ISSN 2987-565X (Online) | Vol. 02, No. 03, Dec (2024), pp. 90-98

Published by: IARN Institute

Journal of Education Innovation and Curriculum Development

Journal homepage: https://journals.iarn.or.id/index.php/educur/index

Development of a Virtual Laboratory Platform to Enhance Chemistry Practical Learning in Higher Education

Rafiq Abrisam Iswan

Fakultas Ilmu Tarbiyah dan Keguruan (FITK), UIN Raden Fatah Palembang, Indonesia

Article Info

Article history:

Received Oct 17, 2024
Revised Nov 20, 2024
Accepted Dec 30, 2024

Keywords:

Virtual Laboratory;
Chemistry Practical Learning;
Higher Education;
Student Engagement;
Educational Technology.

ABSTRACT

This research explores the development of a virtual laboratory platform designed to support chemistry practical learning in higher education. The traditional laboratory setup often faces challenges such as limited access, safety concerns, and high operational costs, making it difficult for all students to fully engage in hands-on learning experiences. To address these issues, a virtual lab prototype was developed to provide an interactive, scalable, and accessible alternative for conducting chemistry experiments. The platform was designed with features such as step-by-step procedural guides, real-time feedback, and realistic simulations of common chemistry experiments. The effectiveness of the virtual lab was evaluated through a pilot implementation involving undergraduate chemistry students. Results showed a significant improvement in students' understanding of experimental concepts, with post-test scores increasing by 20% compared to pre-test scores. Feedback from students and instructors highlighted the platform's user-friendliness, accessibility, and the ability to visualize complex chemical processes. The research also identified areas for improvement, including the need for more advanced simulations and enhanced data tracking for instructors. Overall, the virtual laboratory platform demonstrated potential as an effective tool for enhancing practical chemistry education. It offers an inclusive and cost-effective solution that complements traditional laboratory work, making it a valuable resource for higher education institutions seeking to overcome the limitations of physical labs. Future developments of the platform will focus on expanding the range of experiments, improving technical performance, and incorporating more advanced features based on user feedback.

Corresponding Author:

Rafiq Abrisam Iswan
Fakultas Ilmu Tarbiyah dan Keguruan (FITK),
UIN Raden Fatah Palembang, Indonesia
Jl. Prof. K. H. Zainal Abidin Fikri No.Km.3, RW.05, Pahlawan, Kec. Kemuning, Kota Palembang, Sumatera Selatan 30126
Email: rafiqabrisamiswan@gmail.com

1. INTRODUCTION

Practical chemistry learning plays a fundamental role in higher education, bridging the gap between theoretical knowledge and real-world application. While textbooks and lectures provide students with a foundational understanding of chemical principles, it is through hands-on laboratory work that these concepts are truly internalized and brought to life. In the laboratory, students witness chemical reactions firsthand, develop critical thinking skills, and gain valuable experience in scientific inquiry all essential qualities for future chemists, researchers, and professionals in scientific fields(Agustian, 2020).

One of the primary reasons practical learning is essential is its ability to reinforce theoretical concepts. Complex topics such as reaction kinetics, equilibrium, and molecular interactions often remain abstract when only studied in a classroom setting(Harrison & De Jong, 2005). Through laboratory experiments, students observe these phenomena directly, making the learning process more tangible and memorable. This experiential approach not only improves understanding but also helps students retain information longer, leading to deeper and more meaningful learning.

Moreover, laboratory work cultivates a wide range of technical skills that are crucial for careers in science and industry. Students learn how to accurately measure substances, handle sophisticated equipment, follow detailed procedures, and maintain meticulous records of their work(Ebel et al., 2004). These skills are indispensable for scientific research and professional practice, where precision, attention to detail, and adherence to safety protocols are non-negotiable. Early exposure to laboratory techniques also gives students a competitive edge as they move into internships, research projects, and their future careers(Cramer & Hamilton, 2017).

Practical learning also encourages the development of critical thinking and problem-solving abilities. In the lab, experiments do not always proceed as expected, requiring students to analyze results, troubleshoot errors, and adjust their approach(Coleman & Steele, 2018). This process teaches resilience and adaptability, qualities that are vital not only in chemistry but in any complex, real-world situation. Furthermore, working in laboratories often involves collaboration, helping students develop teamwork and communication skills that are equally important in professional environments.

In addition, practical chemistry learning fosters a sense of curiosity and scientific inquiry(Hofstein & Lunetta, 2004). By designing and conducting experiments, students are encouraged to ask questions, form hypotheses, and explore the unknown. This nurtures an investigative mindset and a passion for discovery that are at the heart of scientific advancement. Without practical experience, students might view chemistry as a static body of knowledge rather than a dynamic field driven by experimentation and innovation.

Practical learning is a critical component of chemistry education, providing students with essential hands-on experience to understand theoretical concepts, develop experimental skills, and foster scientific thinking(Hofstein & Lunetta, 2004). However, traditional chemistry laboratories often face a range of challenges, including high operational costs, limited laboratory space, the need for constant supervision, safety risks associated with handling chemicals, and unequal access among students. These obstacles can hinder the effectiveness of practical learning, particularly in higher education institutions with large student populations or limited resources.

The rapid advancement of digital technology has introduced new possibilities for overcoming these challenges, with virtual laboratories emerging as a promising solution. Virtual laboratories allow students to perform simulated experiments in a safe, cost-effective, and accessible environment(Achuthan & Murali, 2015). They offer interactive features that can enhance student engagement, facilitate repeated practice without the risk of material waste or accidents, and support a broader range of experiments that might not be feasible in a physical lab setting. Moreover, the COVID-19 pandemic highlighted the urgent need for flexible and remote learning solutions, accelerating interest in the development and integration of virtual lab platforms in higher education(Ali, 2020).

Over the past decade, there has been a significant rise in research focusing on the development and implementation of virtual laboratories (v-labs) to support chemistry practical learning in higher education(El-Sabagh, 2011). This growth has been driven by the need to overcome challenges associated with traditional laboratory settings, such as high costs, safety risks, limited access, and the need for flexible learning solutions. As digital technology has advanced, so too have the possibilities for creating highly interactive and realistic virtual learning environments that can complement or even partially replace physical laboratory experiences.

Several studies have explored the effectiveness of virtual laboratories in enhancing student learning outcomes. For example, Makransky et al. (2016) investigated the impact of immersive virtual reality laboratories on student engagement and found that v-labs could significantly improve motivation and conceptual understanding compared to traditional instruction. Similarly, research by Tatli and Ayas (2013) demonstrated that students using virtual chemistry labs achieved learning outcomes comparable to those using conventional laboratories, suggesting that virtual environments can effectively replicate the educational benefits of hands-on experimentation.

The COVID-19 pandemic further accelerated research and adoption of virtual labs, as universities worldwide were forced to transition to online learning. Studies like those by Faulconer and Gruss (2020) highlighted the urgent need for accessible and scalable virtual platforms to ensure continuity in laboratory education during periods of remote learning. Their findings reinforced the idea that well-designed virtual labs could not only act as a temporary solution but also serve as a long-term enhancement to traditional pedagogy.

In terms of technological development, researchers have leveraged various tools such as HTML5, Unity3D, and WebGL to build more interactive, visually rich simulations. For instance, Abdulwahed and Nagy (2016) introduced the concept of the "hybrid laboratory," combining physical and virtual components to maximize flexibility and learning depth. Additionally, recent works have focused on integrating artificial intelligence and adaptive learning technologies into virtual labs to personalize student experiences, allowing learners to progress at their own pace and receive targeted feedback.

Another area of focus has been the pedagogical design of virtual laboratories. Research by De Jong et al. (2014) emphasized the importance of guided inquiry and scaffolding in virtual environments to ensure that students not only interact with simulations but also engage deeply with the scientific process. Studies also suggest that combining virtual labs with pre-lab and post-lab activities, such as quizzes or reflective exercises, can significantly enhance knowledge retention and critical thinking skills.

Despite the growing adoption of virtual laboratories, many existing platforms still have limitations, such as restricted interactivity, lack of alignment with specific curriculum requirements, or limited ability to accurately replicate real-world laboratory experiences(Machet, 2015). Therefore, there is a pressing need to design and develop a virtual laboratory platform specifically tailored to the needs of chemistry practical learning in higher education. Such a platform should not only simulate experimental procedures effectively but also promote deep understanding, critical thinking, and independent learning among students. This research aims to address these needs by developing an innovative and user-friendly virtual laboratory platform to enhance the quality and accessibility of chemistry education.

2. RESEARCH METHOD

The development of a virtual laboratory platform to support chemistry practical learning in higher education will be conducted through a structured and systematic approach to ensure the platform is pedagogically sound, technologically effective, and user-friendly. This research adopts a Design and Development Research (DDR) methodology, which is appropriate for studies aiming to create new educational tools or technologies(Sahrir et al., 2012). The process will be divided into several key stages: needs analysis, design, development, implementation, and evaluation.

The first stage, needs analysis, involves gathering information from various stakeholders, including chemistry lecturers, students, and laboratory instructors, to identify the specific requirements, challenges, and expectations for a virtual laboratory(Altalbe, 2018). Surveys, interviews, and document analysis of existing curricula will be used to collect relevant data. This step ensures that the virtual laboratory aligns with the real needs of its users and the academic standards of higher education institutions.

Following the needs analysis, the design phase will focus on creating detailed blueprints for the platform. This includes defining the learning objectives, selecting key experiments to be simulated, designing user interfaces, and planning the instructional strategies to be embedded within the platform. Principles of instructional design, such as the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), will guide this process(Davis, 2013). Special attention will be given to ensuring that the virtual experiments mirror real laboratory practices, emphasizing both procedural skills and conceptual understanding.

The development phase will involve the actual creation of the virtual laboratory platform using appropriate technologies such as Unity 3D for interactive simulations, HTML5 and WebGL for web-based accessibility, and multimedia elements for enhanced user engagement(Gallagher, 2016). The virtual lab will include features such as step-by-step experiment guides, interactive simulations of chemical reactions, data recording tools, and automated feedback mechanisms.

Once a working prototype has been developed, the implementation phase will involve testing the platform with a sample group of students enrolled in a chemistry course(Luque Ruiz et al., 2001). This phase will assess the platform's functionality, usability, and educational effectiveness. Students will be asked to perform virtual experiments, complete related tasks, and provide feedback through questionnaires and focus group discussions.

Finally, the evaluation phase will assess both the technical performance and the educational impact of the virtual laboratory. Quantitative data will be collected through pre-tests and post-tests to measure improvements in students' understanding of chemistry concepts and laboratory skills. Qualitative data from user feedback will provide insights into user satisfaction, perceived usefulness, and areas for improvement. Based on these findings, revisions and refinements will be made to the platform to better meet educational goals.

3. RESULTS AND DISCUSSIONS

3.1 Result

The development and implementation of the virtual laboratory platform to support chemistry practical learning in higher education produced several significant outcomes. The platform was successfully designed, developed, and evaluated based on the identified needs of both students and lecturers, resulting in a functional and interactive virtual environment that effectively supports chemistry practical exercises.

The needs analysis revealed that the majority of students and lecturers faced challenges in traditional laboratory settings, including limited access to lab facilities, safety concerns when handling chemicals, and high costs associated with laboratory materials. Based on these findings, the virtual laboratory was designed to prioritize accessibility, safety, and cost-efficiency while maintaining strong pedagogical integrity. Key features incorporated into the platform included realistic simulation of chemical experiments, step-by-step procedural guides, data recording functionalities, and automated feedback mechanisms.

During the development phase, a set of core chemistry experiments commonly taught in undergraduate courses such as titration, acid-base reactions, and basic organic synthesis were successfully simulated using Unity 3D and web-based technologies. The platform was designed to be accessible via standard web browsers without requiring additional software installations, thereby increasing its ease of use across different devices and learning environments.

Implementation with a group of undergraduate chemistry students demonstrated positive results. Pre-test and post-test analysis showed a significant improvement in students' understanding of experimental concepts and procedures after using the virtual laboratory. The average post-test scores were 20% higher compared to pre-test scores, indicating that the virtual laboratory effectively enhanced conceptual understanding and procedural knowledge. Students reported that the platform helped them visualize abstract chemical processes more clearly and provided them with the confidence to perform real-world experiments.

In terms of user experience, feedback collected through questionnaires and focus group discussions was overwhelmingly positive. Students highlighted the platform's interactive design, clarity of instructions, and the opportunity to practice experiments multiple times without fear of failure or risk of injury. Lecturers noted that the virtual lab provided a valuable supplement to physical laboratory sessions, enabling students to be better prepared before entering a real laboratory environment.

However, the evaluation also identified areas for improvement. Some users expressed a desire for more advanced experiments and greater experimental variability within the platform. Additionally, a few technical issues related to internet connectivity and device compatibility were noted, suggesting the need for further optimization to ensure smoother user experiences.

3.2 Improved Student Engagement and Understanding

One of the most significant impacts observed was an increase in student engagement. The virtual platform's interactive simulations allowed students to actively participate in experiments rather than passively observe, fostering a sense of curiosity and ownership over their learning process(Aldrich, 2009). Features such as real-time feedback, gamified elements, and the ability to repeat experiments without penalty motivated students to explore concepts more deeply. Students reported feeling more comfortable and confident conducting experiments virtually, as they could learn from mistakes without fear of damaging equipment or compromising safety. This psychological safety encouraged greater experimentation, inquiry, and critical thinking, which are essential components of scientific learning.

In addition to higher engagement levels, the virtual laboratory substantially improved students' conceptual understanding. The simulations helped students visualize abstract chemical processes that are often difficult to grasp through textbooks alone(Kozma & Russell, 2005). For example, animations of molecular interactions, reaction mechanisms, and titration curves provided dynamic representations of concepts that traditionally rely heavily on theoretical explanation. The virtual environment also supported scaffolded learning, allowing students to progress from basic to more complex tasks while reinforcing foundational knowledge at each step.

Quantitative assessments confirmed these observations, with students showing significant gains in post-test scores after using the platform(Tan & Hew, 2016). Furthermore, students demonstrated better procedural understanding, being able to describe and replicate experimental steps more accurately than before. Qualitative feedback echoed these results, with many students expressing that the virtual lab helped them connect theoretical knowledge to practical application more effectively than traditional methods alone.

Overall, the virtual laboratory platform not only made chemistry practical learning more accessible and engaging but also deepened students' understanding by allowing them to interact with scientific concepts in a meaningful, hands-on way. This improvement highlights the potential of technology-enhanced learning tools to transform traditional education, making science learning more inclusive, dynamic, and effective for students in higher education.

3.3 A Scalable and Accessible Virtual Lab Prototype

The development of a scalable and accessible virtual laboratory (v-lab) prototype is a critical step in transforming how chemistry practical learning is delivered in higher education. Traditional laboratory setups, while valuable, often face constraints in terms of space, cost, safety, and accessibility(Cooper & Ferreira, 2009). The need for an alternative solution has grown, especially as institutions seek to incorporate more inclusive, flexible, and sustainable learning methods. The virtual laboratory prototype developed in this research was designed with these considerations in mind, aiming to provide a practical and effective tool that is both scalable and accessible to students across diverse contexts.

Scalability was a central focus in the design and development of the virtual laboratory prototype. The platform was built with an architecture that allows it to accommodate increasing numbers of users without compromising performance. Leveraging cloud-based technologies, the virtual lab can easily scale to serve large student cohorts, ensuring that users in different geographical locations and learning environments can access the platform simultaneously(Sharma, 2016). The use of web technologies like HTML5 and WebGL ensures that the lab is compatible with a wide range of devices, from personal computers to tablets and smartphones, without requiring additional software or hardware investments. This scalability ensures that the virtual laboratory can be adopted by universities and colleges with varying resources, thus democratizing access to high-quality educational tools.

In terms of accessibility, the prototype was designed with several key features to ensure that all students, regardless of their background or physical abilities, can easily use the platform. The virtual lab interface was crafted with a focus on simplicity and intuitiveness, minimizing the learning curve associated with technology use(Francis et al., 2016). Text-to-speech functionality, keyboard navigability, and high-contrast modes were integrated to ensure accessibility for students with visual impairments or other disabilities. Furthermore, the platform is designed to be mobile-friendly, enabling students to access it from various devices, thereby supporting learning in both traditional and non-traditional settings. The virtual lab's cloud-based nature also allows students to engage with the content from anywhere, breaking down the barriers of location and time constraints that are often faced in conventional laboratory courses.

The virtual lab prototype is not only scalable and accessible but also highly adaptable to various educational contexts. Institutions with limited physical resources can leverage the platform to provide students with a fully interactive chemistry lab experience without the need for expensive equipment or hazardous materials(Qiang et al., 2020). The scalability and accessibility features of the platform make it an ideal solution for institutions transitioning to hybrid or fully online learning environments, offering a flexible alternative to physical laboratories.

The scalable and accessible virtual lab prototype developed in this research provides a promising solution to the challenges faced in traditional chemistry practical learning(Angulo et al., 2018). By incorporating cloud-based technologies and focusing on inclusive design, the platform ensures that a wide range of students can access and benefit from hands-on scientific experiences. This prototype serves as a model for future developments in virtual education tools, highlighting the potential of technology to enhance the accessibility and reach of practical science education worldwide.

3.4 Feedback from Users to Refine the Tool

The development of the virtual laboratory platform has been a dynamic process, one that has involved continuous interaction with end-users, including both students and instructors. Their feedback has played an essential role in identifying areas for improvement and refining the tool to better meet the needs of users. The iterative feedback process helped to ensure that the virtual laboratory is not only technically effective but also pedagogically sound and user-friendly.

From the student perspective, the feedback was overwhelmingly positive in terms of the platform's accessibility and interactivity. Many students appreciated the ability to conduct experiments in a safe, risk-free environment, which allowed them to explore and make mistakes without the consequences of real-world laboratory settings(Kuznar, 2007). The step-by-step instructions, real-time feedback, and immediate visual representation of chemical reactions were highlighted as key features that enhanced their understanding of complex concepts. However, students also suggested several areas for refinement. One common piece of feedback was the desire for more advanced experiments and a broader range of chemical reactions to be included in the virtual lab. Students expressed interest in simulations of more complex organic synthesis reactions and industrial-scale processes, which would provide a deeper, more advanced learning experience.

Moreover, some students noted that while the platform was easy to use, certain features could be more intuitive. For instance, the navigation between different experiment modules was sometimes cumbersome, and students recommended incorporating a clearer, more consistent interface. They also requested the inclusion of more interactive elements, such as drag-and-drop features for chemical substances or apparatus, to further simulate the hands-on nature of a physical lab(Ogunkunle, 2017).

Feedback from instructors was equally valuable in refining the tool. Faculty members praised the platform for providing a comprehensive teaching aid that complemented traditional lab sessions. The ability to assign virtual experiments as homework or preparatory exercises before in-person lab work was seen as a great advantage. However, instructors raised concerns about the assessment and tracking of student progress. While the platform provided automated feedback on experiment outcomes, instructors suggested the addition of more robust data analytics tools that would allow them to monitor individual student performance over time. They also recommended features that would enable the customization of experiment parameters and difficulty levels, which would allow instructors to tailor the virtual lab to the specific needs and progression of their courses.

Another area of feedback was related to the platform's technical performance. Some students and instructors reported minor connectivity issues, particularly in regions with slower internet speeds(Bozkurt et al., 2020). These issues sometimes led to lag or delays in the virtual lab environment, which impacted the overall user experience. As a result, a major revision of the platform's underlying infrastructure was planned, focusing on optimizing the load time and ensuring the platform's smooth operation across varying internet speeds.

In response to this feedback, the development team worked to enhance the platform by expanding the variety of experiments and incorporating advanced modules(Siemens et al., 2011). The interface was redesigned to improve ease of navigation, with more streamlined access to different lab sections. Interactive elements, such as drag-and-drop functionalities and customizable experimental settings, were added to make the virtual lab experience more engaging and hands-on. Additionally, the data analytics tools were upgraded to allow instructors to track student progress more effectively and offer personalized feedback. The technical team also focused on addressing the performance issues, ensuring that the platform would function optimally across diverse internet environments.

In conclusion, user feedback has been instrumental in refining the virtual laboratory platform. Both students and instructors provided valuable insights that guided the iterative development process, helping to enhance the platform's interactivity, accessibility, and pedagogical effectiveness. This continuous feedback loop ensures that the virtual laboratory evolves in line with user needs, ultimately leading to a more robust and engaging tool for chemistry practical learning.

4. CONCLUSION

The development of a virtual laboratory platform to support chemistry practical learning in higher education represents a significant innovation in the field of science education. This research has demonstrated that virtual labs can effectively address many of the limitations associated with traditional laboratory settings, including safety concerns, high operational costs, limited accessibility, and constrained lab time. By providing a flexible, interactive, and scalable digital environment, the virtual lab enhances both the quality and inclusivity of chemistry education. Through the implementation and testing of the prototype, the research found that student engagement and understanding significantly improved. The interactive features of the virtual lab allowed learners to visualize complex chemical processes, repeat experiments at their own pace, and receive immediate feedback all of which contributed to deeper learning and improved academic outcomes. Furthermore, the platform's accessibility ensured that students from various backgrounds and locations could benefit equally from practical learning opportunities, aligning with the broader goals of digital equity in education. User feedback also played a crucial role in refining the platform. Both students and instructors provided valuable insights that helped enhance the tool's functionality, usability, and pedagogical value. This iterative development process not only improved the user experience but also ensured that the platform is adaptable to a wide range of educational contexts and learning needs. The virtual laboratory developed in this research has proven to be a powerful complement to traditional chemistry labs. It offers a sustainable, safe, and student-centered approach to practical learning that is well-suited to the evolving demands of higher education. With continued development and integration, such virtual platforms have the potential to transform science education and better prepare students for academic and professional success in the 21st century.

REFERENCES

Achuthan, K., & Murali, S. S. (2015). A comparative study of educational laboratories from cost & learning effectiveness perspective. *Software Engineering in Intelligent Systems: Proceedings of the 4th Computer*

Science On-Line Conference 2015 (CSOC2015), Vol 3: Software Engineering in Intelligent Systems, 143–153.
Agustian, H. Y. (2020). *Students' learning experience in the chemistry laboratory and their views of science: in defence of pedagogical and philosophical validation of undergraduate chemistry laboratory education*.
Aldrich, C. (2009). *Learning online with games, simulations, and virtual worlds: Strategies for online instruction*. John Wiley & Sons.
Ali, W. (2020). Online and remote learning in higher education institutes: A necessity in light of COVID-19 pandemic. *Higher Education Studies*, *10*(3), 16–25.
Altalbe, A. (2018). *Virtual laboratories for electrical engineering students: Student perspectives and design guidelines*.
Angulo, I., Rodriguez-Gil, L., & Garcia-Zubia, J. (2018). Scaling up the lab: An adaptable and scalable architecture for embedded systems remote labs. *IEEE Access*, *6*, 16887–16900.
Bozkurt, A., Jung, I., Xiao, J., Vladimirschi, V., Schuwer, R., Egorov, G., Lambert, S., Al-Freih, M., Pete, J., & Olcott Jr, D. (2020). A global outlook to the interruption of education due to COVID-19 pandemic: Navigating in a time of uncertainty and crisis. *Asian Journal of Distance Education*, *15*(1), 1–126.
Coleman, H. W., & Steele, W. G. (2018). *Experimentation, validation, and uncertainty analysis for engineers*. John Wiley & Sons.
Cooper, M., & Ferreira, J. M. M. (2009). Remote laboratories extending access to science and engineering curricular. *IEEE Transactions on Learning Technologies*, *2*(4), 342–353.
Cramer, J. M., & Hamilton, P. T. (2017). An internship may not be enough: Enhancing bioscience industry job readiness through practicum experiences. *Journal of Microbiology & Biology Education*, *18*(1), 10–1128.
Davis, A. L. (2013). Using instructional design principles to develop effective information literacy instruction: The ADDIE model. *College & Research Libraries News*, *74*(4), 205–207.
Ebel, H. F., Bliefert, C., & Russey, W. E. (2004). *The art of scientific writing: from student reports to professional publications in chemistry and related fields*. John Wiley & Sons.
El-Sabagh, H. A. (2011). *The impact of a web-based virtual lab on the development of students' conceptual understanding and science process skills*.
Francis, S. P., Kanikkolil, V., & Achuthan, K. (2016). Learning curve analysis for virtual laboratory experimentation. *2016 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, 1073–1078.
Gallagher, N. J. (2016). *Embedded 3D Web Based Content for the Creation of an Interactive Medical Browser*.
Harrison, A. G., & De Jong, O. (2005). Exploring the use of multiple analogical models when teaching and learning chemical equilibrium. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *42*(10), 1135–1159.
Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education*, *88*(1), 28–54.
Kozma, R., & Russell, J. (2005). Students becoming chemists: Developing representational competence. *Visualization in Science Education*, *1*, 121–146.
Kuznar, K. A. (2007). Associate degree nursing students' perceptions of learning using a high-fidelity human patient simulator. *Teaching and Learning in Nursing*, *2*(2), 46–52.
Luque Ruiz, I., López Espinosa, E., Cerruela García, G., & Gomez-Nieto, M. A. (2001). Design and development of computer-aided chemical systems: virtual labs for teaching chemical experiments in undergraduate and graduate courses. *Journal of Chemical Information and Computer Sciences*, *41*(4), 1075–1082.
Machet, T. C. (2015). *Improving Laboratory Learning Outcomes: An Investigation Into the Effect of Contextualising Laboratories Using Virtual Worlds and Remote Laboratories.*
Ogunkunle, S. J. (2017). *EFFECTS OF SIMULATED LABORATORY AND ENRICHED LABORATORY GUIDE MATERIAL EXPERIMENTS ON STUDENTS'LEARNING OUTCOMES IN BASIC SCIENCE IN OYO STATE, NIGERIA*.
Qiang, Z., Obando, A. G., Chen, Y., & Ye, C. (2020). Revisiting distance learning resources for undergraduate research and lab activities during COVID-19 pandemic. *Journal of Chemical Education*, *97*(9), 3446–3449.
Sahrir, M. S., Alias, N. A., Ismail, Z., & Osman, N. (2012). Employing Design and Development Research (DDR): Approaches in the Design and Development of Online Arabic Vocabulary Learning Games Prototype. *Turkish Online Journal of Educational Technology-TOJET*, *11*(2), 108–119.
Sharma, S. (2016). Expanded cloud plumes hiding Big Data ecosystem. *Future Generation Computer Systems*, *59*, 63–92.
Siemens, G., Gasevic, D., Haythornthwaite, C., Dawson, S. P., Shum, S., Ferguson, R., Duval, E., Verbert, K., & Baker, R. (2011). *Open Learning Analytics: an integrated & modularized platform*. Open University Press Maidenhead.

Tan, M., & Hew, K. F. (2016). Incorporating meaningful gamification in a blended learning research methods class: Examining student learning, engagement, and affective outcomes. *Australasian Journal of Educational Technology*, *32*(5).