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Virtual Laboratories in STEM

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Abstract

Virtual laboratory utilization has been trending in STEM undergraduate curricula for over twenty years. A virtual laboratory is an interactive computer simulation that mimics real-world laboratory experiences in silico. Virtual labs are cost-effective pedagogical options for academic institutions that lack adequate funding for physical infrastructure and instrumentation. Virtual labs are an excellent proxy for lab activities threatening individual safety and public health. Further, during the COVID-19 pandemic, virtual labs were the primary pedagogical strategy for laboratory instruction. STEM faculty have developed numerous techniques for incorporating virtual labs into classroom and laboratory activities. New technology like artificial intelligence will expand virtual lab usability and effectiveness. Educational research demonstrates positive student outcomes and other benefits from virtual lab engagement. Continued effective mixed-methods research and production of essential virtual lab-based evaluation materials, such as discipline-specific rubrics, are needed to advance the application of this vital technology further. Moreover, from a software development perspective, many more virtual laboratories are needed in technology, engineering, mathematics, and specialized scientific fields.

Keywords: Virtual Laboratory; Undergraduate; STEM; Distance Education

1. Introduction

The global COVID-19 pandemic served as the ultimate warning to educators that having access to online educational tools is not only complementary but mandatory. In 2020, science faculty worldwide were forced to quickly deploy virtual methods to instruct and train students [1-2]. Many science, technology, engineering, and math (STEM) faculty needed to prepare for the challenges of administering a high-quality laboratory experience during the deadliest periods of the pandemic. Faculty either failed to offer laboratory experiences or utilized free distance education materials provided by various companies for a limited time. Moreover, many institutions needed more monetary and technological resources to assist faculty and, more importantly, STEM students. Virtual laboratories are interactive and dynamic computer simulations designed to mimic real-world laboratory experiences and accepted by employers as viable training options [3-4]. In addition to the convenience of virtual labs in the curriculum as viable substitutes for traditional labs, virtual labs allow users to understand the scientific method and hypothesis testing better. In a conventional lab, many resources are typically required to adjust experimental variables and identify the effects on the dependent variable; with virtual labs, variable changes and experimental iterations can be made with a simple click. The author has explored virtual laboratory integration for many years and continues exploring economical and sustainable solutions for virtual laboratory integration in STEM education [5-7].

The confluence of traditional inculcation methods combined with some form of laboratory training has significantly improved student learning and STEM career preparation. Additionally, virtual laboratories in isolation from conventional scientific lab experiences demonstrated students' comprehension of critical scientific research skills and other skills necessary for success in the workplace. Unsurprisingly, undergraduate research experiences are integrated

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into many grant-funded programs designed to augment student success and broaden participation in STEM [8-10]. Moreover, the conflation of virtual laboratories and course-based undergraduate research experiences (CURE) would cost-effectively enhance undergraduate research experiences for a sizeable portion of the student population in STEM departments [11]. Virtual lab platforms with improved collaboration, data documentation, data analysis, and data presentation features will facilitate better student outcomes from CURE-based virtual lab investigations.

Increased guidance is needed to ensure that virtual laboratory platforms are compatible with cell phones (i.e., iOS and Android), tablets, laptops, and desktops. Commercial virtual labs are accessible from textbook companies, including McGraw-Hill and Pearson. Regarding the relevance of virtual labs, a segment of undergraduate STEM course developers believe it is more prudent to employ virtual labs exclusively for non-major courses since the cost of traditional lab activities may outweigh student interest. A fundamental goal of any application engineer is to enhance the usability of a specific software product. To that end, one recommendation for virtual laboratory developers would be to include user-interface modification features such as granting users the ability to alter software code. Allowing users to add specific code that meets the standards of their discipline and remains current with the ever-changing landscapes of STEM fields will facilitate usability. Moreover, grant-funded initiatives, technology projects, and specialized software engineering training that teach students and faculty how to code virtual labs will increase the coverage of virtual labs in diverse disciplines.

2. Virtual Laboratories in STEM

Several studies have demonstrated the effectiveness of virtual laboratories in STEM education and research [12]. It is important to note that over the years, there has been an increase in the number of virtual labs and scientific disciplines utilizing virtual labs [13-15]. The expansion in disciplines denotes the popularity of computer simulations as an essential mechanism to facilitate learning.

Recently, researchers conducted a quasi-experimental design study to assess the impact of virtual labs in a biology course. The results of their research show that a biology-based virtual laboratory intervention improved students' attitudes and made learning complex biological topics easier [16]. Additionally, this research study included a focus group to collect qualitative data about virtual labs and students' feelings about learning biological content using virtual labs. Focus groups are particularly effective research activities when combined with other research techniques. In a first-of-its-kind study, microbiome researchers created a traditional microbiome lab to teach undergraduates how to explore microbial diversity in human saliva samples using molecular and computational procedures [17]. Since standard microbiome research projects involve complex hands-on protocols, researchers utilized molecular biology-based and bioinformatics-based virtual labs before wet lab engagement to determine if virtual labs could provide undergraduates with sufficient background knowledge and skills to perform complicated microbiome research procedures successfully. Data demonstrated that pre-virtual lab exploration enhanced students' ability to complete their microbiome course projects.

In addition to undergraduate programs, medical schools have also investigated the use of virtual labs in a training capacity. A comparison study was performed with medical students participating in traditional labs and virtual labs. A student satisfaction questionnaire was administered after completing protein and carbohydrate analytical computer simulations, and performance grades were assessed to determine which method was better [18]. Students who engaged in the analytical protein virtual lab had higher grades than the traditional lab group. Students who engaged in the analytical carbohydrate traditional lab had higher grades than the virtual lab group. While using grades to determine effectiveness showed mixed results, data from student satisfaction questionnaires clearly showed that students believe virtual labs are an effective pedagogical medium.

3. Conclusion

Virtual laboratories are digital learning platforms instructing and training undergraduate students from various STEM disciplines. This review article serves as a brief compendium of research on the advantages of virtual laboratory integration. The article also highlights student outcomes that indicate the effectiveness of virtual labs at post-secondary institutions. The impact of artificial intelligence technology on virtual laboratory software remains to be determined. If the immediate past is any indication, artificial intelligence is poised to enhance student-platform interactivity, skills acquisition, and learning gains associated with virtual labs [19-20]. Moreover, the future confluence of virtual labs with virtual reality, augmented reality, and mixed reality technology, such as Meta Quest, Apple Vision Pro, and Microsoft's Hololens, will transform how virtual laboratories are implemented [21]. Within this decade, technology will allow hundreds of undergraduate students from a specific institution, lecture, or laboratory course to engage in the scientific

process in a virtual reality-based environment. While acquiring virtual reality headsets and requisite virtual reality accessories may be challenging initially, the long-term savings on infrastructure, setup costs, waste removal costs, hazard/risk mitigation costs, and equipment costs will be helpful to the sustainability of immersive virtual labs.

Despite the many advantages of virtual labs for some undergraduate institutions, such as historically black colleges and universities (HBCUs) and other minority-serving institutions (MSIs), virtual lab subscriptions and license costs can still be relatively high and exceed operating budget costs. Efforts to lower the costs of virtual lab user licenses and subscription services would allow more students to benefit from these dynamic, interactive digital laboratory solutions. The development of multi-institutional collaborations and advisory boards that meet regularly to discuss and develop strategies to defray the cost of virtual labs is needed.

Compliance with ethical standards

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References

[1] Kapilan N, Vidhya P, Gao X. Virtual laboratory: A boon to the mechanical engineering education during COVID-19 pandemic. Higher Education for the Future. 2021; 8: 31-46.

[2] Sasmito A, Sekarsari P. Enhancing students' understanding and motivation during COVID-19 pandemic via development of virtual laboratory. Journal of Turkish Science Education. 2022; 19: 180-193.

[3] Mercado J, Picardal J. Virtual laboratory simulations in biotechnology: A systematic review. Science Education International. 2023; 34: 52-57.

[4] Hirshfield L, Koretsky M. Cultivating creative thinking in engineering student teams: Can a computer-mediated virtual laboratory help? Journal of Computer Assisted Learning. 2021; 37: 587-601.

[5] Flowers L, White E, Raynor J, Sambit B. African American students' participation in online distance education in STEM disciplines: Implications for HBCUs. SAGE Open. 2012; 3: 1-5.

[6] Flowers L. Investigating the effectiveness of virtual laboratories in an undergraduate biology course. The Journal of Human Resource and Adult Learning. 2011; 7: 110-116.

[7] Flowers L, Moore J, Flowers L. Effective use of the virtual laboratory in online science courses. Online Classroom. 2011; 2-3.

[8] Donovan E, Wiglesworth L. Enhancing the undergraduate research experience by engaging in cross-institutional research. PRIMUS. 2023; 33: 16-29.

[9] Borrego M, Mastronardi M, Choe H, Hartman R. The impact of undergraduate research experiences on participants' career decisions. Journal of STEM Education: Innovations and Research. 2021; 22: 1-8.

[10] Guo F, Young J, Deese N, Pickens-Flynn T, Sellers D, Perkins D, Yakubu M. Promoting the diversity, equity, and inclusion in organic chemistry education through undergraduate research experiences at WSSU. Education Sciences. 2021; 11: 1-9.

[11] Flowers L. CURES and increasing participation in STEM. International Education and Research Journal. 2020; 6: 29-31.

[12] Serrano-Perez J, González-García L, Flacco N, Taberner-Cortés A, García-Arnandis I, Pérez-López G, et al. Traditional vs. virtual laboratories in health sciences education. Journal of Biological Education. 2023; 57: 36-50.

[13] Faridaddin V, Ilona B, Sajad M, Bas K. Application of gamified virtual laboratories as a preparation tool for civil engineering students. European Journal of Engineering Education. 2024; 49: 164-191.

[14] Reeves S, Crippen K. Virtual laboratories in undergraduate science and engineering courses: A systematic review, 2009-2019. Journal of Science Education and Technology. 2021; 30: 16-30.

[15] Mercado J, Picardal J. Virtual laboratory simulations in biotechnology: A systematic review. Science Education International. 2023; 34: 52-57.

[16] Céline B, Florien N, Albert P. Investigating the effect of virtual laboratories on students' academic performance and attitudes towards learning biology. Education and Information Technologies. 2024; 29: 1147-1171.

[17] Sun H, Wang P, Li Y. An integrated microbiome project for charactering microbial diversity in classroom based on virtual simulation experiments. Biochemistry and Molecular Biology Education. 2023; 51; 171-179.

[18] Ibrahim G, Morcos G, Ghaly W, Botros A, Hassan M, Hussein U. Perception of competence achievement and students' satisfaction using virtual laboratories in medical biochemistry course: Lessons from the COVID-19 pandemic. Biochemistry and Molecular Biology Education. 2023; 51: 254-262.

[19] Lin C, Yu C, Shih P, Wu, L. STEM-based artificial intelligence learning in general education for non-engineering undergraduate students. Educational Technology & Society. 2021; 24: 224-237.

[20] Lazarus M, Truong M, Douglas P, Selwyn N. Artificial intelligence and clinical anatomical education: Promises and perils. Anatomical Sciences Education. 2024; 17: 249-262.

[21] Allcoat D, Hatchard T, Azmat F, Stansfield K, Watson D, von Mühlenen A. Education in the digital age: Learning experience in virtual and mixed realities. Journal of Educational Computing Research. 2021; 59: 795-816.