Virtual Labs in Electrical Engineering Education During the Covid-19 Pandemic: A Systematic Literature Review

Edi Sarwono[1,2(✉)] and Nyan-Myau Lyau[2]

[1] Electrical Engineering Department, Universitas Negeri Semarang, Semarang, Indonesia
edisarwono@mail.unnes.ac.id

[2] Graduate School of Technological and Vocational Education, National Yunlin University of Science and Technology, Yunlin 64002, Taiwan

Abstract. This paper reviews the advantages of the implementation of virtual labs in the electrical engineering field, especially in practical courses. Practical courses in the electrical engineering department really support students' skills and abilities for their future. This study used a systematic literature review of selected research papers based on relevant keywords on virtual labs in electrical engineering education. Practical courses of learning in electrical engineering field education with virtual labs become more flexible without limited space and time. Virtual labs can accommodate all the limitations that exist, like the tools and materials of practical equipment in schools, which isn't in line with the current technology. Virtual labs are also a good solution for schools or colleges, especially if they don't have a lot of equipment or space.

Keywords: Virtual labs · Electrical engineering education · Covid-19

1 Introduction

The COVID-19 pandemic that has occurred throughout the world has resulted in changes in all aspects of human life, from the economic, health, social, cultural, spiritual, and even education sectors. The COVID-19 pandemic also brought with it a slew of never-before-seen alterations to the way the world works [1]. Most countries moved into full lockdowns even before the WHO declared COVID-19 a pandemic [2]. To reduce the impact of the COVID-19 pandemic, governments in various countries have issued several policies. One of these policies is the implementation of work from home and study from home.

Many educational institutions were forced to close in-person classes due to global lockdowns [3]. Therefore, this prompted educational institutions to adopt an online/remote learning strategy [4, 5]. The implementation of online learning brings its own challenges in the world of education. New learning styles and learning atmospheres, economic limitations, and low ability to operate information and communication technologies are factors that affect the effectiveness of learning. As a result, online learning

A. Kusumastuti et al. (Eds.): VEIC 2022, ASSEHR 697, pp. 52–59, 2023.
https://doi.org/10.2991/978-2-494069-47-3_8

requires teachers at schools and lecturers, especially in universities, to be skilled at creating a virtual learning atmosphere without face-to-face contact. Both teachers and students experienced several challenges as they transitioned to online learning [6–8].

Students need to comply with and carry out online learning activities and be able to use technology. The evolution of technology in recent decades has posed a growing challenge to the educational system. Access to and use of digital technologies can help close the educational gap between pupils from affluent and low-income families. Students, particularly those pursuing engineering jobs, are receptive to new technologies and eager to put them to use. Providing laboratories with high-performance equipment to stay up with the newest developments in their field of interest is costly, and budgetary constraints can cause these purchases to be postponed. Students' preparation in the engineering profession, on the other hand, necessitates participation in practical work. In addition to traditional laboratories where students learn about the equipment used in their topic of study, specialist software is increasingly being utilized to model and mimic its operation.

Therefore, there is a need for effective new understanding efforts from educators, especially in practicum courses. Online practicum lectures are looking for solutions so that teaching and learning activities can be maximized both formally and non-formally in order to obtain effective and quality learning outcomes. Then they are able to be active and think at least as well as offline or face-to-face learning in the laboratory. Online practicum learning poses obstacles, like students who cannot use practical tools physically but only in the form of pictures that are displayed through online learning. This is certainly a big challenge for practical courses. The main point of the practicum learning process is the activity in the laboratory, where students are trained to develop skills as an application of the knowledge that has been acquired in class.

The absence of a practicum learning process in a real laboratory requires alternative solutions so that the skills transfer process can still take place. This alternative form is the use of simulation software in a virtual laboratory. This method was chosen so that students still feel the offline practicum atmosphere and so that the learning process of higher-order thinking skills that are beneficial for character building, literacy strengthening, competency improvement, and curriculum enrichment continues. The goal of this study is to provide a review of virtual labs in electrical engineering education. The advantages of virtual labs, as well as how this learning strategy could be implemented in the field of electrical engineering education, are discussed.

2 Virtual Labs

Practical activities are the main learning medium in training student skills. This activity trains students to realize the theories in the book as well as to visualize the workings of the practical and theoretical guidebooks. This trains concentration and stimulates students' psychomotor and analytical abilities [9]. Laboratory activities strive to use a scientific approach that leads to training, debriefing, and improvement in three aspects, which include attitude, knowledge, and skills [10]. The traditional learning paradigm views laboratory activities as aiming to prove the truth of the information conveyed by the teacher when meeting face-to-face in class [11]. Traditional laboratory activities have

limitations. Students must be present in the laboratory to carry out laboratory activities. Students must do it step by step according to the practicum instructions that have been determined. The focus of activities is only on developing students' experimental abilities [12–14].

The virtual laboratory provides a series of laboratory equipment, algorithms, and other equipment to simulate activities in the laboratory. Along with technological developments and the need for students to interact in learning, virtual laboratories can contain materials, videos, images, and simulations so that students do not only understand abstract theory by means of virtual practicum [15]. In addition, the existence of a virtual laboratory makes it possible to simulate experiments from a physical laboratory, which is made for the purpose of giving instructions to students in using laboratory facilities that in operation produce results that are similar to those of a student's experience. Then, with strong support from virtual labs, the delivery of information in practical courses makes students more skilled in analysing problems that require critical thinking during learning. The ability to think critically as a measure of the ability that exists in humans in quality is able to know and reason about the criticality in the surrounding environment that is actively involved based on knowledge and is quick to respond [16]. Someone who is said to think critically will be able to adapt by understanding his own characteristics through several stages, starting from identifying the problems that are around him, understanding problems, analysing problems to be simpler, evaluating, and formulating them to problem-solving to be able to find measurable and effective solutions [17].

When compared to real-life practice, virtual labs make it easier for users to operate and reduce the risk of mishaps. Virtual labs also offer numerous benefits to aid in the learning process. Virtual labs not only require fewer resources than a real lab but also with no time constraints [18, 19]. Virtual labs also provide versatility in the teaching and learning process [20]. The virtual lab is presently a widely developed medium [21, 22], and its effectiveness as a tool for improving students' laboratory experience [23, 24], and they have been tested standing balanced with real labs [25–27]. In addition, virtual labs can also save money by reducing the costs of equipment, space, and practical laboratory maintenance staff [28, 29].

3 Method

This study of a systematic review of the literature was conducted and reported according to the recommendations of Preferred Reporting Items for Systematic Reviews and Meta-Analyses-PRISMA [30]. The articles obtained from relevant international journals from several conference proceedings were also examined. The articles reviewed are from the period 2020–2021, or a period of 2 years during the COVID-19 pandemic.

The steps in the systematic literature review method are as follows:

a. Identification
   The first step in this research is to identify the objectives. The main objective of this study was to investigate the use of virtual labs in electrical engineering education.
b. Screening
   The researcher conducts the process of selecting articles from Google Scholar databases. The keywords are "virtual labs," "electrical engineering education," and

"covid-19". The selection of articles considers the suitability of the themes and objectives that have been determined. After that, the articles that have been obtained are selected according to the theme and purpose of the review.

c. Eligibility
This step aims to explore information from articles that have gone through selection in the previous process by making a research matrix. This research matrix contains information relating to the title of the article, the theme of the research, keywords, and conclusions from the results of the study. Selected articles are then selected based on a range that is more detailed about the advantages and influences of the use of simulation software in the field of electrical engineering education.

d. Included
The final step is the process of combining data and facts found. Then the results are written in the form of articles and analysed according to the intended purpose.

4 Discussion

In the subject of electrical engineering education, virtual labs play an important role, particularly in practical learning. Not only understanding of the Outcome-Based Education (OBE) paradigm underlying engineering programs but also significant metacognitive and learning competency are required in engineering education settings during and beyond the COVID-19 pandemic [19]. Strategies, learning approaches, and practical instructions for using virtual laboratories can be provided online, in the cloud, on the web, or as videos [20–24].

The use of remote labs and AR/VR can be used to support practical learning in virtual labs because it can visualize models in 3-dimensional form and provides cognitive and pedagogical benefits for students as well as a cost-effective investment for higher education institutions [18, 25–29]. For example, the use of remote labs in practical learning for programmable logic controllers (PLC) can work well and is easy to use [31], the development of a VR-based application for teaching and training for condition-based maintenance in induction motors [32], virtual office development to process basic telecommunication engineering practical work [33], and the design of augmented reality-based learning media on the sensors and transducers course [34]. The advantages of using augmented reality in virtual labs are cost reduction in the purchase of materials, increased availability, practicality, risk control, increased performance, and student engagement [35]. Because of this, the developed virtual labs could be used in emergency situations like the COVID-19 pandemic [36] instead of traditional face-to-face lab education.

However, some students also did not like virtual labs because skills in using laboratory equipment were not achieved for their future. Therefore, the teaching team can also take a hybrid learning approach on campus for a short time, so that students still have lab experience, work with lab equipment and components, teamwork, and student interaction [37, 38]. Virtual laboratories can be established as companion training in technical specialties [39] and can be used to reduce the need for lab space infrastructure and create a safer lab work environment for students [40]. Virtual laboratories have risen to prominence in engineering education because they are low-cost, easy-to-maintain facilities that provide students with access anywhere, at any time. Modern graphical interfaces include

realistic representations of laboratories, allowing students to complete simulations faster and analyse the results more thoroughly [41].

When compared to real-life practice, virtual labs make it simple for students to engage in practical and diminish the risk of mishaps. Virtual labs also offer numerous benefits to aid in the learning process. Virtual labs not only require fewer resources than physical labs, but they also have no time constraints [42, 43] in the teaching and learning process is also provided [44]. The virtual lab is presently a widely developed medium [45, 46], and its effectiveness as a tool for improving students' laboratory experience [47, 48], and they have been tested standing balanced with real labs [49–51]. Furthermore, virtual labs can save money by lowering the costs of equipment, space, and practical laboratory maintenance personnel [52, 53].

5 Conclusion

In recent years, a number of studies have looked into the benefits and usefulness of virtual labs. The majority of the publications analyzed focus on students' advantages of virtual lab-based learning. Existing difficulties in the traditional laboratory learning atmosphere must be addressed through alternative methods in order to boost student motivation. Students will be more engaged if you use engaging learning tactics. Virtual labs will be extremely beneficial in improving studying in the discipline of electrical engineering, particularly in the area of practical learning. Virtual laboratories have a number of characteristics that can be tweaked to facilitate more effective and efficient learning, particularly in practical electrical engineering courses during or after the COVID-19 pandemic. The Virtual labs can accommodate practical courses with all of their constraints, such as equipment and components for practice in schools and colleges that aren't up to date. Virtual laboratories are also a good option for schools and colleges, especially if they have limited resources and infrastructure.

References

1. S.J..Daniel, Education and the COVID-19 pandemic, in: Prospects 49, 2020, pp. 91–96.
2. D. Koh, COVID-19 lockdowns throughout the world. Occupational Medicine, Oxford, England, 2020.
3. E. Onyema, C. Nwafor, F. Obafemi, S. Sen, F. Atonye, A. Sharma, and A. Alsayed, Impact of Coronavirus Pandemic on Education, in: Journal of Education and Practice, 11, 2020, pp. 108–121. https://doi.org/10.7176/JEP/11-13-12
4. J. Chiodini, Online learning in the time of COVID-19, in: Travel medicine and infectious disease, 34, 101669, 2020.
5. S. Dhawan, Online Learning: A Panacea in the Time of COVID-19 Crisis, in: Journal of Educational Technology Systems, 49(1), 2020, pp. 5-22.
6. M.F. Fox, A. Werth, J.R. Hoehn, and H.J. Lewandowski, Teaching labs during a pandemic: Lessons from Spring 2020 and an outlook for the future. arXiv preprint arXiv:2007.01271.
7. T. Angelico, Educational Inequality and the Pandemic in Australia: Time to Shift the Educational Paradigm, in: International Studies in Educational Administration (Commonwealth Council for Educational Administration & Management (CCEAM)), 48(1), 2020, pp. 46–53.

8. N. Mustafa, Impact of the 2019–20 coronavirus pandemic on education, in: International Journal of Health Preferences Research, 2020, pp. 1–12.
9. F. Bellotti, R. Berta, and A. De Gloria, Designing Effective Serious Games: Opportunities and Challenges for Research, in: International Journal of Emerging Technologies in Learning (IJET), 5(SI3), 2010, pp. 22–35.
10. C.J. Wenning, Experimental inquiry in introductory physics courses, in: J. Phys. Tchr. Educ. Online, 6(2), 2011, pp. 1–8.
11. S.M. Baladoh, A.F. Elgamal, and H.A. Abas, Virtual lab to develop achievement in electronic circuits for hearing-impaired students, in: Education and Information Technologies, 22(5), 2016, pp. 2071–2085.
12. A. Hofstein, and V.N. Lunetta, The laboratory in science education: Foundation for the twenty-first century, in: Science Education, 88(1), 2004, pp. 28–54.
13. C. Wieman, Comparative cognitive task analyses of experimental science and instructional laboratory courses, in: The Physics Teacher, 53(6), 2015, pp. 349-351.
14. B.R. Wilcox and H.J. Lewandowski, A summary of research-based assessment of students' beliefs about the nature of experimental physics, in: American Journal of Physics, 86(3), 2018, pp. 212-219.
15. M. Thees, S. Kapp, M.P. Strzys, F. Beil, P. Lukowicz, and J. Kuhn, Effects of augmented reality on learning and cognitive load in university physics laboratory courses, in: Computers in Human Behavior, 108, 106316, 2020.
16. J.D. Williams, How Science Works: Teaching and Learning in the Science Classroom, Continuum, London & NY, 2011.
17. J.Y.F. Lau, Metacognitive Education: Going beyond Critical Thinking, In: Davies M., Barnett R. (eds) The Palgrave Handbook of Critical Thinking in Higher Education, Palgrave Macmillan, New York, 2015.
18. A. Alvarez-Marin and J.A. Velazquez-Iturbide, Augmented Reality and Engineering Education: A Systematic Review, in: IEEE Transactions on Learning Technologies, 2022.
19. J. Qadir and A. Al-Fuqaha, A Student Primer on How to Thrive in Engineering Education during and beyond COVID-19, in: Education Sciences, 10 (9), 2020, p. 236.
20. T. Hristova, K. Gabrovska-Evstatieva, and B. Evstatiev, Prediction of engineering students' virtual lab understanding and implementation rates using SVM classification, in: Journal of e-Learning and Knowledge Society, 17 (1), 2021, pp. 62-71.
21. W.D. Kularatne, L.H.Dissawa, T.M. Ekanayake, and J.B. Ekanayake, Developing and delivering a remote experiment based on the experiential learning framework during COVID-19 pandemic. arXiv e-prints, arXiv-2107, 2021.
22. S. Asgari, J. Trajkovic, M. Rahmani, W. Zhang, R.C. Lo, A. Sciortino, An observational study of engineering online education during the COVID-19 pandemic, in: PLoS ONE 16(4): e0250041, 2021.
23. N. Slamnik-Kriještorac, R. Van den Langenbergh, T. Huybrechts, S.M. Gutierrez, M.C. Gil and J.M. Marquez-Barja, Cloud-based virtual labs vs. low-cost physical labs: what engineering students think, In 2021 IEEE Global Engineering Education Conference (EDUCON), 2021, pp. 637–644.
24. T.M. Nassef, A. Aboshosha, A. Haggag, A. and S. Nessim, An Efficient E-Learning Simulation Web-Based Tool for a Virtual Lab for Electronics Measurements, in: Int. J. Sci. Res. in Computer Science and Engineering, 8(5), 2020.
25. B. Stender, J. Paehr, and T.N. Jambor, Using AR/VR for Technical Subjects in Vocational Training–Of Substancial Benefit or Just Another Technical Gimmick?, In 2021 IEEE Global Engineering Education Conference (EDUCON), 2021, pp. 557-561.
26. M.A. Gunasekaran, T.D. Maddumapatabandi, and K.A.A. Gamage, Remote lab activities in a digital age: insights into current practices and future potentials, in: Journal of Education, Innovation, and Communication, 3(1), 2021, pp. 59-78.

27. M. Soliman, A. Pesyridis, D. Dalaymani-Zad, M. Gronfula, and M. Kourmpetis, The Application of Virtual Reality in Engineering Education, in: Applied Sciences, 11(6), 2021, p. 2879.
28. J. Solis-Lastra and B. Albertini, A Light Systematic Literature Review on Remote Laboratories for Engineering, 2021 IEEE Sciences and Humanities International Research Conference (SHIRCON), 2021, pp. 1-4.
29. B. Marks and J. Thomas, Adoption of virtual reality technology in higher education: An evaluation of five teaching semesters in a purpose-designed laboratory, in: Education and information technologies, 2021, pp. 1–19.
30. D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement, in: PLoS Med 6(6): e1000097. doi: https://doi.org/10.1371/journal.pmed1000097, 2009.
31. R.D. Purnomo, B. Mulyanti, and J. Kustija, 2021 PLC (Programmable Logic Controller) distance learning using remote lab system, In IOP Conference Series: Materials Science and Engineering, Vol. 1098, No. 4, p. 042014, IOP Publishing, 2021.
32. D. Checa, J.J. Saucedo-Dorantes, R.A. Osornio-Rios, J.A. Antonino-Daviu and A. Bustillo, Virtual Reality Training Application for the Condition-Based Maintenance of Induction Motors, in: Applied Sciences, 12(1), 2022, p. 414.
33. Z. Bonok, B.P. Asmara, and S. Abdussamad, An implementation of virtual office information system services in basic telecommunication technique practices, In IOP Conference Series: Materials Science and Engineering, Vol. 1098, No. 4, p. 042052), IOP Publishing, 2021.
34. D. Hariyanto, T. Triasih, M.S. Wati, and G.K. Kassymova, The Design of Sensor and Transducer Learning Media based on Augmented Reality, In Journal of Physics: Conference Series, Vol. 2111, No. 1, p. 012043, IOP Publishing, 2021.
35. F. Gutiérrez, C. de Armas, G. Bressan, R. Tori, and S. Kofuji, Augmented Reality for Distance Education: A Systematic Literature Review, In Proceedings of ICERI2021 Conference, Vol. 8, p. 9th, 2021.
36. B. Evstatiev, K. Gabrovska-Evstatieva, and D. Trifonov, A Realistic Virtual Lab for Investigation of Single-Phase Transformers, 2021 17th Conference on Electrical Machines, Drives and Power Systems (ELMA), 2021, pp. 1–4.
37. J.P Devaji, P.V. Achari, S.B. Hiremath, S.G. Revankar, N.C. Iyer, and R.V. Hangal, A Hybrid Model for the Undergraduate laboratory Course in Analog Electronics amid the COVID-19 Pandemic Challenges, 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), 2021, pp. 291–296.
38. Jayawardena, A., Kahandawa, G., & Piyathilaka, L. (2021). Delivery of online electronics and mechatronics labs during lockdowns. In IECON 2021–47th Annual Conference of the IEEE Industrial Electronics Society (pp. 1–6). IEEE.
39. Evstatiev, BI, & Hristova, TV (2020). Adaptation of Electrical Engineering Education to the COVID-19 Situation: Method and Results. In 2020 IEEE 26th International Symposium for Design and Technology in Electronic Packaging (SIITME) (p. 304 -308). IEEE..
40. Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M., & Kourmpetis, M. (2021). The Application of Virtual Reality in Engineering Education. Applied Sciences, 11(6), 2879.
41. Sarac, V. J., Minovski, D. I., & Stefanov, G. G. (2020). Virtual Laboratories-an Innovative Concept in Teaching of Electrical Engineering. In 2020 24th International Conference on Information Technology (IT) (pp. 1–4). IEEE
42. Gibbons, N. J., Evans, C., Payne, A., Shah, K., & Griffin, D. K. (2004). Computer simulations improve university instructional laboratories. Cell Biology Education, 3(4), 263-269.
43. N. Mikhaylov and D. Chernov, From virtual lab to virtual development lab. IFAC Proceedings Volumes, 45(11), 2012, pp. 177-182.
44. S. Flint and T. Stewart, Food microbiology—design and testing of a virtual laboratory exercise, in: Journal of Food Science Education, 9(4), 2010, pp. 84-89.

45. L. de la Torre, R. Heradio, C.A. Jara, J. Sanchez, S. Dormido, F. Torres, and F.A. Candelas, Providing collaborative support to virtual and remote laboratories, in: IEEE transactions on learning technologies, 6(4), 2013, pp. 312-323.
46. L. de la Torre, J.P. Sánchez, and S. Dormido, What remote labs can do for you, Physics Today, 69(4), 2016, pp. 48-53.
47. S. Gautam, Z. Qin, and K.C. Loh, Enhancing laboratory experience through e-lessons, in: Education for Chemical Engineers, 15, 2016, pp. 19–22.
48. L. Hawkins and A.J. Phelps, Virtual laboratory vs. traditional laboratory: which is more effective for teaching electrochemistry?, in: Chemistry Education Research and Practice, 14(4), 2013, pp. 516–523.
49. L.M. Triona and D. Klahr, Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments, in: Cognition and Instruction, 21(2), 2003, pp. 149-173.
50. Z.C. Zacharia, G. Olympiou, and M. Papaevripidou, Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature, in: Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 45(9), 2008, pp. 1021-1035.
51. J.R. Brinson, Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research, in: Computers & Education, 87, 2015, pp. 218–237.
52. M.E. Ahmed and S. Hasegawa, An instructional design model and criteria for designing and developing online virtual labs, in: International Journal of Digital Information and Wireless Communications (IJDIWC), 4(3), 2014, pp. 355-371.
53. C. Tüysüz, The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry, in: International Online Journal of Educational Sciences, 2(1) 2010.