EURASIAN EXPERIMENT JOURNAL OF SCIENTIFIC AND APPLIED RESEARCH
(EEJSAR) ISSN: 2992-4146
©EEJSAR Publications Volume 5 Issue 2 2024

Virtual Laboratories in Science Education: Benefits and Challenges

Nyiramukama Diana Kashaka

Faculty of Education, Kampala International University, Uganda

ABSTRACT

Over the past two decades, virtual laboratories have become a significant component of science education, offering students and educators a flexible, cost-effective, and innovative way to engage with scientific experiments. This paper explores the benefits and challenges associated with virtual laboratories, analyzing their role in enhancing conceptual understanding, procedural skills, and accessibility. While virtual labs provide unique opportunities for interactive learning and self-paced education, they also pose challenges related to technical requirements, curriculum integration, and the potential reduction of hands-on experience. The paper concludes with best practices for integrating virtual laboratories into science curricula to maximize their effectiveness while mitigating drawbacks.

Keywords: Virtual laboratories, Science education, E-learning, Experimental inquiry, Educational technology.

INTRODUCTION

Over the past two decades, the development of virtual laboratories for science education has flourished. As major technological advances, including software and web development, have occurred, many researchers and instructors have sought to capitalize on these advances by integrating virtual lab experiences into traditional and online learning environments. We provide an overview of the emergent key issues, lessons learned, and best practices for the effective use of virtual laboratories in science education. In particular, we focus on factors governing the selection and use of virtual laboratories; strategies to maximize the benefits of using a virtual laboratory to develop conceptual, procedural, and visualization skills; and the role of virtual labs in providing authentically scientific activities for students [1]. One key question many science instructors, administrators, and researchers have is about the value and usefulness of virtual labs. The literature demonstrates that many individuals and classrooms have access to a diverse array of online, readily available lab experiences without the cost or coordination necessary for local facilities, trained technicians, or on-site safety and access. A number of studies have pointed to the benefits of using virtual laboratories, such as learner control over the pace of the activity, automatic replay and tutorials, rapid feedback, and zero-cost to students. What are the challenges and problems in the use of virtual laboratories? This essay aims to explore, in an accessible and coherent manner, the current state of the practice and research for designing and evaluating virtual labs in science learning [2].

THE ROLE OF VIRTUAL LABORATORIES IN SCIENCE EDUCATION

Virtual laboratories have increasingly been used across different educational fields, from primary schools to universities. Nonetheless, the discussion on their use is limited. In the past few years, this has started to change, and virtual laboratories have gained more attention. This paper serves as an outline of recent scholarship on this topic. It will first explore the advantages and the purpose of such virtual laboratories. The following paper will shed light on their implementation in pedagogical research for science education. We argue that the use of virtual laboratories is mainly justified by the innovative and incidentally motivational learning experience [3]. The potential of the innovative learning process concerns virtual laboratories themselves, communication with teaching staff or peers, changes in the teaching and assessment strategies, and unforeseen opportunities to connect learning intention with research-oriented activities. The occurrence of these potentials underlines the nature and the role of virtual laboratories in the educational process. Virtual laboratories are used in the first place for pedagogical reasons in order to enhance the learning process. This indicates their functioning as a bridge between learning and education. Moreover, the occasional absence of both the access potential to research instruments and the communication function in virtual laboratories indicates their secondary role in the process of conducting research [4].

ENHANCING HANDS-ON LEARNING

Learning is best imbibed when linked with past experiences. Direct experiences make enduring and effective memories - as years later, that memory is tied to a feeling or a smell or a taste. For a whole ecology of educational reasons, a practical component of undergraduate science degrees has been the norm. It has been lamented that students never understand the raw complexity of the modern laboratory, as the undergraduate exercises are too simplified, often presented in brightly lit spaces with no whirring machines [5]. Students of chemistry are warned that "experiments must remain safely small to allow a number of students adequate access... and allow an analytical skill or knowledge... to be the prime focus." Sure, a number of academic and technical requirements need to be met, and in dealing with thirty students there are issues of space, of chemicals, and of safety. But if these difficulties can be set aside only for a few moments, just think of the following experiences when reengineered to involve hundreds of students: holidaying in Paris, listening to the theory, then virtually walking the pavement outside to identify architectural styles, gain an idea of the agendas of certain special interest groups in Paris, check heights, grooviness, noise, aircraft traffic, shops, café styles, menus, and prices, and then finally returning to the classroom to hear debriefs on the French domestic economy, my impressions of homeless people in Paris, and how VMware did nothing to slow my computer at all. You can legitimately say "when I was in Paris." The magic in these practicals is that they do not require the suspension of much disbelief [6]. Students studying biology may be given the seedlings germinated in sterile tissue culture by a botanical garden, from which they are to grow plants, take cuttings, and establish a mini garden. Such modules provide students with the opportunity to learn through doing, involving all their senses - seeing, touching, hearing, smelling, and often tasting, offering them the joy of direct experience - of literally "first hand" knowledge. In both these modules, students demonstrate and advance their practical skills in natural science inquiry and experimental design, as well as extending their general transferable skills. More advanced students supervising the first years understand that this component of this course offered them "the best lecturers I have ever had" [7]. Virtual laboratories have the advantage of providing a more accurate representation of an experiment. They are interactive and can also be used for preparing other practical exercises, such as "dry-runs" for ceramics work or surgical procedures in a medical degree. Carry out the experiment by using controls to see what difference one factor makes, such as the morphological acronym used for dissecting flowers, seedlings, or crayfish in Moodle DisPress, and the practical wet lab version MorphICTY, in wine tasting, to show how a swizzle-stick tests the taste of silicates and carbonates, and in engineering procedures. Would this virtual reality environment (VRE) greatly enhance the practical wet laboratory experience for the enrolled students? [8].

BENEFITS OF VIRTUAL LABORATORIES

The benefits of virtual laboratories (VLs) for educational practice are multiform and range from changes in the teachers' role and new possibilities for the teaching of experimental inquiry, to improved learning opportunities for students, which support the development of both scientific literacy and specific conceptual competences. Regarding the changes in the overall learning process, the introduction of virtual experiments has been shown - in some studies - to improve students' sense of self-efficacy and to foster a more self-regulated approach to learning. The main advantage of VL use for the learning of specific physics concepts is the possibility to manipulate multiple representational modes, with which students can make observations in both the macro- and the micro-world. This should help in surmounting alternative ideas and common misconceptions, which have been found to be particularly resistant to conceptual change [9]. Virtual laboratories provide educators with improved opportunities for both explicit and implicit teaching. As for explicit teaching, VLs can be used in presenting and discussing physical concepts in an interactive way. This can foster a general attitude of open-minded inquiry, which values experimentation and will thereby lead to increased reliability in knowledge acquisition. The implicitly teaching powers lie in the available concrete collaboration opportunities, which provide the possibility to reconcile conflicting opinions by means of auto- or hetero-competition, and in developing a more epistemic motivation in subsequently performing a physical hands-on experiment as already exemplified in the VL. This will reduce the "can we trust the physics?" dilemma. Another asset is the integration of cognitive with meta-cognitive experiences which affect attitude changes, such as positive feelings and intrinsically motivating issues. For example, performing small-scale physics experiments at a computer in class instead of a "plain eye"-experiment requires a skill transfer process to adapt to the technology surrounding [10].

ACCESSIBILITY AND FLEXIBILITY

Accessibility and flexibility are large attractive features of virtual laboratories. They provide a level of access that is more difficult or even impossible to achieve in physical science classrooms. Science resources such as telescopes, labs, and geological features are expensive, have limited access, and may be restricted due to safety and privacy concerns. Virtual labs allow access to unique features, such as remote-controlled telescopes, that would otherwise be inaccessible [11]. Another important aspect of virtual laboratories is that they offer flexibility to students who are at a distance (online or place-bound due to job and family responsibilities). Virtual laboratories are educational resources that can be accessed electronically, either on a computer workstation, over the internet, or through a combination of both. This medium has obvious advantages for different students who may have different inclinations, disabilities, and practical limitations. The National Center on Universal Design for Learning lists flexibility as one key principle of Checkpoint 5 of their three guiding principles. Learner goals may not be homogenous. Virtual labs provide choice in learners' goals and provide flexibility and choice to scientists, as they can choose to specialize in both labs and types of samples. A chemistry researcher may specialize in biologically active molecules such as drugs or environmental chemicals, while a geologist might specialize in sediments, rocks, or hydrothermal vents [12]. Stretching beyond typical audiences to those who might not normally learn subjects should be encouraged, as this audience may actually benefit. This has been seen with the Life-long Learning and Innovation Activities in Space, an initiative to stimulate the imaginations of children and teachers in geometrical math, biological, and physical sciences. Different disciplines and education establishments with different cultures and traditions mean a diversity of models, language, and viewpoints. All learners can benefit from knowing these other perspectives [13].

CHALLENGES OF IMPLEMENTING VIRTUAL LABORATORIES

Haslbeck et al. (2005, p. 115) mention the difficulties of integrating e-learning in university curricula. These difficulties include the outdated curricula and infrastructure, lack of time, effort, and appreciation by educators, or skepticism of potential employers toward the e-learning outcomes. They also address the negative impact of online experiments on students' enjoyment of practical work since many students prefer practical work, especially in groups. Integrating virtual experiments is also time-consuming for teachers to create counterparts for all available real experiments. However, some authors challenge this argument, arguing that the time spent on developing a virtual laboratory will eventually pay off by enabling a larger number of students to learn in a way that suits them [14]. The first challenge associated with using virtual laboratories is that there is a multitude of formats that the platform has to support or be as agnostic as possible with regards to software operation. A seemingly good option would be to use a web-based platform that can be accessed using a web browser, but this might add additional constraints to the type of software the web platform can host and must be portable across different operating systems, including Linux, MacOS, and Windows [15]. Other challenges are related to programming. Virtual laboratories must be properly designed to avoid language and system dependence and must be fixable by other designers. In many cases, a laboratory has actually been designed around a complex piece of software and is so dependent on the software for operation that if the software does not work as expected, the laboratory is effectively inoperable. Then, the specific characteristics of remote operation imply the challenge of having to deal with network programming and the differences between management and data porting. Another aspect of the design, including didactical aspects and platform independence, that poses a challenge is the development of a specialized code for the interface that might turn obsolete very fast because of either software incompatibility or changes [16].

TECHNICAL REQUIREMENTS AND INFRASTRUCTURE

An important aspect to be considered for the implementation of virtual laboratories is that students and lecturers have to be equipped with the appropriate technology, which implies specific requirements of hard- and software for the use in teaching and learning. The wishes of a future user group should be taken into account when defining the demands and requirements. The key factor from the user perspective is a suitable software environment with beneficial user interface and functioning procedures. Only a proper exploitation of the virtual laboratories assures a learning effect of the exercise and thus an improvement of the educational quality. In contrast, major difficulties for the user may appear in a complex installation and orientation. They lead to time-consuming practice, which represents a further obstacle to acceptance [17]. report additional technological obstacles for e-learning tools in general and thus also for virtual laboratories. The successful and maintained usage of online courses and labs depends not only on the design of the application and the motivation of their potential adopters, but also on the existing well-functioning e-learning infrastructure. To guarantee better service, the staff needs to have the necessary skills and coordination and cooperation with other departments and stakeholders are equally important. Virtual laboratories may be seen as one aspect of a transition to new forms of education, the "pedagogical shift" or "paradigm shift" in education that require not only the understanding and support of students and lecturers, but also considerable efforts concerning the technical equipment and infrastructure [18].

BEST PRACTICES FOR INTEGRATING VIRTUAL LABORATORIES INTO CURRICULUM

To ensure the efficacy of virtual laboratories in science education, we must first acknowledge the benefits and potential drawbacks of the concept of virtual labs. By outlining both the assets and limitations here, we've laid the groundwork for developing best practices for integrating virtual labs into a science program curriculum. Given these benefits and drawbacks outlined here, the overarching method for effectively integrating a virtual lab to replace a face-to-face lab is summarized as a "complementary" approach. By using a complete or almost complete virtual lab with options or requests for the students to complete one part of the information in "real life," we capitalize on the benefits of "real life" experimentation while minimizing the drawbacks and ensuring the efficiency and cost-savings of virtual labs are maintained [19]. Best Practices: 1) Unless students are training to primarily use virtual labs post-graduation, it is taken as best practice to use some introductory "real life" labs to ensure that students have had some "real life" lab experience. 2) The best student/teacher ratio for online instruction is thought to be 40:1, but 20:1 for face-to-face teaching. To allow for effective face-to-face engagement with students, especially in a lab scenario where students are working with chemicals and equipment, modules one parlaboratories have an estimated 1:10 ratio for a learning facilitator to students. 3) Beyond the first year of science study, real life labs are recommended for science theory study [20]. Overall, the consensus of benefits and limitations demonstrates that dosing a science program predominantly with virtual labs is not recommended for a number of reasons. However, they can be useful in restricted application, particularly in particular situations of remote learning [21].

CONCLUSION

Virtual laboratories represent a transformative tool in science education, offering unparalleled accessibility, flexibility, and opportunities for interactive learning. They play a critical role in developing students' conceptual and procedural skills, making scientific inquiry more accessible to a diverse student population. However, the successful implementation of virtual labs requires careful consideration of technical infrastructure, curriculum design, and the balance between virtual and physical laboratory experiences. By adhering to best practices, educators can effectively integrate virtual laboratories into their teaching, thereby enhancing educational outcomes while addressing the challenges inherent in this innovative approach.

REFERENCES

1. McPherson H, Pearce R. The shifting educational landscape: science teachers' practice during the COVID-19 pandemic through an activity theory lens. Disciplinary and Interdisciplinary Science Education Research. 2022 May 4;4(1):19. springer.com
2. Castelli FR, Sarvary MA. Why students do not turn on their video cameras during online classes and an equitable and inclusive plan to encourage them to do so. Ecology and Evolution. 2021. wiley.com
3. Liu R, Wang L, Lei J, Wang Q, Ren Y. Effects of an immersive virtual reality-based classroom on students' learning performance in science lessons. British Journal of Educational Technology. 2020 Nov;51(6):2034-49. researchgate.net
4. Kapilan N, Vidhya P, Gao XZ. Virtual laboratory: A boon to the mechanical engineering education during covid-19 pandemic. Higher Education for the Future. 2021 Jan;8(1):31-46. sagepub.com
5. Cuzzolino MP. "The Awe is In the Process": The nature and impact of professional scientists' experiences of awe. Science Education. 2021. [HTML]
6. Topalsan AK. Development of scientific inquiry skills of science teaching through argument-focused virtual laboratory applications. Journal of Baltic Science Education. 2020. ed.gov
7. Rajesh C, Muthukumar K, Asraf SS, Palanichelvam K. Development of essential skills from a research project in biotechnology: coelomic fluid of earthworm induces adventitious roots in tobacco plants. Journal of Engineering Education Transformations. 2024 Jan 20;37(Special Issue 2). amazonaws.com
8. Anwyl-Irvine A, Dalmaijer ES, Hodges N, Evershed JK. Realistic precision and accuracy of online experiment platforms, web browsers, and devices. Behavior research methods. 2021 Aug;53(4):1407-25. springer.com

9. Lin YJ, Wang H. Using virtual reality to facilitate learners' creative self-efficacy and intrinsic motivation in an EFL classroom. Education and Information Technologies. 2021. [HTML]
10. Juhji J, Nuangchalerm P. Interaction between science process skills and scientific attitudes of students towards technological pedagogical content knowledge. Journal for the Education of Gifted Young Scientists. 2020;8(1):1-6. dergipark.org.tr
11. Alip SL, Kim J, Rha KH, Han WK. Future platforms of robotic surgery. Urologic Clinics. 2022. [HTML]

12. Chan P, Van Gerven T, Dubois JL, Bernaerts K. Virtual chemical laboratories: A systematic literature review of research, technologies and instructional design. Computers and Education Open. 2021 Dec 1; 2:100053. sciencedirect.com
13. Halász G. From Teacher Education to Lifelong Teacher Learning and Teacher Innovation: The Case of Hungary. InResearch, Policymaking, and Innovation: Teacher and Education Development in Belt and Road Countries 2023 Apr 6 (pp. 83-104). Singapore: Springer Nature Singapore. [HTML]
14. Verstege S, Vincken JP, Diederen J. Blueprint to design virtual experiment environments. Computers and education open. 2021. sciencedirect.com
15. Campbell CD, Challen B, Turner KL, Stewart MI. # DryLabs20: a new global collaborative network to consider and address the challenges of laboratory teaching with the challenges of COVID-19. Journal of Chemical Education. 2020 Aug 3;97(9):3023-7. ox.ac.uk
16. Morrison-Smith S, Ruiz J. Challenges and barriers in virtual teams: a literature review. SN Applied Sciences. 2020. springer.com
17. El Kharki K, Berrada K, Burgos D. Design and implementation of a virtual laboratory for physics subjects in Moroccan universities. Sustainability. 2021. mdpi.com
18. Saay TS, Margaria T. XMDD as Key Enabling Technology for Integration and Organizational Collaboration: Application to E-Learning Based on NRENs. Advances in Science, Technology and Engineering Systems Journal. 2021;6(3):213-30. researchgate.net
19. Agustian HY, Finne LT, Jørgensen JT, Pedersen MI, Christiansen FV, Gammelgaard B, Nielsen JA. Learning outcomes of university chemistry teaching in laboratories: A systematic review of empirical literature. Review of Education. 2022 Aug;10(2): e3360. wiley.com
20. Bradley-Dorsey M, Beck D, Maranto R, Tran B, Clark T, Liu F. Is cyber like in-person? Relationships between student-student, student-teacher interaction and student achievement in cyber schools. Computers and Education Open. 2022 Dec 1; 3:100101. sciencedirect.com
21. Yusuf I, Widyaningsih SW. Implementing E-Learning-Based Virtual Laboratory Media to Students' Metacognitive Skills. International Journal of Emerging Technologies in Learning. 2020 May 1;15(5). semanticscholar.org

CITE AS: Nyiramukama Diana Kashaka. (2024). Virtual Laboratories in Science Education: Benefits and Challenges. EURASIAN EXPERIMENT JOURNAL OF SCIENTIFIC AND APPLIED RESEARCH, 5(2):21-25