A Scoping Review of Online Laboratory Learning Outcomes in Engineering Education Research

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SCOPING REVIEW OF ONLINE LABORATORIES LEARNING OUTCOMES IN ENGINEERING EDUCATION RESEARCH

Abstract

This scoping review reports an ongoing review that synthesizes existing online laboratories research in engineering education. The paper identifies the learning outcomes that are assessed in empirical studies of online laboratories, the measurement tools that are used to assess these outcomes, and the adequacy of these tools. The review was based on studies selected after an extensive search of academic databases using relevant search terms and strategies. The articles retrieved were filtered using inclusion and exclusion criteria that helped us identify peer-reviewed articles, published on online laboratory learning outcomes within the last two decades (2002 - 2022). The selected articles were read and coded based on the KIPPAS (Knowledge and Understanding, Inquiry Skills, Practical Skills, Perception, Analytical Skills, Social and Scientific Communication) framework. The findings from this review suggest there is a need for more research into students' practical, inquiry, and analytical learning outcomes. This study also identifies current practices and identifies gaps in the existing literature. The implication of the findings for further research and practice were also discussed.

Introduction

Laboratory education is an important feature of the science curriculum at all levels of education [1]. Experiments are essential to science learning because they are the avenue through which students experience, demonstrate, or practice the theories they encounter in scientific disciplines like Chemistry, Physics, Engineering, and Medicine amongst others. Preparing students to practice engineering is the overall goal of engineering education and engineering laboratories are germane to fulfilling this educational goal [2]. For example, engineering educational laboratories introduce learners to engineering to use these tools efficiently and effectively. While learners gain a lot of theoretical knowledge from regular classroom instruction, they gain a deeper appreciation for scientific theories and abstract engineering concepts and acquire practical experiential knowledge through engineering laboratory instructions and activities.

Traditionally, engineering laboratories exist in and are confined to physical spaces and hands-on equipment. Majorly, physical laboratories have limited staff and equipment to support students' needs and can only be available by time allotment for a limited time. This limitation makes them less scalable to support many students. However, advances in computing technologies have made it possible to host and support alternative forms of laboratory facilities and experiences that defy the confines of space and time [3]. Such alternative laboratory platforms have included remote labs, virtual labs, and online labs, amongst others. Tuttas and Wagner [4] distinguished between online labs and virtual labs. They propose that online laboratories provide remote access to laboratory equipment over the internet while virtual laboratories simulate physical engineering equipment. From a broader perspective, De Jong, et al. [5] defined online laboratories as science laboratories that are offered through computer technology. This paper uses online labs as an umbrella term for alternative forms of laboratory (remote lab, virtual lab) other than the physical laboratory. The most common groups of online laboratories are remote labs, virtual labs, or hybrid labs [6] Remote labs allow remote access to physical equipment, virtual labs include software simulations of physical labs that can be accessed via a computer device, and hybrid labs are a combination of both virtual and remote labs.

Educational uses of Alternative laboratory forms

The use of online laboratories enhances students' laboratory educational experience. For example, they may be used to facilitate pre-lab activities that increase students' contact time with laboratory activities – thus giving them multiple exposures to laboratory curricular contents. Abdulwahed and Nagy [7] examined the effect of offering pre-lab activities through blended laboratory (virtual and physical) mode on knowledge comprehension and procedural skill development in learners. They reported that students learned lab contents better when virtual labs were used as a pre-lab preparatory exercise for a physical laboratory activity. Similarly, Vrellis, et al. [8] conducted a study to assess differences in learning outcomes for learners who used physical activity and a virtual simulation to study light reflection. They measured learning outcomes using a questionnaire focused on basic concepts of light reflection using trigonometry and observed similar learning outcomes in learners from both laboratory types. Makransky, et al. [9] also reported that virtual simulations (as a substitute for physical demonstrations) were effective in teaching key laboratory skills. These studies reveal the adoption of online laboratories and their impact on a variety of learning objectives.

Prior Work and related reviews

In an earlier related study, Ma and Nickerson [10] conducted a comparative review of different forms of laboratories, where they observed an emphasis on; conceptual understanding, social, professional, and design skills in the implementation of physical laboratories and a major focus on conceptual understanding and professional skills in the implementation of remote and simulated (online) labs. They discussed a probable cause for the continued debate on one form of laboratory type being more effective than the other; the effectiveness of different laboratory types is often measured relative to the objectives of the lab type. This highlights a need to evaluate the literature on varied laboratory implementation relative to a standard framework that serves to objectively measure their effectiveness in fostering learning outcomes. Brinson [11] expanding on these findings conducted a similar review using a framework derived from the National Research Council's goals of laboratory experience and influenced by the National Science Teachers Association's position statement on laboratory roles in science education to categorize and evaluate recent literature (2005-2015) on traditional (physical) laboratories and non-traditional (virtual and remote) laboratories. In tandem with Ma and Nickerson [10], he observed similar learning outcomes fulfilled in both forms of laboratories with the degree of achievement being dependent on the outcome category measured; studies with higher achievement in the non-traditional laboratories emphasized content knowledge and understanding while studies with higher achievement in traditional laboratories emphasized qualitative data on instructor and student perceptions. Our scoping review study builds on these reviews, examining and categorizing the learning outcomes that are investigated in online lab research in engineering education.

Study Scope

A growing number of studies in engineering have examined the use of alternative labs (such as remote and online labs) in the last decade to foster different educational and learning outcomes. As this research literature increases, there is an increasing need to synthesize this mounting body of studies to provide an overview that informs researchers and instructors about the different forms of learning outcomes that have been investigated in online engineering laboratory research.

To facilitate systematic categorization of learning outcomes in laboratory research, our study will draw on the framework of learning outcomes developed by Brinson [11] in a recent review study. The Knowledge and understanding, Inquiry skills, Practical skills, Perception, Analytical skills, Social and scientific communication (KIPPAS) model proposed by Brinson provide a multi-dimensional framework for categorizing learning outcomes, especially in laboratory environments. Drawing on this framework, we intend to identify the breadth of learning outcomes in the implementation of online laboratory studies. This scoping review could inform instructors about the different kinds of educational learning outcomes that can be supported using online laboratories curriculum. This review could also inform the engineering education research community about issues in the assessment and evaluation of learning outcomes in online laboratory research. We also hope to identify contextual factors that are associated with facilitating these outcomes and existing gaps in the online lab literature on these learning outcomes. Our review study is guided by the following research questions:

(1) What learning outcomes are typically targeted in engineering education online laboratories in higher education?

(2) What assessment tools are most frequently used in engineering education online laboratories to assess the achievement of intended learning outcomes?

Methods

An exhaustive literature search was conducted in academic databases using relevant search terms and strategies to identify suitable studies for this review. A literature search of the academic databases was performed by using the advanced search features of the University of Georgia (UGA) Library search facility. The following Boolean operations and search terms were combined: "(online OR virtual OR augmented reality OR mixed reality OR hands-on OR simulated OR simulation OR physical OR remote OR Web) AND (lab OR laboratory* OR experiment*) AND learning AND (objective OR objectives OR outcome OR outcomes)".

The initial search returned 619 articles, but after filtering by the following relevant databases: ERIC, Social Sciences Citation Index, Science Citation Index Expanded, APA PsycInfo, Education Research Complete, Academic Search Complete, IEEE Xplore Digital Library, Directory of Open Access Journals, MEDLINE with Full Text, ScienceDirect, Science & Technology Collection, and ACM Full-Text Collection resulted in 325 articles. The articles were screened according to the selection criteria for a first screening of the articles shown in Figure 1 below, 62 duplicates were removed resulting in 212 articles. The 212 articles were exported to endnote software for further examination, based on the criteria in the second screening of the articles shown in Figure 1 below. Finally, 21 articles that passed all the literature evaluation criteria were subjected to full-text review and coding (See Table A1 in Appendix for the coding sheet).

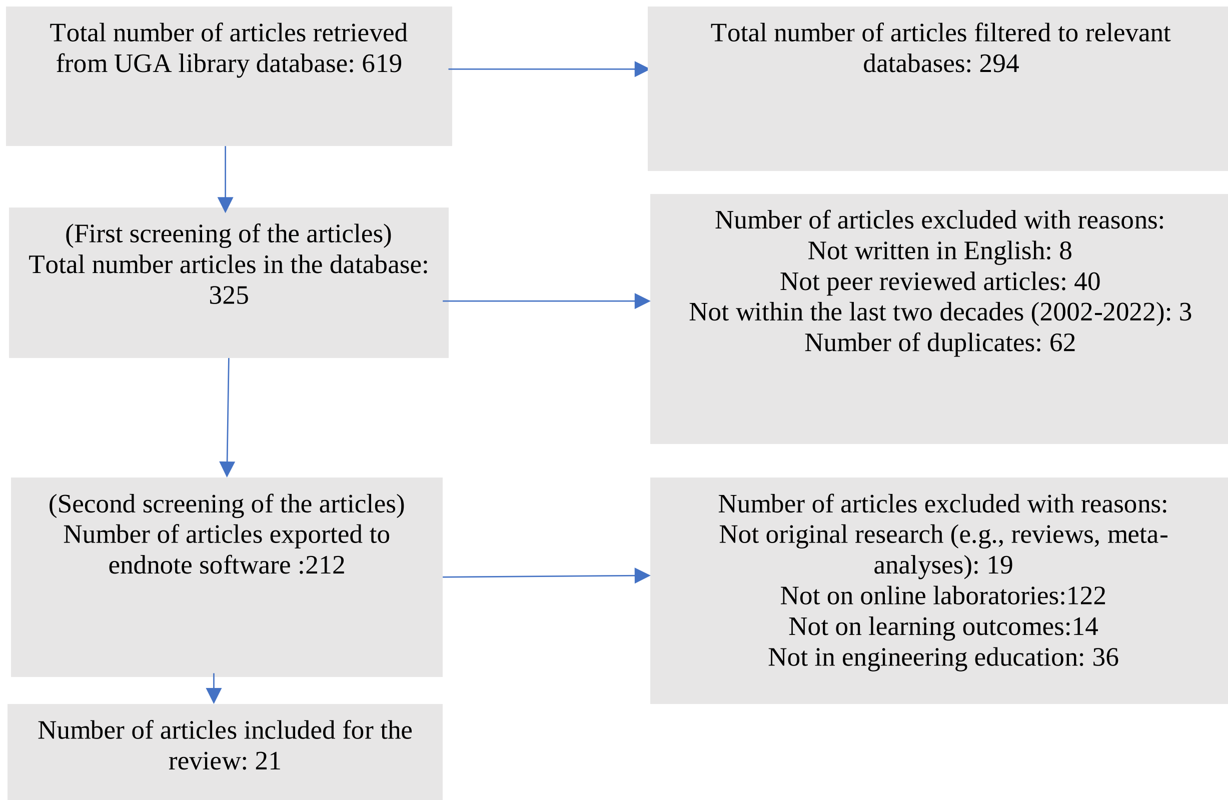

Figure 1: Flowchart for study the selection process

Results and Discussion

The selected articles were read and coded based on the KIPPAS (explained in Table 1 below) framework to identify outcome measures examined in prior studies. As part of our review efforts, we also noted the types of online laboratories that were discussed in the papers. The different online laboratories used in the literature include VISIR [12], OPTILAB [13], RT-UTM [14], CT-Vlab and ET-Vlab [15].

Table 1: The KIPPAS categories of intended outcomes for laboratory learning [11]

Learning outcome	Definition	Laboratory goals
Knowledge & Understanding	The degree to which students model theoretical concepts and confirm, apply, visualize, and/or solve problems related to important lecture content	Enhancing mastery of subject matter
Inquiry Skills	The degree to which students make observations, create and test hypotheses, generate experimental designs, and/or acquire an epistemology of science	Developing scientific reasoning, understanding the nature of science
Practical Skills	The degree to which students can properly use scientific equipment, technology, and instrumentation follow technical and professional protocols, and/or demonstrate proficiency in physical laboratory techniques, procedures, and measurements	Developing practical skills
Perception	The degree to which students engage in and express interest, appreciation, and/or desire for science and learning.	Cultivating interest in science and interest in learning science
Analytical Skills	The degree to which students' critique, predict, infer, interpret, integrate, and recognize patterns in and experimental data, and use this to generate models of understanding.	Developing scientific reasoning. Understanding the complexity ambiguity of empirical work
Social & Scientific abilities Communication	The degree to which students can collaborate, summarizes and present experimental findings, prepare scientific reports, and graph and display data	Developing teamwork

By examining the articles, the authors, year, outcomes measure and the evaluation instrument used to evaluate the learning outcomes, the findings of articles surveyed are further discussed below:

Learning Outcomes

The learning outcomes that were assessed by the literature varied across the study. As shown in Figure 2 below, the most prominent of the learning outcomes assessed was **knowledge and understanding** (N=17, 32.1 %). Most of the papers discussing knowledge and understanding as the learning outcome are connected to the electrical engineering field [12, 15-19]. Other engineering fields that could be identified by the literature review include control engineering [20], biomedical engineering [13], computer engineering [17], mechanical engineering [14, 21-23] environmental engineering [21, 24], civil/water engineering [25], and industrial engineering [26]. Summarizing the found publications, we can say that these studies reveal that online and virtual laboratories can improve students' understanding of abstract concepts across various engineering disciplines.

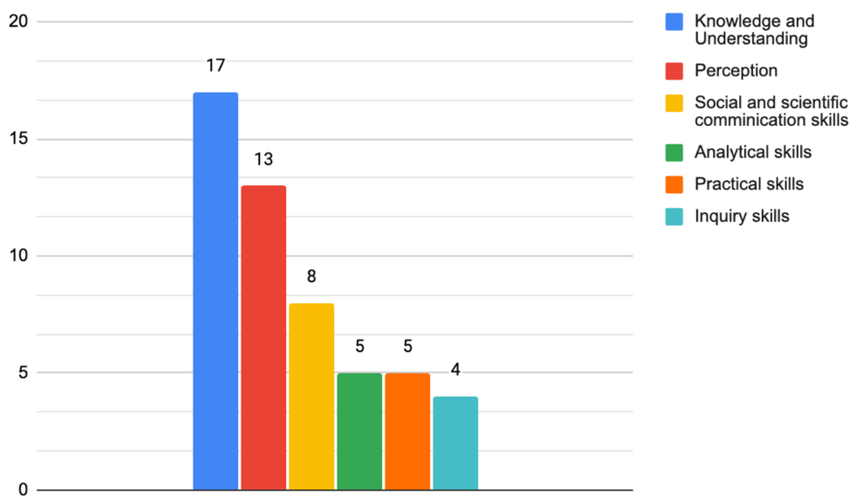

Figure 2: The distribution of the learning outcomes targeted in engineering education online laboratories literature.

In total, we identified N=13 studies that covered **perception** as a learning outcome [14, 15, 18-23, 26-29]. The types of students' perceptions as a learning outcome found in the literature cover motivation [27, 29], sense of immersion [18], enjoyment [28], the richness of feedback received [21], spatial ability [15], self-regulation [30] and performance [19]. Looking at the engineering fields that discuss perception as a learning outcome are mechanical/mechanical engineering [14, 21-23], electrical engineering [15, 18, 19], industrial engineering [26], and other STEM fields such as biotechnology/food technology [30], general, no further specified engineering [27, 29] and general sciences [15, 28]. Additionally, the literature also shows that the students have a generally positive perspective on the use of online and virtual laboratories.

Other learning outcomes such as **social and scientific communication skills** are also represented across diverse engineering fields, including control engineering [20], mechanical/manufacturing engineering [22], civil/water engineering [25], and industrial engineering [26]. In total, N= 8 the examined studies discussed social and scientific communication skills [15, 20, 22, 25-27]. The learning outcomes of **analytical skills** and **practical skills** were assessed in the fields of control engineering [20], electrical engineering [19], and biotechnology/food technology [30, 31]. In total, N=5 of the studies examined analytical skills [15, 20, 26, 30, 31], and N=5 of the studies referenced practical skills [15, 19-21, 29]. Students' **inquiry skills** (N=4) as a learning outcome were assessed across the fields of civil/water engineering [25], industrial engineering [26], science and technology [15], and general, not further specified engineering [27]. Although the literature references the students' analytical, practical, and inquiry skills, not many of the found publications discussed those learning outcomes. This is specifically surprising as these skills are vital for engineering graduates to transfer the conceptual knowledge they develop in the classroom to real-world engineering practice.

Assessments Instruments

The distribution of discussed evaluation instruments to assess the respective learning outcomes in the literature is shown in Figure 3 below. Fourteen (14) of the articles employed the **questionnaires** as an assessment or evaluation tool. Out of the 14 articles, four (4) did not specify the questions posed to the students [15, 16, 24, 30]. The questionnaires include closed-ended questions [30] multiple-choice questions [16], and open-ended questions [19, 21, 28, 30] that allow participants to share their thoughts and feelings in the online laboratories' environment. Furthermore, N=5 of the studies used **practical laboratory activities** [14-16, 20, 21], N=2 used **laboratory reports and assignments** [14, 22], and finally, N=2 of the studies utilized **interviews** [24, 25] and **case study [12, 23]** as their respective assessment tools.

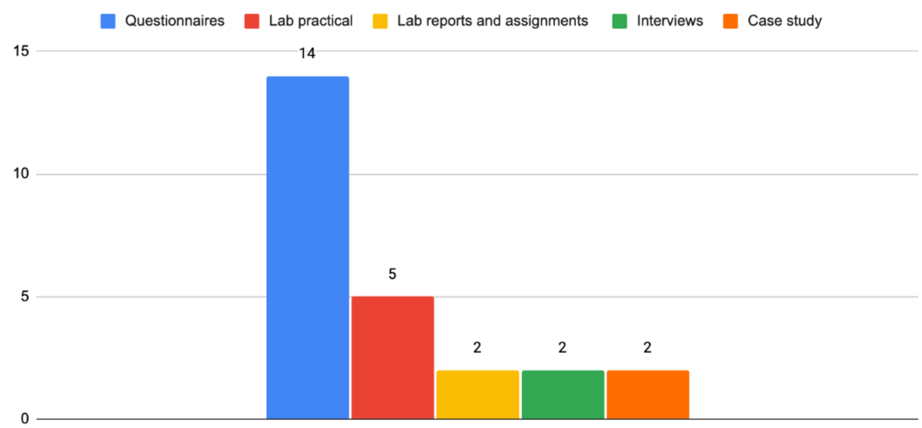

Figure 3: The distribution of the evaluation instruments used to assess the learning outcomes.

Though **questionnaires** are used across multiple studies to assess all the KIPPAS learning outcomes, it is not clear how effective or how comprehensive this mode of assessment can be to reliably assess the learning outcome's achievement. **Practical laboratory activities** are used to evaluate students' knowledge and understanding, perception of online laboratories, and the gained practical skills [14-16, 21]. **Lab reports and assignments** were used to assess knowledge and understanding, perception, social and scientific communication [14, 22]. **Interviews** were used to evaluate knowledge and understanding, inquiry skills, and social & scientific communication [24, 25]. For **case study, the** surveyed literature was used to assess knowledge and understanding, perception, and social communication [12, 23].

Implication of the study

The scoping review shows that most online lab studies focus on the use of online labs to facilitate knowledge and understanding. This limits our understanding of how engineering labs can be used to facilitate many of the learning outcomes outlined in Brinson's framework of learning outcomes. Future studies may explore how online labs can be used to promote other learning outcomes that the KIPPAS suggests. Also, future studies could conduct the reliability of the identified assessment tools and other assessment tools such as model design and construction, mind and concept mapping, and the development of mini projects could be incorporated into the assessment of the learning outcomes. This work is specifically relevant, as one of the major objectives of the educational process is for students to acquire theoretical and conceptual knowledge [32]. However, the educational imperative for engineering education goes beyond this objective. Developing technical expertise also requires developing practical skills through hands-on experiences. Instructional labs in engineering help translate conceptual knowledge to practical experiences that reflect real-world scenarios, which engineering graduates will encounter during their engineering careers. However, gaps often exist between the skill sets that engineering employers expect of engineering graduates and the breadth of the practical skill they acquire in school [33]. Engineering graduates need to have acquired inquiry, practical, and analytical skills that are essential to being ready for a career in engineering. To bring engineering students up to speed, many employers spend additional costs to retrain engineering graduates on some of the skills that a well-rounded and robust practical laboratory curriculum might have provided. There is still work remaining to connect the use of online laboratories with robust and well-rounded student preparation for the workforce. The presented study shows that so far online labs are not used to their full potential and that they are not equally used with respect to a diverse set of learning outcomes as displayed by the KIPPAS framework.

Limitations of the Study

The literature search used for this scoping review is limited to the databases referenced above. Using those databases may have left out some literature from online laboratories in the field of engineering education. We would suggest future research should use a more robust literature search strategy; this could involve using more databases and different search terms. Further research such as systematic reviews and meta-analysis will be necessary to critically evaluate the findings of the literature on online laboratories in engineering education.

Conclusion

This study presents the findings of a scoping review on the evaluation and assessment of learning outcomes in online laboratory engineering education. The purpose of the scoping review was to identify the different kinds of learning outcomes that have been explored in these online labs using the KIPPAS framework. We observed that most studies (33%) focused on outcomes associated with knowledge and understanding. In addition, 25% of the represented studies reported centered on perception-based outcomes. In contrast, very few studies examined learning outcomes based on inquiry, practical, or analytical-based outcomes. A lack of evaluation of these outcomes may hinder our ability to understand how online labs can be used to support these outcomes. As such future engineering online laboratories research should consider doing more to explore these outcomes. Future studies may also explore these outcomes using case-based and qualitative research methodologies.

References

[1] N. Reid and I. Shah, "The role of laboratory work in university chemistry," *Chemistry Education Research and Practice,* vol. 8, no. 2, pp. 172-185, 2007.

[2] L. D. Feisel and A. J. Rosa, "The Role of the Laboratory in Undergraduate Engineering Education," *Journal of Engineering Education,* vol. 94, no. 1, pp. 121-130, 2005, doi: https://doi.org/10.1002/j.2168-9830.2005.tb00833.x.

[3] V. Potkonjak *et al.*, "Virtual laboratories for education in science, technology, and engineering: A review," *Computers & Education,* vol. 95, pp. 309-327, 2016/04/01/ 2016, doi: https://doi.org/10.1016/j.compedu.2016.02.002.

[4] J. Tuttas and B. Wagner, "Distributed online laboratories," in *International Conference on Engineering Education*, 2001, pp. 6-10.

[5] T. De Jong, S. Sotiriou, and D. Gillet, "Innovations in STEM education: the Go-Lab federation of online labs," *Smart Learning Environments,* vol. 1, no. 1, pp. 1-16, 2014.

[6] M. Hernández-de-Menéndez, A. Vallejo Guevara, and R. Morales-Menendez, "Virtual reality laboratories: a review of experiences," *International Journal on Interactive Design and Manufacturing (IJIDeM),* vol. 13, no. 3, pp. 947-966, 2019/09/01 2019, doi: 10.1007/s12008-019-00558-7.

[7] M. Abdulwahed and Z. K. Nagy, "Applying Kolb's Experiential Learning Cycle for Laboratory Education," *Journal of Engineering Education*, vol. 98, no. 3, pp. 283-294, 2009, doi: https://doi.org/10.1002/j.2168-9830.2009.tb01025.x.

[8] I. Vrellis, N. Avouris, and T. A. Mikropoulos, "Learning Outcome, Presence and Satisfaction from a Science Activity in Second Life," *Australasian Journal of Educational Technology*, vol. 32, no. 1, pp. 59-77, 01/01/ 2016. [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=eric&AN=EJ1094754&site=eds-live&custid=uga1http://ajet.org.au/index.php/AJET/article/view/2164.

[9] G. Makransky, M. W. Thisgaard, and H. Gadegaard, "Virtual Simulations as Preparation for Lab Exercises: Assessing Learning of Key Laboratory Skills in Microbiology and Improvement of Essential Non-Cognitive Skills," *PLOS ONE,* vol. 11, no. 6, p. e0155895, 2016, doi: 10.1371/journal.pone.0155895.

[10] J. Ma and J. V. Nickerson, "Hands-on, simulated, and remote laboratories: A comparative literature review," *ACM Computing Surveys (CSUR),* vol. 38, no. 3, pp. 7-es, 2006.

[11] J. R. Brinson, "Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research," *Computers & Education,* Article vol. 87, pp. 218-237, 09/01/September 2015 2015, doi: 10.1016/j.compedu.2015.07.003.

[12] M. A. Marques *et al.*, "How Remote Labs Impact on Course Outcomes: Various Practices Using VISIR," *IEEE Transactions on Education,* vol. 57, no. 3, pp. 151-159, 2014, doi: 10.1109/TE.2013.2284156.

[13] J. Gamo, "Assessing a virtual laboratory in optics as a complement to on-site teaching," *IEEE Transactions on Education,* vol. 62, no. 2, pp. 119-126, 2018.

[14] K. Achuthan, D. Raghavan, B. Shankar, S. P. Francis, and V. K. Kolil, "Impact of remote experimentation, interactivity and platform effectiveness on laboratory learning outcomes," *International Journal of Educational Technology in Higher Education,* vol. 18, no. 1, pp. 1-24, 2021.

[15] S. Sriadhi, H. Sitompul, R. Restu, S. Khaerudin, and W. A. Wan Yahaya, "Virtual-laboratory based learning to improve students' basic engineering competencies based on their spatial abilities," *Computer Applications in Engineering Education*, vol. 30, no. 6, pp. 1857-1871, 2022.
[16] J. Garcia-Zubia *et al.*, "Empirical Analysis of the Use of the VISIR Remote Lab in Teaching Analog Electronics," *IEEE Transactions on Education*, vol. 60, no. 2, pp. 149-156, 2017, doi: 10.1109/TE.2016.2608790.
[17] G. Geaney and T. O'Mahony, "Design and evaluation of a remote PLC laboratory," *International Journal of Electrical Engineering Education*, vol. 53, no. 3, pp. 212-223, 2016.
[18] I. Gustavsson *et al.*, "On objectives of instructional laboratories, individual assessment, and use of collaborative remote laboratories," *IEEE Transactions on learning technologies*, vol. 2, no. 4, pp. 263-274, 2009.
[19] C. Viegas *et al.*, "Impact of a remote lab on teaching practices and student learning," *Computers & Education*, vol. 126, pp. 201-216, 2018.
[20] M. Stefanovic, D. Tadic, S. Nestic, and A. Djordjevic, "An assessment of distance learning laboratory objectives for control engineering education," *Computer Applications in Engineering Education*, vol. 23, no. 2, pp. 191-202, 2015.
[21] E. Lindsay and M. Good, "The impact of audiovisual feedback on the learning outcomes of a remote and virtual laboratory class," *IEEE Transactions on Education*, vol. 52, no. 4, pp. 491-502, 2009.
[22] E. D. Lindsay and M. C. Good, "Effects of laboratory access modes upon learning outcomes," *IEEE transactions on education*, vol. 48, no. 4, pp. 619-631, 2005.
[23] E. D. Lindsay and P. C. Wankat, "Going the way of the slide rule: Can remote laboratories fungibly replace the in-person experience?," *International Journal of Engineering Education*, vol. 28, no. 1, pp. 192-201, 2012.
[24] L. B. Cole, J. Quinn, A. Akturk, and B. Johnson, "Promoting green building literacy through online laboratory experiences," *International Journal of Sustainability in Higher Education*, vol. 20, no. 2, pp. 264-287, 2019.
[25] P. Gibbings, "Qualitatively different ways students experience remote access laboratories," *International Journal of Engineering Education*, vol. 30, no. 5, pp. 1120-1129, 2014.
[26] M. Stefanovic, "The objectives, architectures and effects of distance learning laboratories for industrial engineering education," *Computers & Education*, vol. 69, pp. 250-262, 2013.
[27] J. E. Corter, S. K. Esche, C. Chassapis, J. Ma, and J. V. Nickerson, "Process and learning outcomes from remotely-operated, simulated, and hands-on student laboratories," *Computers & Education*, Article vol. 57, no. 3, pp. 2054-2067, 01/01/January 2011 2011, doi: 10.1016/j.compedu.2011.04.009.
[28] J. M. Harley, E. G. Poitras, A. Jarrell, M. C. Duffy, and S. P. Lajoie, "Comparing virtual and location-based augmented reality mobile learning: emotions and learning outcomes," *Educational Technology Research and Development*, vol. 64, pp. 359-388, 2016.
[29] G. Makransky, S. Borre-Gude, and R. E. Mayer, "Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments," *Journal of Computer Assisted Learning*, vol. 35, no. 6, pp. 691-707, 2019.
[30] S. Verstege, H. J. Pijeira-Díaz, O. Noroozi, H. Biemans, and J. Diederen, "Relations between students' perceived levels of self-regulation and their corresponding learning

behavior and outcomes in a virtual experiment environment," *Computers in Human Behavior,* vol. 100, pp. 325-334, 2019.

[31] M. Seifan, N. Robertson, and A. Berenjian, "Use of virtual learning to increase key laboratory skills and essential non-cognitive characteristics," *Education for Chemical Engineers,* vol. 33, pp. 66-75, 2020.

[32] D. R. Garrison, T. Anderson, and W. Archer, "Critical inquiry in a text-based environment: Computer conferencing in higher education," *The internet and higher education,* vol. 2, no. 2-3, pp. 87-105, 1999.

[33] K. E. Joyce and N. Cartwright, "Bridging the gap between research and practice: Predicting what will work locally," *American Educational Research Journal,* vol. 57, no. 3, pp. 1045-1082, 2020.

Appendix

Table A1: Coding Sheet for the Literatures

S/N	Author(s)	Year	Evaluation Instrument
1	S. Sriadhi, Harun Sitompul, R. Restu, S. Khaerudin, Wan A. J. Wan Yahaya	2022	Questionnaire
2	Miladin Stefanovic, Danijela Tadic, Snezana Nestic, Aleksandar Djordjevic	2013	Lab Practical
3	Javier Gamo	2019	Questionnaire
4	Jason M. Harley, Eric G. Poitras, Amanda Jarrell, Melissa C. Duffy, Susanne P. Lajoie	2016	Open questions, questionnaire
5	Gerard Geaney and Tom O'Mahony	2015	Survey/Questionnaire
6	Euan D. Lindsay and Malcolm C. Good	2005	Lab report, Assignment
7	Javier Garcia-Zubia, Jordi Cuadros, Susana Romero,Unai Hernandez-Jayo, Pablo Orduña, Mariluz Guenaga,Lucinio Gonzalez-Sabate,and Ingvar Gustavsson.	2016	Lab Practical, multiple choice questions, questionnaire
8	Euan D. Lindsay, Philip C. Wankat	2012	Case study
9	Maria A. Marques, Maria Clara Viegas, Maria Cristina Costa-Lobo, André V. Fidalgo, Gustavo R. Alves,João S. Rocha, and Ingvar Gustavsson	2022	Case study
10	Clara Viegas, Ana Pavani, Natércia Lima, Arcelina Marques, Isabel Pozzo,Elsa Dobboletta, Vanessa Atencia, Daniel Barreto, Felipe Calliari, André Fidalgo,Delberis Lima, Guilherme Temporão, Gustavo Alves	2018	Open questions, Questionnaire
11	Krishnashree Achuthan, Dhananjay Raghavan, Balakrishnan Shankar, Saneesh P. Francis and Vysakh Kani Kolil	2021	Lab Practical, assignments
12	Guido Makransky, Stefan Borre-Gude, Richard E. Mayer	2019	Questionnaire
13	Ingvar Gustavsson, Kristian Nilsson, Johan Zackrisson,Javier Garcia-Zubia, Unai Hernandez-	2009	Questionnaire

	Jayo, Andrew Nafalski, Zorica Nedic, Ö zdemir Gö l, Jan Machotka,Mats I. Pettersson, Thomas Lagö, and Lars Hå kansson		
14	James E. Corter,*, Sven K. Esche, Constantin Chassapis, Jing Ma, Jeffrey V. Nickerson	2011	Survey
15	Laura Brianna Cole, Jerod Quinn, Aysegul Akturk, Briana Johnson	2019	Surveys, Interviews
16	Peter Gibbings	2014	Interviews
17	Sjors Verstege, Héctor J. Pijeira-Díaz, Omid Noroozi, Harm Biemans, Julia Diederen	2019	Closed questions, open questions
18	Miladin Stefanovic	2013	Surveys
19	Euan Lindsay and Malcolm Good	2009	Lab Practical, Open questions
20	Mostafa Seifan, Nigel Robertson, Aydin Berenjian	2020	Surveys
21	Sriadhi Sriadhi, Abdul Hamid, Restu Restu	2022	Lab Practical
S/N	**Outcome measure**	**Field**	
1	Knowledge and Understanding; Perception	Electrical Engineering Education study program and Information and Computer Technology Education	
2	Knowledge & Understanding, Practical Skills, Analytical Skills, Social & Scientific Communication	Control Engineering Education	
3	Knowledge and Understanding	Biomedical Engineering	
4	Knowledge and Understanding, Perception, Social Communication	Science or Engineering	
5	Knowledge and Understanding	Electrical/Computer Engineering	
6	Knowledge and Understanding, Perception, Social Communication	Mechanical and Manufacturing Engineering	
7	Knowledge and Understanding; Perception	Electrical Engineering	
8	Knowledge and Understanding, Perception, Social Communication	Mechanical Engineering	

9	Knowledge and Understanding	Electrical Engineering Education	
10	Practical skills, Perception	Electrical Engineering	
11	Knowledge and Understanding, Perception,	Mechanical Engineering	
12	Practical skills, Perception	Engineering	
13	Perception	Electrical Engineering	
14	Knowledge & Understanding, Inquiry Skills, Perception, Social & Scientific Communication,	Engineering	
15	Knowledge and Understanding	Environmental Engineering	
16	Knowledge & Understanding, Inquiry Skills, Social & Scientific Communication,	Civil/Water Engineering	
17	Analytical skills, Perception	Biotechnology and Food technology	
18	Knowledge & Understanding, Inquiry Skills, Perception, Analytical Skills, Social & Scientific Communication	Industrial Engineering	
19	Knowledge & Understanding, Practical Skills, Perception	Mechanical, Mechatronic, and Environmental Engineering	
20	Knowledge and Understanding, Analytical Skills	Biotechnology	
21	Knowledge & Understanding, Inquiry Skills, Practical Skills, Perception, Analytical Skills, Social & Scientific Communication	Science and Technology	