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A Critical Analysis of the Impact of Virtual Laboratories on Educational Advancement

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Abstract: This article presents the findings of a comprehensive literature review that investigates the use of virtual laboratories in educational settings. Virtual laboratories offer numerous advantages for students, teachers, and the advancement of a nation, particularly in the realm of education and learning. Some advantages of this platform include the promotion of students' critical thinking abilities, cost-effectiveness due to its modest resource requirements, adaptability, flexibility, and enhancement of students' scientific literacy. Nevertheless, despite the advantages offered by virtual laboratories, it is crucial to continuously evaluate this platform. For example, the proficiency of instructors who teach students via virtual laboratories, as well as the instructional materials used in this platform, need to be constantly updated. A systematic literature analysis was conducted on 10 publications retrieved from multiple databases. The findings of the review indicate that virtual laboratories in education have a positive impact across various domains such as enhancing students' cognitive capacities, enhancing the efficiency of e-learning, being cost-effective and adaptable, and enhancing students' scientific literacy skills.

Keywords: Education, Learning, Virtual laboratory

Introduction

The introduction of virtual technology has significantly transformed education, becoming deeply embedded in today's contemporary social structure. A growing number of individuals, especially those in the education industry, acknowledge the significance of progress in virtual technology (Shaw et al., 2022). One of the emerging virtual technologies in recent years is the virtual laboratory, which now offers various forms, each with its distinct advantages. There are multiple justifications for employing virtual laboratories in the process of learning, such as: it facilitates a dynamic classroom setting where learners can actively participate in meetings, ask questions through written or audio channels, receive prompt responses, engage in discussions, upload files, and assign students to manage the classroom and practice collaborative discussions. It also allows for a classroom-like experience without the need for physical presence (Bawaneh, 2021).

Before digging into virtual laboratories, it is important to briefly address virtual classrooms, which can be considered as the foundation for virtual laboratories. According to a study, virtual classrooms enhance communication among professors, students, and universities. The platform provides both synchronous and asynchronous meetings, along with a range of media choices including sound/audio, photos, graphics, and electronic

libraries. These characteristics guarantee the effective and efficient communication of information to students, therefore optimizing their learning experience.
Moreover, it fosters students' involvement in self-directed learning and offers convenience in terms of time and location for all individuals participating in the educational learning process (Bawaneh, 2021). In line with that, Wang et.al stated that a virtual laboratory is a computer-based environment that uses multimedia, simulation, and virtual reality technologies to create 3D models of real experimental scenes. It aims to replicate and replace traditional experimental procedures by providing software and hardware operating environments on the computer (Huang & Looi, 2020). Virtual laboratory also offers the following (Bose, 2013):

(a) Provide engineering colleges lacking lab facilities with access to high-quality laboratories.
(a) Provision of high-quality laboratories as an additional amenity for colleges that already possess laboratory facilities
(c) An all-encompassing Learning Management System centered around these laboratories
(b) Enhancing the training and expertise of teachers through workshops and training conducted on-site.

Method

The methodology employed is a comprehensive review of existing literature. Randolph (2009) said that a literature review, also known as a literature study, aims to establish a framework that connects new and previous findings. Its purpose is to determine whether there has been any progress in the results of a study by conducting thorough research and interpreting literature related to a specific topic. This involves searching for and analyzing relevant literature using a systematic approach to identify research questions (Suhendi et al., 2022). In the same paper, Aveyard (2019) stated that the literature review was conducted using a simplified approach. This involved analyzing the data by combining the information from each journal article and simplifying the findings (Suhendi et al., 2022). Journal articles are acquired from several international and national databases.

During the initial phase, the search yielded a total of 1,268 journal articles from various databases covering the period from 2013 to 2023. The search was conducted using the keywords "virtual laboratory," "education," and "mathematics," which were chosen since they had not been previously investigated for their relevance to the collection. A total of 32 articles were acquired, which were evaluated based on the author's specified criteria. Out of these, only 10 articles were found to fit the criteria as per the requested search.

Results and Discussion

The data analysis was conducted methodically utilizing a simplified approach. A search across multiple databases yielded 1,268 journal papers on the topic of virtual laboratories in education. The article search process involves the utilization of the terms "virtual laboratory", "education", and "mathematics". Researchers employ the Boolean operator "AND". The boolean operator "AND" is utilized to combine many concepts and aspects as search keywords to refine the search results and obtain more specific content. Out of the journal articles examined, about 32 articles were found to be relevant based on the author's specific criteria, and only 10 articles were determined to fulfill the intended search criteria. The analysis of each item is presented in Table 1.

Table 1. Data analysis matrices are utilized in journal articles for conducting literature review investigations

Author, Title, Journal	**Result**
Abumalloh et al., (2021), Virtual Labs Project: A Paradigm Shift in Internet-Based Remote Experimentation, Technology in Society	Implications in theory: 1) this study introduces the Push-Pull-Moring model to provide a complete understanding of the various aspects that can impact a user's perceived benefits when transitioning from traditional learning to online learning during the COVID-19 pandemic; 2) the second contribution of this study is the development of a significant model for evaluating the effectiveness of e-learning in the context of the coronavirus pandemic; 3) this study conducted an empirical investigation of a constructed model that integrates several

	aspects influencing the effectiveness of online learning systems. Pragmatic consequences: 1) the importance of enticing folks to utilize technological platforms is highly significant for decision-makers; 2) Regarding the influence of moored, electronic interactions pose a security risk.
Nicolas & Trgalova (2020), A virtual environment dedicated to spatial geometry to help students to see better in space, HAL	The implementation of the VR activity appears to have facilitated the development of students' heuristic comprehension of drawings in cavalier perspective. This was achieved through the recognition of smaller figurative units, thereby enhancing their spatial visualization abilities. Presence in a VR setting refers to the conviction that one is immersed in the artificial environment, rather than being physically present in a laboratory or classroom and only communicating with a computer. The coupling effect results in a cognitive permeability between the physical reality and the virtual reality. A virtual world, perceived as genuine by users, yet programmed with certain interactions and rules, presents a multitude of valuable learning opportunities.
Salmerón-Manzano & Manzano-Agugliaro (2018), The Higher Education Sustainability through Virtual Laboratories: The Spanish University as Case of Study, Sustainability	The advent of virtual laboratories presents new opportunities for ensuring the long-term viability of higher education. This necessitates a reevaluation of national educational policies and regular updates to course content, ensuring that university students are equipped to meet the demands of our interconnected global society.
Lenzen et al. (2014), Compiling and using input-output frameworks through collaborative virtual laboratories, Science of The Total Environment	The IELab in the Virtual Laboratory infrastructure offers several advantages: (a) it allows for significant savings in terms of human and financial resources due to its collaborative nature; (b) it ensures timely deployment through automation procedures; and (c) it provides flexibility for future choices regarding sectoral and spatial representation through the flexible root-mother-daughter concept.
Budai & Kuczmann (2018)**,** Towards a Modern, Integrated Virtual Laboratory System, Acta Polytechnica Hungarica	With the aid of the novel perspective of using cognitive info-communication to describe the learning process in a virtual laboratory, it was possible to identify new key aspects that a designer of a virtual laboratory system ought to take into consideration to attain a high didactic potential. The requirements that have been stated for the new virtual laboratory system have the potential to serve as a design template for applications that are being developed. Implementing a new virtual laboratory system that is based on this architecture is the next step that needs to be taken. Following that, the new system will be put through its paces with the assistance of both instructors and students to validate the design and make certain that the new system successfully satisfies all of the objectives that have been outlined in this paper.
Noris et al. (2022), The Virtual Laboratory Based on Problem-Based Learning to Improve Students' Critical Thinking Skills, European Journal of Mathematics and Science Education	The PBL-based virtual laboratory media developed by the researcher for the excretory system material consists of 6 stages based on the problem-based learning syntax. Additionally, the developed media is combined with cognitive components of critical thinking abilities. The virtual laboratory media, which is grounded on problem-based learning, has been validated by experts in materials, media, language, and practitioners. The average feasibility percentage of virtual laboratory media is approximately 82.64%, placing it within

	the category of very good. Hence, the utilization of problem-based learning virtual laboratory media is viable as an instructional tool for the excretory system material. The utilization of virtual laboratory media as learning tools is regarded as an efficient method to enhance the critical thinking abilities of students in comprehending the excretory system information. This holds for both SMP N Woha and SMP 2 Belo.
Diwakar et al. (2016), Complementing Education via Virtual Labs: Implementation and Deployment of Remote Laboratories and Usage Analysis in South Indian Villages, International Journal of Online Engineering (iJOE)	Utilizing remote laboratories in mixed learning environments enabled students to perceive some laboratory elements as they would in traditional laboratory courses. Multiple challenges must be addressed before implementing remote laboratories for big online courses. Additionally, we observed that the quality of connectivity can impact how users evaluate the value of remote labs. Usage case studies suggest that remote labs have the potential to be implemented as a supplementary educational tool to enhance conceptual comprehension and facilitate hands-on learning experiences. These platforms help address both general and specific disparities in laboratory resources and environments among institutions in India and other developing nations. They also assist in dealing with the issue of inadequately equipped laboratories.
Yilmaz & Coskun Simsek (2023)**,** The Use Of Virtual Reality, Augmented Reality, And The Metaverse In Education: The Views Of Preservice Biology And Mathematics Teachers, MIER Journal of Educational Studies, Trends & Practices	To facilitate the integration of emerging technologies such as VR, AR, and the metaverse into education, it is essential to ensure that learning environments are appropriately designed. Additionally, teachers and students should receive guidance and information on how to effectively utilize these technologies in education. Furthermore, there should be a greater emphasis on creating pedagogical material and content that is specifically tailored for these technologies.
Susanti et al. (2023), The Inquiry Collaborative Learning Design Virtual Laboratory Based and Remote Virtual, Indonesian Journal of Informatics Education	According to the findings of the research, it was discovered that the development of a collaborative inquiry learning model in conjunction with a virtual lab-based and remote lab-based model has the potential to enhance the student experience in terms of exercising skills related to discipline, collaboration, discussion, and a sense of responsibility. This instructional design has been validated by specialists. Having determined that the design and learning model are both valid and practicable, the findings of the practicality test have been declared. It is possible to recommend this model for the purpose of programming education by developing computer labor that is connected with net support. This allows the computer that is used by the lecturer to be utilized as a server computer, which acts as a controller for the client computer that is located in the computer lab.
Ismail et al. (2016), STEM Virtual Lab: An Alternative Practical Media To Enhance Student's Scientific Literacy, Jurnal Pendidikan IPA Indonesia	A virtual laboratory focused on the issue of water pollution, with a strong emphasis on STEM (Science, Technology, Engineering, and Mathematics) principles, has been constructed. The lab demonstrates satisfactory effectiveness in achieving its objectives. The product has been validated by professionals and users, confirming its validity and excellent quality. This product serves as a viable substitute for conducting experiments related to water contamination. The utilization of this virtual tool also yields a substantial increase in students' scientific literacy level, as evidenced by the test data.

The utilization of virtual laboratory media as a learning tool is regarded as an effective strategy that has a major impact on the enhancement of students' critical thinking abilities in the process of comprehending information derived from the content that is presented. This is consistent with a research study that investigates the utilization of a Higher-Order Thinking Laboratory (HOTLAB) in conjunction with a hybrid virtual laboratory, which has the potential to improve students' critical thinking skills (Setya et al., 2021). In a manner that is not dissimilar to the findings of earlier studies, virtual laboratories have the potential to enhance the cognitive abilities of students (Widowati et al., 2017). Furthermore, this particular sort of laboratory can help students better comprehend abstract scientific ideas (Aboraya, 2021).

Virtual laboratories are the impact of the transition from traditional learning to online learning during the COVID-19 pandemic. This transition proved to be effective in e-learning within the context of online learning for the COVID-19 pandemic, and decision-makers now can make use of this platform. This is the first finding that emerged from this review of the relevant literature and it is consistent with the findings of research conducted by Kapilan et al. (2021); Sasmito & Sekarsari (2022); and Vasiliadou (2020). In addition, virtual laboratories offer a multitude of educational opportunities that are extremely beneficial.

In this literature review, the author concluded that the advent of virtual laboratories gives new options to ensure the long-term viability of higher education to satisfy the expectations of global society. This was the second result that the author accomplished. Also, virtual laboratories provide numerous advantages, such as significant cost and resource reduction, streamlined operation through automated processes, adaptability, and the ability to enhance educational potential. Hence, the research conducted by Sasmito & Sekarsari (2022); Trnka et al. (2016); and Vasiliadou (2020) further elaborates on some of the aforementioned advantages.

The third finding in this study is that to promote the incorporation of novel virtual laboratory technologies into education, it is crucial to ensure that the learning environment is appropriately designed. Additionally, teachers and students must be provided with guidance and information on how to effectively utilize these platforms in education. There are also several earlier research that lends evidence to this, specifically by Ilyas et al. (2020); Lewis (2014); and Okono et al. (2016).

The fourth and final finding that emerged from our review of the relevant literature was that the utilization of a virtual laboratory has the potential to bring about a substantial improvement in the scientific literacy levels of students and these findings are consistent with research from other studies, such as Abeldina et al. (2018); Arieska Putri et al. (2021); (Liu et al., 2022); Petersson et al. (2013); and Supahar & Widodo (2021).

Conclusion

A virtual laboratory is a multimedia platform that serves as an alternate platform for learning. It enhances students' cognitive capacities, enhances the efficiency of e-learning, is cost-effective and adaptable, and enhances students' scientific literacy skills. However, the benefits of virtual laboratories must also be weighed against the pedagogical capabilities of the instructor in the use of this platform, as well as the requirement for some kind of manual or guide to understand how to utilize this kind of laboratory. Taking into consideration the environment that is capable of supporting the utilization of a virtual laboratory platform is still another factor that needs to be evaluated.

Recommendations

Future research should focus on investigating the significance of pedagogical frameworks tailored to virtual learning environments. Although virtual laboratories enhance critical thinking and problem-solving skills, further research is necessary to identify the most effective instructional strategies that optimize these advantages. Exploring frameworks like inquiry-based learning, collaborative learning, or cognitive scaffolding within virtual learning contexts may provide valuable insights into enhancing engagement and benefits for diverse learners across various age groups and educational backgrounds.

Furthermore, longitudinal studies are essential to assess the enduring effects of VL use on students’ cognitive and

scientific skills. Although current research highlights the short-term advantages, conducting longer-term studies would be beneficial in assessing the extent to which skills acquired in virtual labs translate successfully to real-world applications and physical laboratory settings. Monitoring students over an extended period may provide insights into the impact of VLs on their advancement in scientific disciplines, critical thinking abilities, and the application of practical skills.

Future research must also tackle the technical and accessibility challenges related to VLs. Although virtual labs offer greater accessibility compared to conventional laboratories, challenges persist, particularly in areas with inadequate internet infrastructure or among individuals who possess lower levels of digital literacy. Research should concentrate on developing low-bandwidth, user-friendly virtual labs that uphold educational quality while expanding accessibility to a wider audience. Furthermore, accessibility features may be designed to assist students with disabilities, guaranteeing that virtual learning environments are inclusive and tailored to diverse educational requirements.

Another crucial area for future exploration is the advancement of educators who support learning in virtual environments. Given that teacher proficiency has a substantial impact on the effectiveness of virtual learning, it would be beneficial for research to investigate the most effective training models for educators. Research could assess different teacher training methodologies and their results, pinpointing effective strategies for equipping educators to effectively manage and leverage VL platforms.

There is a pressing requirement for research focused on the multi-disciplinary and cross-curricular applications of virtual laboratories. While the majority of recent studies emphasize STEM fields, virtual learning environments hold significant potential in other disciplines, including social sciences, art, and humanities. Future research may investigate the potential of virtual laboratories to enhance practical experiences in various fields beyond conventional lab-based disciplines, providing valuable insights into how virtual laboratories can enrich a diverse range of academic subjects.

In conclusion, enhancing research in these domains would yield a deeper insight into the operation of virtual laboratories, increase their accessibility, maximize their educational effectiveness, and expand their use across various fields. With the expanding role of virtual laboratories, these research recommendations provide a solid foundation for developing more impactful, inclusive, and sustainable experiences for learners globally.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPESS Journal belongs to the authors.

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