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Effectiveness of Simulation-Based Learning Media in The Understanding of Physics Concepts: A Literature Review

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Abstract: *This study aims to evaluate the effectiveness of simulation-based learning media in enhancing conceptual understanding of physics at the senior high school level. The method used is a Systematic Literature Review (SLR) by adopting a systematic protocol for searching and selecting articles. Literature was retrieved from three main databases: Google Scholar, Semantic Scholar, and ScienceDirect. The analysis focused on 10 articles that met the inclusion criteria, namely: published between 2010–2024; used experimental methods with simulation media in physics education; had high school students as research subjects; and examined aspects of conceptual understanding. The review results show that simulation media is effective in presenting abstract and complex physics concepts in a visual manner that helps students understand the relationship between theory and everyday phenomena. Simulations also enable students to control variables, engage in independent exploration, and build stronger mental models. In addition, simulations have been proven to improve student performance in terms of recall, understanding, and analysis. However, there are some limitations, such as the lack of hands-on laboratory experience, the limited ability of simulations to represent real-world conditions, and minimal social interaction among students during the use of virtual media. Therefore, the use of simulation media should be integrated with other instructional approaches to optimize its effectiveness.*

Keywords: *conceptual understanding, learning media, literature review, physics, simulation*

Efektifitas Media Pembelajaran Berbasis Simulasi terhadap Pemahaman Konsep Fisika: Literature Review

Abstrak: Penelitian ini bertujuan untuk mengevaluasi efektivitas media pembelajaran berbasis simulasi dalam meningkatkan pemahaman konsep fisika pada jenjang pendidikan menengah atas. Metode yang digunakan adalah Systematic Literature Review (SLR) dengan mengadopsi protokol pencarian dan seleksi artikel secara sistematis. Pencarian literatur dilakukan melalui tiga basis data utama: Google Scholar, Semantic Scholar, dan ScienceDirect. analisis terhadap 10 artikel yang memenuhi kriteria inklusi, yaitu: diterbitkan antara tahun 2010–2024; menggunakan metode eksperimen dengan media simulasi dalam pembelajaran fisika; subjek penelitian adalah siswa SMA; dan meneliti aspek pemahaman konsep. Hasil tinjauan menunjukkan bahwa media simulasi efektif dalam menyajikan konsep-konsep fisika yang abstrak dan kompleks dengan cara visual yang memudahkan siswa memahami hubungan antara teori dan fenomena sehari-hari. Simulasi juga memungkinkan siswa mengendalikan variabel, melakukan eksplorasi mandiri, dan membangun model mental yang lebih kuat. Selain itu, simulasi terbukti meningkatkan performa siswa dalam aspek recall, pemahaman, dan analisis. Namun, terdapat beberapa keterbatasan, seperti kurangnya pengalaman praktikum langsung, keterbatasan model simulasi dalam merepresentasikan kondisi nyata, serta minimnya interaksi sosial antarsiswa selama penggunaan media virtual. Oleh karena itu, penggunaan media simulasi perlu diintegrasikan dengan pendekatan pembelajaran lain agar efektivitasnya semakin optimal.

Kata kunci: fisika, media pembelajaran, pemahaman konsep, simulasi, tinjauan literatur

INTRODUCTION

Conceptual understanding is a complex concept that can be viewed from multiple perspectives. Accurate conceptual understanding is built from basic knowledge that is constantly formed, improved, expanded, and revised (Analita et al., 2023). In the context of learning, a concept is a generalization of thoughts about facts, and deep understanding is required to construct it (Arista & Kuswanto, 2018). In physics in particular, concepts include the principles, laws, and theories of physics, as well as their application in everyday life (Zacharia & de Jong, 2014). Some aspects that are closely related to concept understanding include knowledge of facts and procedures, connection and transfer of skills, meaningful learning, and metacognition (Analita et al., 2023).

Low concept comprehension is often affected by various difficulties, often referred to as misconceptions, naive concepts, and alternative concepts (Docktor & Mestre, 2014). The inability of students to internalize the learning process often leads to the formation of alternative concepts. Alternative concepts refer to the ways in which students understand almost the entire process of the phenomenon but fail to infer the outcome (Analita et al., 2023). Uncovering these different conceptual understandings of students has become a focus for teachers and educational researchers. Exploring how to improve instruction to reduce the adoption of alternative concepts has been a challenge for educators and researchers (Taber et al., 2012). Misconceptions, on the other hand, refer to student beliefs about natural phenomena that contradict scientific concepts (Chambers & Andre, 1997). Misconceptions are permanent cognitive structures that are difficult to modify, influencing pupils' comprehension of scientific topics. This issue impedes long-term and meaningful learning (Docktor & Mestre, 2014).

Learning and understanding the similarities and differences between concepts is considered the best approach to understanding physical phenomena. If students cannot see the similarities and differences between concepts, the learning process becomes more difficult (Kriek & Legesse, 2023). One of the learning methods that teachers can use to teach these phenomena is simulation-based media (Arista & Kuswanto, 2018). Among the various technologies available, simulation-based media has become one of the most popular instruments in numerous sectors of education, including biology, chemistry, and physics (Achuthan et al., 2018; Brinson, 2017; Dyrberg et al., 2017; Hodges et al., 2018; Hsu, 2020; Nolen & Koretsky, 2018).

The purpose of discussing the literature review on simulation-based learning media is to examine the various media that have been used in the classroom and to examine the effectiveness of simulation-based learning media in improving understanding of physics concepts. The literature on simulation is vast and diverse, and researchers have attempted to categorize it in various ways to achieve consistency in each study. The benefits of using simulation-based learning media have encouraged researchers to investigate the effectiveness of simulation in improving students' conceptual understanding. Understanding how information is processed allows students to learn more efficiently and systematically. The question that guides this study is why are simulation-based learning media effective in improving understanding of physics concepts?.

METHOD

This research uses the Systematic Literature Review (SLR) approach to examine the effectiveness of simulation-based media in improving students' concept understanding in physics learning at the upper secondary level. This review followed the PRISMA 2020 guidelines for systematic reviews, which provide a structured framework for reporting the stages of identification, screening, eligibility, and inclusion of articles. The use of these guidelines ensures that the review process is conducted in a transparent, systematic, and replicable manner (Page et al., 2021).

Literature search using Google Scholar, Semantic Scholar, and Science Direct databases. The PRISMA stages are shown in Figure 1.

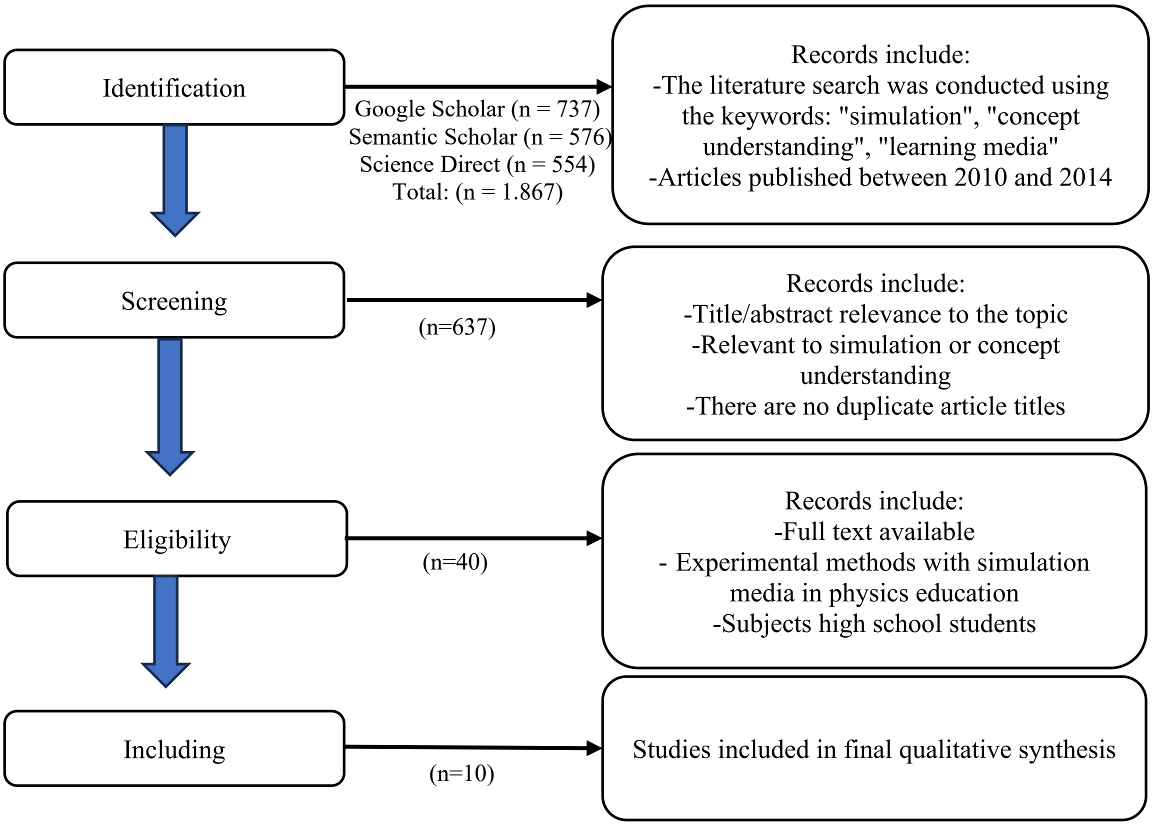

Figure 1. Flowchart PRISMA

The articles reviewed were research articles published between 2010 and 2024. The literature search was conducted using the keywords: "simulation", "concept understanding", "learning media". The articles were then screened by title and abstract to determine relevance to the topic. Articles that did not discuss simulation media or that did not examine students' concept understanding in the context of physics learning were excluded. The inclusion criteria for this study include: (1) articles published between 2010 and 2014; (2) articles using experimental methods with simulation media in physics education; (3) research subjects being high school students; and (4) articles investigating aspects of students' concept understanding. Meanwhile, exclusion criteria included: (1) articles published only in the form of conference proceedings or not available in full text; and (2) articles focusing only on the development of simulation media without direct application to students. After going through the screening process, 10 articles were obtained that met all criteria and were further analyzed.

The analysis of the articles was carried out in several stages, namely: (1) identifying the main results of each article and grouping them based on the main findings; (2) analyzing the definition and indicators of conceptual understanding used in the context of physics learning; (3) identifying the challenges or obstacles in achieving conceptual understanding; (4) categorizing the advantages and disadvantages of simulation media in each article; (5)

analyzing the reasons underlying the effectiveness of using simulation on students' conceptual understanding; and (6) drawing conclusions from the findings to provide an overview, research gaps, and recommendations for future studies (Widiyatmoko, 2018).

RESULTS AND DISCUSSION

Conceptual Understanding in Physics Education

Traditional learning has been critiqued for being unsuccessful at enhancing conceptual understanding (Tongchai et al., 2009). In contrast, systems that foster students' active participation in learning are thought to help students develop meaningful knowledge Powell & Kalina, 2009). Osborne & Wittrock (1983) noted that pupils create meaning to new knowledge by connecting it to existing knowledge, a process Piaget referred to as assimilation. When a new notion cannot be understood using old structures, it causes an imbalance that pushes pupils to investigate new concepts and construct new mental structures, a process called as accommodation.

The conceptual change approach provides a model that helps students organize and reconstruct their prior knowledge (Posner et al., 1982). It is an alternative way to encourage students to gain deeper conceptual understanding and to transform misconceptions into scientific understanding (Thomas & Kirby, 2020). Posner et al. (1982) proposed four conditions that must be met to achieve conceptual change, namely dissatisfaction, clarity, plausibility, and usefulness. According to them, learning should create dissatisfaction with students' preconceptions, introduce the new concept clearly, make the concept plausible, and demonstrate its usefulness in practical situations.

Simulation-based media

National Science Teachers Association (1999) emphasizes the importance of using computers in science education to enhance the learning experience. Nevertheless, simulation-based learning cannot completely replace hands-on laboratory activities (Zacharia & De Jong, 2014). Based on research, virtual learning is as effective as hands-on labs in promoting understanding of simple concepts. However, virtual learning is superior in helping students understand difficult concepts (Hurtado-Bermúdez & Romero-Abrio, 2023). The physical experience of hands-on labs helps students contextualize learning, while virtual experiences make it easier for students to connect the concepts learned to other content in the classroom (Zacharia & de Jong, 2014). The use of simulation can also overcome problems in the field, such as lack of laboratory facilities, time constraints in planning and conducting experiments, and difficulties in tracking student performance during hands-on activities (Faour & Ayoubi, 2018).

Computer simulations are one of the technological advances that are rapidly entering the science classroom as a digital learning technology (Widiyatmoko, 2018). Simulations provide a visual context for learning abstract concepts in science and provide students with important visualization and graphical analysis skills (Faour & Ayoubi, 2018). Simulations create a student-centered environment in which students can investigate systems, control variables, and test hypotheses (Windschitl & Andre, 1998). These applications can be used as demonstrations by teachers or directly by students to investigate phenomena that are not available in everyday contexts. Simulations also give students genuine experiences that allow them to learn and change knowledge in order to grasp the relationships between the subjects being studied (Widiyatmoko, 2018).

Simulation-based learning offers several benefits in science education. Simulations allow for the representation of microscopic and macroscopic phenomena at a given scale, which helps students understand concepts that are difficult to see directly (Arista &

Kuswanto, 2018). In addition, learning with simulations can reduce the time spent on scientific investigations, save time on data collection, and facilitate analysis, discussion, and evaluation of results (Hurtado-Bermúdez & Romero-Abrio, 2023). Teachers can use this technology to overcome the limitations of traditional laboratory practice and increase student independence in learning (Arista & Kuswanto, 2018).

Virtual labs provide a visual context for learning abstract concepts in science. With the visualization and graphical analysis capabilities provided, students can more easily understand complex material (Faour & Ayoubi, 2018; Lismanda Az-Zahra et al., 2024). In addition to providing a visual experience of how systems change, laboratory simulations also support the development of students' mental models. It allows them to predict the behavior of new systems, provides opportunities to engage in authentic learning, generate their own explanations, and make inferences independently (Brophy et al., 2013).

Simulation-Based Media to Improve Concept Understanding

Simulations have been shown to be an effective tool for improving students' conceptual understanding in various subjects. Studies have shown that the use of multimedia tools such as animations, PhET simulations, and YouTube videos have a positive impact on conceptual understanding (Nyirahabimana et al., 2024; Prima et al., 2018). Students who learn through simulation tend to achieve a higher percentage of correct answers in the areas of recall, comprehension, and analysis compared to traditional methods (Nyirahabimana et al., 2024). This suggests that simulation provides a deeper and more meaningful learning experience.

The first reason for using simulation in learning is the need to understand complex and abstract phenomena, especially in physics. Traditional teaching methods often do not provide adequate opportunities for students to deeply understand abstract concepts and models (Al-Qoyyim & Doyan, 2023; Laelawati et al., 2021). As a result, understanding of concepts such as quantum physics is often hindered. However, the use of simulation elements has been shown to be more effective in developing a deep conceptual understanding of quantum physics concepts and principles (Nyirahabimana et al., 2024), and improving students' activity and perceptions (Yusuf & Widyaningsih, 2018). Virtual laboratories provide a visual context for learning abstract concepts in science, providing students with important visualization and graphical analysis capabilities (Faour & Ayoubi, 2018). A study Prima et al. (2018) explained that simulations have a significant impact on students' cognitive levels, especially in understanding abstract concepts related to the solar system.

The second reason that simulations are important is that they help students connect scientific concepts to phenomena that occur in everyday life. Simulations can stimulate students' reasoning and help them relate everyday phenomena to the physics concepts they are learning (Arista & Kuswanto, 2018). In this context, simulations not only help students understand scientific principles, but also allow them to explore natural phenomena through scientific inquiry (Brophy et al., 2013). For example, some teachers use simulations to demonstrate physical phenomena that allow students to learn the principles underlying their field of science (Widiyatmoko, 2018). The experience in the simulation lab also complements the conceptual understanding that students gain from lectures. Students not only gain knowledge of fundamental facts and concepts but also develop the ability to apply their understanding in new contexts (Brophy et al., 2013). The advantages and disadvantages of using simulation media are shown in Table 1.

Table 1. Summary of Studies on the Advantages and Disadvantages of Simulation-Based Media

NO	ARTICLE	SIMULATION-BASED LEARNING MEDIA
ADVANTAGES		
1	(Nyirahabimana et al., 2024)	Multimedia components such as video, animation, and simulations can assist educators in illustrating abstract concepts and demonstrating complicated principles in simple ways that students can grasp and retain.
2	(Arista & Kuswanto, 2018)	Computer simulation allows the representation of microscopic and macroscopic phenomena on a given scale.
3	(Husnaini & Chen, 2019)	Simulations can save time normally spent on data collection, leaving more time for analysis, discussion, and evaluation.
4	(Başer & Durmus, 2010)	Virtual teaching methods have long-lasting effects on the concept comprehension of future physics teachers.
5	(Zacharia & de Jong, 2014)	The use of a combination of lab and virtual lab in this study has a greater impact on conceptual understanding than the use of lab alone.
6	(Faour & Ayoubi, 2018)	The use of virtual laboratories can overcome the lack of laboratory facilities, time constraints in planning and conducting experiments, and difficulties in tracking student performance during practicum activities.
7	(Brophy et al., 2013)	Laboratory simulations help students develop mental models that enable them to predict the behavior of new systems. It provides students with the opportunity to engage in authentic learning that encourages them to generate their own explanations and make inferences independently.
DISADVANTAGES		
8	(Hurtado-Bermúdez & Romero-Abrio, 2023)	Virtual experiments do not account for experimental errors, limitations of simulation models, and lack of hands-on experience and tactile information. Students also rarely socialize or collaborate during virtual experiments, which can reduce the responsibility for the real experimental environment.
9	(Taşlıdere, 2021)	The use of simulation requires integration with other learning approaches to achieve more effective results, as simulation alone may not be sufficient without the support of other teaching methods.
10	(Prima et al., 2018)	Although simulations are attractive to students because of their interactive nature, the variable settings in simulations do not always reflect actual conditions, which can affect learning outcomes.

All of the reviewed articles explain that simulation media can improve concept understanding, but there are several shortcomings that need to be considered. Simulation-based learning often does not take into account experimental errors and limitations of simulation models and lacks practical experience and important tactile information. The lack of socialization and collaboration among students during virtual experiments can also reduce responsibility compared to hands-on experiments (Hurtado-Bermúdez & Romero-Abrio, 2023). In addition, the use of simulation needs to be integrated with other learning approaches to achieve more effective results, as simulation alone is not sufficient without the support of other teaching methods (Taşlıdere, 2021). Although simulations are attractive to students due to their interactive nature, the variable settings in simulations do not always reflect actual conditions, which may affect learning outcomes (Pririchma et al., 2018).

CONCLUSION AND SUGGESTIONS

Based on a review of 10 articles, simulation media have great potential to improve students' conceptual understanding by illustrating abstract concepts and facilitating the representation of phenomena at different scales, thus facilitating the learning process. However, its effectiveness is also limited by several drawbacks, such as the lack of practical experience and tactile information, as well as limitations in accurately replicating real-world conditions. Although simulation media offer many advantages and are attractive to students due to their interactive nature, integration with other learning methods is necessary to achieve more optimal and comprehensive results.

This research still has some limitations that need to be considered. Firstly, this research has not explicitly explained the relationship between the articles studied and compared their results. Secondly, a more in-depth study of the selected articles is still needed to gain a more comprehensive and detailed understanding. Thus, this research needs to refine its methods and approaches so that the results obtained are more accurate and useful.

BIBLIOGRAPHY

Achuthan, K., Kolil, V. K., & Diwakar, S. (2018). Using Virtual Laboratories in Chemistry Classrooms as Interactive Tools Towards Modifying Alternate Conceptions in Molecular Symmetry. *Education and Information Technologies*, *23*(6), 2499–2515. https://doi.org/10.1007/s10639-018-9727-1

Al-Qoyyim, T. M., & Doyan, A. (2023). Application of Problem-Based Learning Model (PBL) as an Effort to Overcome Misconceptions in Black Body Radiation Material. *AMPLITUDO: Journal of Science and Technology Inovation*, *2*(2), 125–129. https://doi.org/10.56566/amplitudo.v2i2.84

Analita, R. N., Bakti, I., Nugraheni, P. W., & Noviyanti, E. (2023). The learners' conceptual understanding: Literature review of vapor-pressure lowering and boiling-point elevation. *Journal of Education and Learning*, *17*(4), 641–651. https://doi.org/10.11591/edulearn.v17i4.20805

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

Başer, M., & Durmus, S. (2010). The Effectiveness of Computer Supported Versus Real Laboratory Inquiry Learning Environments on the Understanding of Direct. *Eurasia Journal of Mathematics, Science & Technology Education*, *6*(1), 47–61.

Brinson, J. R. (2017). A Further Characterization of Empirical Research Related to Learning Outcome Achievement in Remote and Virtual Science Labs. *Journal of Science Education and Technology*, *26*(5), 546–560. https://doi.org/10.1007/s10956-017-9699-8

Brophy, S. P., Magana, A. J., & Strachan, A. (2013). Lectures and Simulation Laboratories to Improve Learners' Conceptual Understanding. *Advances in Engineering Education*, *3*(3), 1–27.

Chambers, S. K., & Andre, T. (1997). Gender, Prior Knowledge, Interest, and Experience in Electricity and Conceptual Change Text Manipulations in Learning about Direct Current. *Journal of Research in Science Teaching*, *34*(2), 107–123. https://doi.org/10.1002/(SICI)1098-2736(199702)34:2<107::AID-TEA2>3.0.CO;2-X

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of Discipline-Based Education Research in Physics. *Physical Review Special Topics - Physics Education Research*, *10*(2). https://doi.org/10.1103/PhysRevSTPER.10.020119

Dyrberg, N. R., Treusch, A. H., & Wiegand, C. (2017). Virtual Laboratories in Science Education: Students' Motivation and Experiences in Two Tertiary Biology Courses. *Journal of Biological Education*, *51*(4), 358–374. https://doi.org/10.1080/00219266.2016.1257498

Faour, M. Abou., & Ayoubi, Zalpha. (2018). The Effect of Using Virtual Laboratory on Grade 10 Students' Conceptual Understanding and Their Attitudes towards Physics | Faour | Journal of Education in Science, Environment and Health. *Journal of Education in Science, Environment and Health*, *4*(1), 54–68. https://doi.org/10.21891/jeseh.387482

Hodges, G. W., Wang, L., Lee, J., Cohen, A., & Jang, Y. (2018). An Exploratory Study of Blending The Virtual World and The Laboratory Experience in Secondary Chemistry Classrooms. *Computers and Education*, *122*(January 2017), 179–193. https://doi.org/10.1016/j.compedu.2018.03.003

Hsu, Y. (2020). Teaching Geometrics to Young Learners Using Computer-Based Simulation: The Interaction Effect of Guidance, In Relation to Representation and Manipulation, with Socio-Cultural Background. *Interactive Learning Environments*, *0*(0), 1–17. https://doi.org/10.1080/10494820.2020.1777168

Hurtado-Bermúdez, S., & Romero-Abrio, A. (2023). The Effects of Combining Virtual Laboratory and Advanced Technology Research Laboratory on University Students' Conceptual Understanding of Electron Microscopy. *Interactive Learning Environments*, *31*(2), 1126–1141. https://doi.org/10.1080/10494820.2020.1821716

Husnaini, S. J., & Chen, S. (2019). Effects of Guided Inquiry Virtual and Physical Laboratories on Conceptual Understanding, Inquiry Performance, Scientific Inquiry Self-Efficacy, And Enjoyment. *Physical Review Physics Education Research*, *15*(1), 10119. https://doi.org/10.1103/PhysRevPhysEducRes.15.010119

Kriek, J., & Legesse, A. (2023). The Effects of The Multiple Representation Approach on Undergraduate Students Understanding of Archimedes Principle. *Journal of Pedagogical Research*, *7*(5), 291–306. https://doi.org/10.33902/jpr.202322724

Laelawati, M., Nana, N., & Sulistyaningsih, D. (2021). Analisis Model Blended POE2WE Terhadap Keterampilan Proses Sains Siswa Melalui Penggunaan Laboratorium Virtual Pada Materi Dualisme Gelombang Partikel. *Jurnal Penelitian Pembelajaran Fisika*, *12*(1), 83–89. https://doi.org/10.26877/jp2f.v12i1.7162

Lismanda Az-Zahra, P., Rohim, F., Amarulloh, R. R., Nanto, D., Aini, &., & Herpi, N. (2024). Comparative Study Between Virtual Laboratory PhET Colorado Versus Applets in Photoelectric Effect. *Kasuari: Physics Education Journal (KPEJ)*, *7*(2), 289–299. https://doi.org/10.37891/kpej.v7i2.644

National Science Teachers Association. (1999). *NSTA Position Statement: The Use of Computers in Science Education*.

Nolen, S. B., & Koretsky, M. D. (2018). Affordances of Virtual and Physical Laboratory Projects for Instructional Design: Impacts on Student Engagement. *IEEE Transactions on Education*, *61*(3), 226–233. https://doi.org/10.1109/TE.2018.2791445

Nyirahabimana, P., Minani, E., Nduwingoma, M., & Kemeza, I. (2024). Assessing The Impact of Multimedia Application on Student Conceptual Understanding in Quantum Physics at The Rwanda College of Education. *Education and Information Technologies*, *29*(3), 3423–3444. https://doi.org/10.1007/s10639-023-11970-8

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative Process. *Science Education*, *67*(4), 489–508. https://doi.org/10.1002/sce.3730670406

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S. (2021, March 29). The PRISMA 2020 statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ*, *372*, Article n71. https://doi.org/10.1136/bmj.n71

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change. *Science Education*, *66*(2), 211–227. https://doi.org/10.1002/sce.3730660207

Prima, E. C., Putri, A. R., & Rustaman, N. (2018). Learning Solar System Using PheT Simulation to Improve Students' Understanding and Motivation. *Journal of Science Learning*, *1*(2), 60. https://doi.org/10.17509/jsl.v1i2.10239

Taber, K. S., Tsaparlis, G., & Nakiboğlu, C. (2012). Student Conceptions of Ionic Bonding: Patterns of Thinking Across Three European Contexts. *International Journal of Science Education*, *34*(18), 2843–2873. https://doi.org/10.1080/09500693.2012.656150

Taşlıdere, E. (2021). Relative Effectiveness of Conceptual Change Texts with Concept Cartoons and 5e Learning Model with Simulation Activities on Pre-Service Teachers' Conceptual Understanding of Waves. *Participatory Educational Research*, *8*(4), 215–238. https://doi.org/10.17275/PER.21.87.8.4

Thomas, C. L., & Kirby, L. A. J. (2020). Situational Interest Helps Correct Misconceptions: an Investigation of Conceptual Change in University Students. *Instructional Science*, *48*(3), 223–241. https://doi.org/10.1007/s11251-020-09509-2

Tongchai, A., Sharma, M. D., Johnston, I. D., Arayathanitkul, K., & Soankwan, C. (2009). Developing, Evaluating and Demonstrating The Use of A Conceptual Survey in Mechanical Waves. *International Journal of Science Education*, *31*(18), 2437–2457. https://doi.org/10.1080/09500690802389605

Widiyatmoko, A. (2018). The Effectiveness of Simulation in Science Learning on Conceptual Understanding : A Literature Review. *Journal of International Development and Cooperation*, *24*(1 & 2), 35–43.

Windschitl, M., & Andre, T. (1998). Using Computer Simulations to Enhance Conceptual Change: The Roles of Constructivist Instruction and Student Epistemological Beliefs. *Journal of Research in Science Teaching*, *35*(2), 145–160. https://doi.org/10.1002/(SICI)1098-2736(199802)35:2<145::AID-TEA5>3.0.CO;2-S

Yusuf, I., & Widyaningsih, S. W. (2018). Pengembangan Simulasi Interaktif Menggunakan Aplikasi Open Source pada Mata Pelajaran Fisika untuk Meningkatkan Aktivitas dan Persepsi Peserta Didik. *Berkala Fisika Indonesia, 10*(1), 12-21. https://doi.org/10.12928/bfi-jifpa.v10i1.9486

Zacharia, Z. C., & de Jong, T. (2014). The Effects on Students' Conceptual Understanding of Electric Circuits of Introducing Virtual Manipulatives Within a Physical Manipulatives-Oriented Curriculum. *Cognition and Instruction*, *32*(2), 101–158. https://doi.org/10.1080/07370008.2014.887083