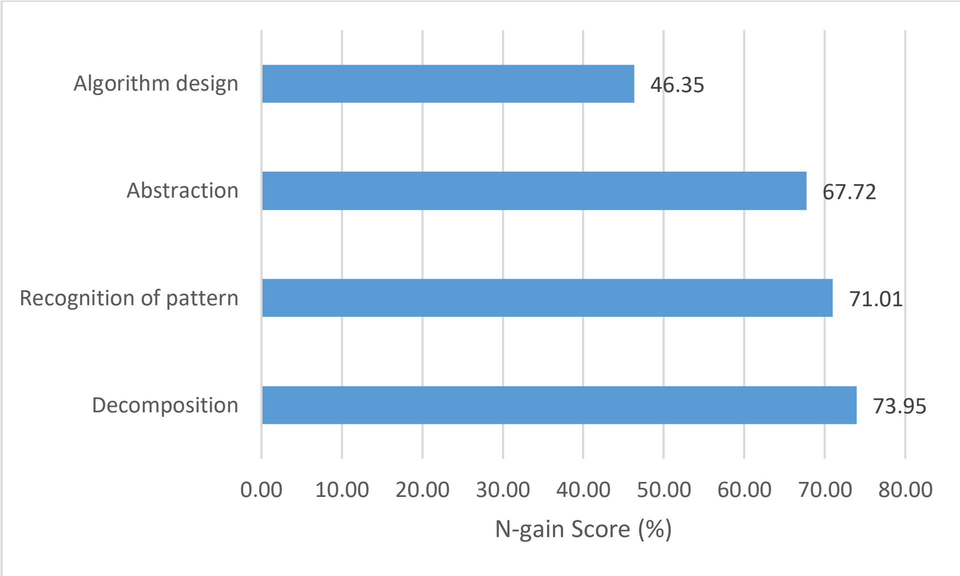

Figure 1. Graph of Computational Thinking Improvement for each Indicator

The significant gains in the decomposition indicator were particularly noteworthy. Decomposition, the process of breaking down complex problems into more manageable parts, was a foundational skill in computational thinking and was crucial for effective problem-solving across various disciplines (Gunawan et al., 2019). The PhET simulations provided a visual and interactive platform where students could practice and hone this skill by manipulating different variables and observing the outcomes, thereby reinforcing their understanding of the underlying principles.

Similarly, the development of skills in abstraction and algorithm design, although showing comparatively lower gains, still indicated a substantial improvement. Abstraction, which involved identifying the essential details while ignoring irrelevant information, was a critical step in solving complex problems. Algorithm design, which entailed creating step-by-step procedures to solve problems, was another fundamental component of computational thinking. The improvement in these areas demonstrated that PhET simulations effectively scaffolded students' learning, allowing them to build and refine these skills through repeated practice and experimentation (Taibu et al., 2021).

Moreover, the study's findings corroborated the results of previous studies that highlighted the benefits of virtual laboratories in enhancing students' computational thinking skills. For example, Eliza (2024) found that virtual laboratories provided an interactive and engaging learning environment that supported students in developing their skills in recognizing patterns and designing algorithms. This was further supported by the work of Kharki et al. (2021) and Rowe et al. (2017), who demonstrated that virtual laboratories helped students to analyze problems, identify patterns, and create systematic solutions, thereby enhancing their computational thinking skills.

The significant improvements in computational thinking skills observed in this study underscored the efficacy of PhET simulations in enhancing educational outcomes. These results had important implications for the integration of virtual laboratories into the curriculum, particularly in disciplines requiring complex problem-solving abilities. By fostering essential skills in abstraction, decomposition, pattern recognition, and algorithmization, PhET simulations prepared students to tackle real-world challenges more effectively (Gunawan et al., 2019).

Moreover, the interactive nature of these simulations not only enhanced students' cognitive abilities but also increased their motivation and engagement with the learning material (Kharki et al., 2021; Rowe et al., 2017). This hands-on experience in a virtual setting allowed students to experiment and learn at their own pace, leading to a deeper understanding of scientific concepts and principles (Eliza, 2024). The ability to manipulate variables and observe the outcomes in a controlled, virtual environment helped students to better grasp complex concepts, making abstract ideas more concrete and understandable (Hasyim et al., 2020).

The findings also supported the broader educational goal of incorporating computational thinking into chemistry education to address global challenges. As highlighted by York & Orgill (2020) and MacDonald et al. (2022), integrating systems thinking approaches into the curriculum could improve students' conceptual understanding and problem-solving skills, particularly regarding sustainability and other complex issues. The ability to think systemically and understand the interconnections between different components of a system was crucial for addressing complex, real-world problems. By incorporating virtual laboratories like PhET simulations into the curriculum, educators could help students develop these essential skills, preparing them to address the multifaceted challenges of the modern world.

Furthermore, the study's findings highlighted the potential of virtual laboratories to democratize education. By providing an accessible and cost-effective alternative to traditional laboratory experiences, virtual laboratories could help to level the playing field for students in under-resourced schools and institutions. This was particularly important in the context of the COVID-19 pandemic, which highlighted the need for flexible and remote learning solutions. Virtual laboratories like PhET simulations could provide students with high-quality, interactive learning experiences regardless of their geographical location or access to physical laboratory facilities (Kharki et al., 2021; Torre et al., 2015).

The significant improvement in students' computational thinking skills observed in this study also had implications for teacher training and professional development. Educators needed to be equipped with the knowledge and skills to effectively integrate virtual laboratories into their teaching practices. This included understanding how to use these tools to scaffold student learning, facilitate inquiry-based learning, and assess student progress in developing computational thinking skills. Professional development programs that focused on these areas could help teachers to harness the full potential of virtual laboratories, thereby enhancing student learning outcomes (Eliza, 2024).

CONCLUSION

This study demonstrated that the use of virtual laboratories, specifically PhET simulations, significantly enhanced students' computational thinking skills in the context of learning half-life concepts. The integration of these simulations provided a structured and interactive learning environment that improved problem-solving abilities and critical thinking skills. The findings indicated that students' computational thinking skills, as measured by indicators such as decomposition, pattern recognition, abstraction, and algorithm design, showed significant improvement post-intervention. The scaffolded approach of PhET simulations supported students in breaking down complex problems, recognizing patterns, and developing systematic algorithms, leading to a deeper understanding of scientific concepts. These results underscored the potential of virtual laboratories to transform traditional educational practices and foster essential skills in computational thinking, preparing students for the challenges of the digital era. Future research could explore the long-term effects of virtual laboratories on computational thinking and their applicability across different scientific disciplines.

RECOMMENDATIONS

Future research should consider expanding the sample size and including diverse educational settings to validate the findings across a broader population. Additionally, studies could explore the impact of virtual laboratories on other complex scientific concepts to assess their generalizability and effectiveness in various domains of science education. Besides that, conduct longitudinal studies to evaluate the long-term effects of virtual laboratory interventions on students' computational thinking skills. This will provide insights into the sustainability of the learning outcomes and the potential for continuous improvement in problem-solving abilities.

BIBLIOGRAPHY

Aliyu, F., & Talib, C. A. (2019). Virtual Chemistry Laboratory: A Panacea to Problems of Conducting Chemistry Practical at Science Secondary Schools in Nigeria. *International Journal of Engineering and Advanced Technology*, *8*(5c), 544–549. https://doi.org/10.35940/ijeat.e1079.0585c19

Banda, H. J., & Nzabahimana, J. (2022). The Impact of Physics Education Technology (PhET) Interactive Simulation-Based Learning on Motivation and Academic Achievement Among Malawian Physics Students. *Journal of Science Education and Technology*, *32*(1), 127–141. https://doi.org/10.1007/s10956-022-10010-3

Belmar, H. (2022). Review on the Teaching of Programming and Computational Thinking in the World. *Frontiers in Computer Science, 4*. https://doi.org/10.3389/fcomp.2022.997222

Chakraborty, P., & Yadav, S. (2023). Introducing Schoolchildren to Computational Thinking Using Smartphone Apps: A Way to Encourage Enrollment in Engineering Education. *Computer Applications in Engineering Education*, *31*(4), 831–849. https://doi.org/10.1002/cae.22609

Clark, T. M., & Chamberlain, J. M. (2014). Use of a PhET Interactive Simulation in General Chemistry Laboratory: Models of the Hydrogen Atom. *Journal of Chemical Education*, *91*(8), 1198–1202. https://doi.org/10.1021/ed400454p

Eliza, F. (2024). Effective Virtual Laboratory to Build Constructivist Thinking in Electrical Measurement Practicum. *Indonesian Journal of Electrical Engineering and Computer Science*, *34*(2), 814. https://doi.org/10.11591/ijeecs.v34.i2.pp814-824

Ezeamuzie, N. O., Leung, J. S. C., Garcia, R. C. C., & Ting, F. S. T. (2022). Discovering Computational Thinking in Everyday Problem Solving: A Multiple Case Study of Route Planning. *Journal of Computer Assisted Learning*, *38*(6), 1779–1796. https://doi.org/10.1111/jcal.12720

Guggemos, J., Seufert, S., & González, M. R. (2022). Computational Thinking Assessment – Towards More Vivid Interpretations. *Technology Knowledge and Learning*, *28*(2), 539–568. https://doi.org/10.1007/s10758-021-09587-2

Gunawan, G., Harjono, A., Hermansyah, H., & Herayanti, L. (2019). Guided Inquiry Model Through Virtual Laboratory to Enhance Students' Science Process Skills on Heat Concept. *Jurnal Cakrawala Pendidikan*, *38*(2), 259–268. https://doi.org/10.21831/cp.v38i2.23345

Hasyim, F., Prastowo, T., & Jatmiko, B. (2020). The Use of Android-Based PhET Simulation as an Effort to Improve Students' Critical Thinking Skills During the Covid-19

Pandemic. *International Journal of Interactive Mobile Technologies (Ijim)*, *14*(19), 31. https://doi.org/10.3991/ijim.v14i19.15701

Herlika, H. (2022). Analysis of Requirements for Virtual Laboratory Interactive Multimedia for Class X Electrical Conductivity. *Finger Jurnal Ilmiah Teknologi Pendidikan*, *1*(2), 36–41. https://doi.org/10.58723/finger.v1i2.65

Inayah, N., & Masruroh, M. (2021). PhET Simulation Effectiveness as Laboratory Practices Learning Media to Improve Students' Concept Understanding. *Prisma Sains Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan Ipa Ikip Mataram*, *9*(2), 152. https://doi.org/10.33394/j-ps.v9i2.2923

Ismalia, I., Kusumawati., M. P. d. A., & Wahyuni, P. (2022). Investigating the Use of Phet Simulation as a Substitute for Practical Tools in Understanding the Concept of Static Electricity. *International Journal of Education and Teaching Zone*, *1*(1), 20–25. https://doi.org/10.57092/ijetz.v1i1.7

Kharki, K. E., Berrada, K., & Burgos, D. (2021). Design and Implementation of a Virtual Laboratory for Physics Subjects in Moroccan Universities. *Sustainability*, *13*(7), 3711. https://doi.org/10.3390/su13073711

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L., English, L. D., & Duschl, R. A. (2020). Computational Thinking Is More About Thinking Than Computing. *Journal for Stem Education Research*, *3*(1), 1–18. https://doi.org/10.1007/s41979-020-00030-2

MacDonald, R., Pattison, A. N., Cornell, S., Elgersma, A. K., Greidanus, S. N., Visser, S. N., Hoffman, M., & Mahaffy, P. G. (2022). *An Interactive Planetary Boundaries Systems Thinking Learning Tool to Integrate Sustainability Into Chemistry Curriculum*. https://doi.org/10.26434/chemrxiv-2022-84bz2

Mashami, R. A., Ahmadi, Kurniasih, Y., & Khery, Y. (2023). Use of PhET Simulations as a Virtual Laboratory to Improve Students' Problem Solving Skills. *Jurnal Penelitian Pendidikan Ipa*, *9*(12), 11455–11465. https://doi.org/10.29303/jppipa.v9i12.6549

Rafli, M. (2024). Implementation of Computational Thinking in Data Structure Subject Using Problem-Based Learning Models. *J. Gr. Kom.*, *4*(2), 66–75. https://doi.org/10.17509/jgrkom.v4i2.30450

Rowe, R. J., Koban, L., Davidoff, A. J., & Thompson, K. (2017). Efficacy of Online Laboratory Science Courses. *Journal of Formative Design in Learning*, *2*(1), 56–67. https://doi.org/10.1007/s41686-017-0014-0

Salame, I. I., & Makki, J. (2021). Examining the Use of PhET Simulations on Students ' Attitudes and Learning in General Chemistry II. *Interdisciplinary Journal of Environmental and Science Education*, *17*(4), 1–9. https://doi.org/https://doi.org/10.21601/ijese/10966

Srikan, P., Pimdee, P., Leekitchwatana, P., & Narabin, A. (2021). A Problem-Based Learning (PBL) and Teaching Model Using a Cloud-Based Constructivist Learning Environment to Enhance Thai Undergraduate Creative Thinking and Digital Media Skills. *International Journal of Interactive Mobile Technologies (Ijim)*, *15*(22), 68. https://doi.org/10.3991/ijim.v15i22.24963

Taibu, R., Mataka, L. M., & Shekoyan, V. (2021). Using PhET Simulations to Improve Scientific Skills and Attitudes of Community College Students. *International Journal of Education in Mathematics Science and Technology*, *9*(3), 353–370. https://doi.org/10.46328/ijemst.1214

Torre, L. d. l., Guinaldo, M., Heradio, R., & Dormido, S. (2015). The Ball and Beam System: A Case Study of Virtual and Remote Lab Enhancement With Moodle. *Ieee Transactions on Industrial Informatics*, *11*(4), 934–945. https://doi.org/10.1109/tii.2015.2443721

Verawati, N. N. S. P., Handriani, L. S., & Prahanı, B. K. (2022). The Experimental Experience of Motion Kinematics in Biology Class Using PhET Virtual Simulation and Its Impact on Learning Outcomes. *International Journal of Essential Competencies in Education*, *1*(1), 11–17. https://doi.org/10.36312/ijece.v1i1.729

York, S., & Orgill, M. (2020). ChEMIST Table: A Tool for Designing or Modifying Instruction for a Systems Thinking Approach in Chemistry Education. *Journal of Chemical Education*, *97*(8), 2114–2129. https://doi.org/10.1021/acs.jchemed.0c00382