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VIRTUAL LABS IN ENGINEERING EDUCATION: ENHANCING LEARNING OUTCOMES

Mirela Alina SANDU, Veronica IVANESCU

University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Mărăști Blvd, District 1, Bucharest, Romania

Corresponding author email: veronica.ivanescu@fifim.ro

Abstract

This study investigates the integration of virtual laboratories into an undergraduate environmental engineering course through a blended learning approach. Using HybridPraxisLab, a browser-based simulation platform, second-year students engaged in optional virtual modules designed to reinforce theoretical knowledge and procedural skills. Quantitative data collected via a 14-item questionnaire revealed high student satisfaction across accessibility, engagement, and confidence dimensions. Additionally, a significant difference in final laboratory grades was observed between students with high and low virtual engagement, suggesting a positive impact on academic performance. These results support the use of virtual labs as effective and inclusive tools for enhancing learning outcomes in engineering education, especially for part-time or remote learners. The findings highlight the potential of such platforms to supplement traditional instruction and improve readiness for hands-on laboratory tasks.

Key words*: active learning, blended learning, engineering education, student perceptions, virtual laboratories.*

INTRODUCTION

Laboratory-based learning represents a foundational element of engineering education, offering students the opportunity to apply theoretical concepts to real-world scenarios while developing procedural skills and critical thinking (Feisel & Rosa, 2005; Li & Liang, 2024). However, the accessibility of physical laboratories is frequently constrained by logistical, financial, and institutional barriers, such as limited equipment, safety regulations, or scheduling conflicts (Asiksoy, 2023; Balamuralithara & Woods, 2009; Faour & Ayoubi, 2018). These challenges are particularly pronounced in high-enrollment programs or in part-time and distance learning formats (Faour & Ayoubi, 2018; Perales et al., 2019).

To address such limitations, virtual laboratories (VLs) have emerged as flexible, scalable tools that simulate laboratory procedures and allow students to engage with experimental content remotely and safely (Reeves & Crippen, 2021). VLs provide several pedagogical and logistical benefits: they reduce infrastructure costs, increase accessibility, support repeated practice, and minimize environmental and safety risks (Raman et al., 2022). These advantages are especially valuable in applied science and engineering domains where hands-on activities may involve hazardous substances or require specialized equipment that is often unavailable in traditional educational settings (Kapilan et al., 2021; Perales et al., 2019).

When integrated into blended learning models, VLs can enhance student engagement and learning outcomes. Blended approaches combine digital tools with face-to-face instruction, promoting personalized pacing, inclusivity, and active participation (Anjos et al., 2024; Cao, 2023). Within this pedagogical framework, flipped classrooms - where students engage with materials such as simulations or video lectures prior to class - have proven especially effective (Garrison & Vaughan, 2008; Lage et al., 2000). Such formats promote equity in access to learning, regardless of students' geographic location or time constraints (Abdelmoneim et al., 2022; Bonfield et al., 2020; Cao, 2023).

A growing body of evidence supports the effectiveness of VLs in improving conceptual understanding, procedural accuracy, and learner confidence (Abdelmoneim et al., 2022; Asiksoy, 2023; Li & Liang, 2024). VLs have also been linked to reduced student anxiety and improved readiness for physical laboratories, offering a safe environment for experimenttation and repetition (Gungor et al., 2022;

Schnieder et al., 2022). During the COVID-19 pandemic, their role was amplified as institutions sought to maintain educational continuity (Kapilan et al., 2021; Schnieder et al., 2022). Beyond emergency use, VLs support inclusive education, particularly for non-traditional, part-time, or remote learners (Abdelmoneim et al., 2022; Bonfield et al., 2020).

Despite the expanding research, most studies on virtual laboratories have focused on domains such as physics, chemistry, or computer science (Faour & Ayoubi, 2018; Reeves & Crippen, 2021). By contrast, their application in environmental engineering - a field that demands interdisciplinary knowledge and specialized equipment - remains relatively underexplored (Wahyudi et al., 2024). Furthermore, few investigations have analyzed how engagement with virtual labs influences academic performance in blended formats that include both full-time and part-time learners (Schnieder et al., 2022).

In this context, the present study explores the use of HybridPraxisLab, a browser-based simulation platform, in an undergraduate Environmental Engineering in Agriculture course at the University of Agronomic Sciences and Veterinary Medicine of Bucharest. The objectives are threefold: (1) to assess students' perceptions of the platform in terms of accessibility, engagement, and confidence; (2) to examine the relationship between virtual lab engagement and academic performance; and (3) to evaluate the potential of virtual labs to enhance traditional laboratory instruction in a sustainable and inclusive manner.

MATERIALS AND METHODS

Study context and participants

This study was conducted at the Faculty of Land Reclamation and Environmental Engineering, within the *Environmental Engineering in Agriculture* undergraduate program at the University of Agronomic Sciences and Veterinary Medicine of Bucharest. The research involved second-year students enrolled in both full-time and part-time (distance learning) formats, who participated voluntarily in a virtual laboratory project aimed at exploring digital tools to enhance engineering education.

A total of 39 students participated: 22 from the full-time program and 17 from the part-time program. All students engaged with the same set of virtual laboratory modules and completed an online questionnaire evaluating their experience. The activity was conducted independently of the standard course curriculum and introduced solely for research purposes. Participation was voluntary and anonymous, and all students provided informed consent prior to inclusion in the study.

Description of the Virtual Lab Platform

Virtual laboratory activities were delivered using HybridPraxisLab, a browser-based educational platform designed to enhance practical skills in environmental engineering through interactive simulation. The platform provides guided access to digital experiments that replicate procedures commonly performed in environmental laboratories. These simulations are consistent with the growing adoption of scenario-based instructional design in online engineering education (Kapilan et al., 2021; Raman et al., 2022).

Each scenario-based module follows a consistent instructional sequence, consisting of: *Theoretical Background*, *Step-by-Step Method*, *Simulation*, *Self-Assessment Quiz*, and *Bibliographic Resources*. This structure supports three key aspects of effective laboratory learning: conceptual understanding, procedural training, and self-reflection (Feisel & Rosa, 2005).

At the time of this study, the platform hosted the following modules:

- Laboratory safety;
- Protocol for sampling and transport of water samples;
- Pipetting: selecting and using micropipettes;
- Acids and bases;
- Determination of pH for different water samples;
- Preparation of solution: from salt to solution;
- Determination of turbidity for different water samples;
- Determination of Chlorides in different water samples;
- Determination of Dissolved Oxygen in water;

- Mass spectrometry: exploring the instrument.

Although these modules were not part of the formal course curriculum, they were made available as optional preparatory tools to help students reinforce theoretical concepts and gain procedural familiarity before participating in physical laboratory sessions. Students received free access to the platform and could explore the simulations at their own pace, outside scheduled class time, using a standard internet connection and personal login credentials. The integration of such open-access and flexible tools has been recognized as a best practice in inclusive engineering education (Abdelmoneim et al., 2022; Bonfield et al., 2020; Schnieder et al., 2022).

Survey design and data collection

To evaluate students' perceptions of the virtual laboratory experience, a structured question-nnaire was developed and distributed online after completion of the HybridPraxisLab activities.

The survey was designed to capture feedback across three key dimensions that are commonly highlighted in literature as critical to the perceived value of virtual labs: platform accessibility/ease of use, student engagement, and confidence building (preparation for real labs) (Abdelmoneim et al., 2022; Schnieder et al., 2022). These particular aspects were selected based on prior research indicating their relevance in assessing virtual lab experiences in higher education-namely improving ease of access, enhancing engagement, and boosting students' confidence before hands-on labs (Cao, 2023).

The questionnaire consisted of 14 items, grouped into thematic sections:

- Platform accessibility and usability;
- Student engagement and interest during the virtual lab experience;
- Perceived contribution to understanding and confidence before attending physical labs.

Each item was rated using a 7-point Likert scale, which allows for fine-grained analysis of perception-based data in educational research (Revilla et al., 2014). The full scale used in the questionnaire was as follows:

1 - Strongly disagree;
2 - Disagree;
3 - Slightly disagree;
4 - Neutral;
5 - Slightly agree;
6 - Agree;
7 - Strongly agree.

An additional open-ended question was included to collect qualitative feedback and suggestions for improvement. The combination of closed and open-ended responses reflects best practices in mixed-methods research for exploring learner satisfaction and experience (Reeves & Crippen, 2021).

The survey was distributed anonymously via an online form to all 39 students who participated in the virtual laboratory activities. Participation was voluntary, with no incentives offered. Data collection occurred over a one-week period following the completion of the virtual sessions.

Academic performance evaluation

To complement the perception-based data, this study also examined students' academic performance in the associated laboratory course. The aim was to explore whether engagement with the virtual lab activities was associated with learning outcomes, even though the virtual component was not part of the formal assessment. Similar analytical approaches have been used in engineering education research to evaluate the impact of supplementary digital tools on final course performance (Schnieder et al., 2022).

Final grades from the physical laboratory evaluation were used as the primary indicator of academic performance. These grades reflected students' ability to perform technical procedures, interpret results, and demonstrate understanding of laboratory concepts, as assessed through practical work and written reports.

Although participation in the virtual labs was voluntary and not formally linked to course requirements, students' final laboratory grades were analyzed in relation to their level of engagement with the HybridPraxisLab platform (i.e., number of completed modules). Due to the limited sample size and the exploratory nature of the study, this analysis was descriptive and intended to identify general trends rather than establish causal relationships.

Data analysis

Descriptive statistical methods were used to analyze survey responses and academic performance data. For each Likert-scale item, the mean and standard deviation were calculated, in line with established practices for summarizing perception-based data (Revilla et al., 2014). Survey items were also grouped by dimension to calculate aggregate mean scores for accessibility, engagement, and confidence building, allowing for cross-category comparisons.

In parallel, students' final laboratory grades were analyzed in relation to the number of completed virtual lab modules. As the study was exploratory and based on a relatively small sample (n = 39), the analysis was limited to descriptive comparisons and a Welch's t-test. Inferential analysis was conducted with caution, acknowledging that this does not establish causation but can highlight trends worthy of further investigation (Balamuralithara & Woods, 2009).

All data were processed using Microsoft Excel. No personal identifiers were collected, and all analyses were conducted anonymously to ensure confidentiality. These procedures adhered to standard ethical principles in educational research practice.

RESULTS AND DISCUSSIONS

Survey response rate and overview

Out of the 39 students who participated in the virtual laboratory activities, 36 completed the post-activity survey, resulting in a response rate of 92.3%. The sample included both full-time and part-time students, with no significant difference observed in response behavior between the two groups.

The majority of respondents reported a generally positive experience with the HybridPraxisLab platform. Across all items, responses were well-distributed across the 7-point Likert scale, with only minimal clustering at the extremes. Preliminary review indicated consistently favorable ratings in the areas of ease of use, perceived relevance, and preparation for physical lab work.

The descriptive results of the survey are detailed in the following section, organized by the three evaluated dimensions: accessibility, engagement, and confidence building.

As shown in Figure 1, students rated Confidence Building highest (M = 6.19), followed by Accessibility (M = 6.14) and Engagement (M = 5.98), indicating consistently favorable perceptions across all dimensions.

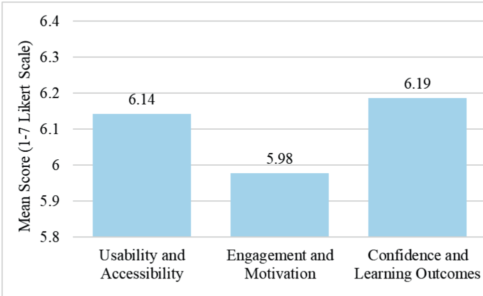

Figure 1. Average scores by survey dimension

Distribution of responses per item

A more detailed analysis of each survey item reveals that students rated the platform consistently high, particularly on items related to clarity of simulation steps, perceived usefulness for understanding lab procedures, and motivational aspects. As shown in Figure 2, the item-wise mean scores ranged between 5.6 and 6.4, reflecting positive reception across all 14 items.

Notably, the highest-rated survey item was *"I would recommend these modules to future students"* (M = 6.36), indicating a strong endorsement of the virtual lab experience. In contrast, the lowest-rated item - *"The design of the simulations encouraged participation"* (M = 5.64) - while still above the neutral midpoint, suggests a potential area for enhancement in terms of simulation interactivity and user engagement features.

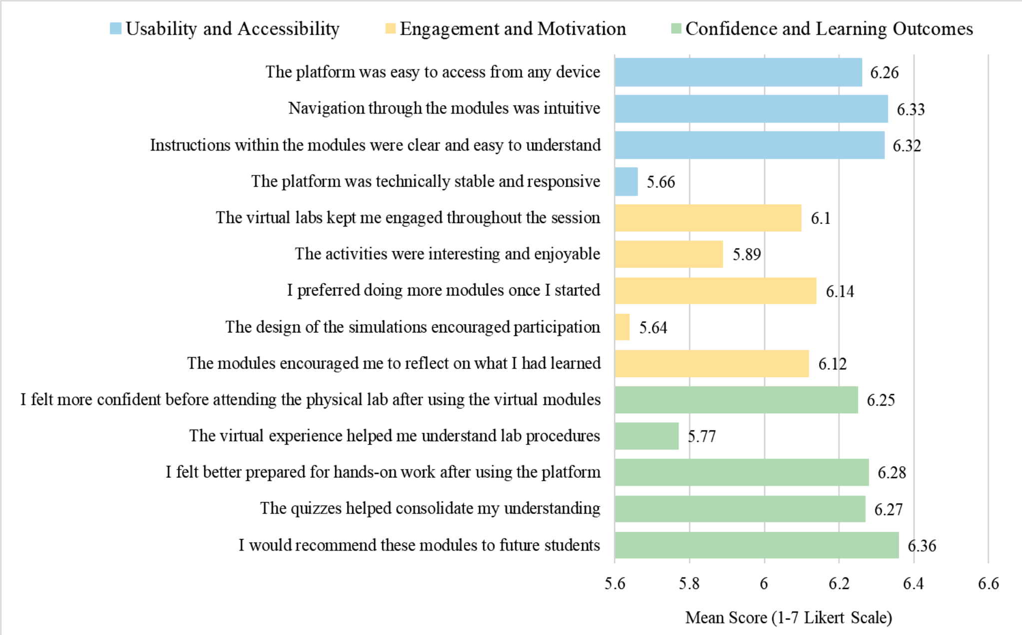

Figure 2. Mean scores on Virtual Lab questionnaire

Qualitative feedback and open-ended responses

Beyond the quantitative data, students were invited to provide open-ended feedback regarding their experience with the virtual lab modules. Out of the 36 respondents, 28 (77.8%) offered qualitative comments. Thematic analysis revealed several recurring patterns:

- **Confidence and preparation**: many students mentioned feeling more confident and better prepared before entering the physical lab session. They appreciated the clarity of procedures and the opportunity to rehearse steps in a safe, self-paced environment (Abdelmoneim et al., 2022; Asiksoy, 2023).
- **Accessibility and flexibility**: respondents frequently highlighted the ease of accessing the simulations from various devices and at their own pace, with part-time students especially valuing this flexibility (Schnieder et al., 2022).
- **Suggestions for improvement**: some students expressed interest in having more modules available, particularly covering additional topics related to sampling and analytical techniques. Others suggested improvements in visual interactivity and feedback mechanisms after quizzes, consistent with observations from prior research (Kapilan et al., 2021).

Selected comments include:

- *"Very well-structured. The simulations made me feel more confident for the real lab."*
- *"I wish more modules were available. I'd be interested in simulations for water analysis."*
- *"Clear and interactive. Helped me understand the pipetting steps in advance."*

Relationship between platform usage and academic performance

To explore whether engagement with the HybridPraxisLab modules had an academic impact, we compared final lab grades between students who completed most of the simulations (≥6 modules) and those who did not.

- **Group A** (n = 19): completed ≥6 virtual modules
  – *Mean final lab grade*: 9.06 (SD = 0.38)
- **Group B** (n = 17): completed <6 modules
  – *Mean final lab grade*: 8.39 (SD = 0.48)

A Welch's t-test indicated that this difference was statistically significant ($t(32.6) = 4.64$, $p < 0.001$), suggesting that greater engagement with the virtual lab platform was associated with better academic performance. As shown in Figure 3, students with higher virtual lab engagement scored significantly better in the final laboratory assessment. These findings mirror those of Schnieder et al., (2022), who reported improved performance among engineering students using virtual simulations, and with Murillo-Zamorano et al., (2021), who observed similar benefits in gamified digital learning environments.

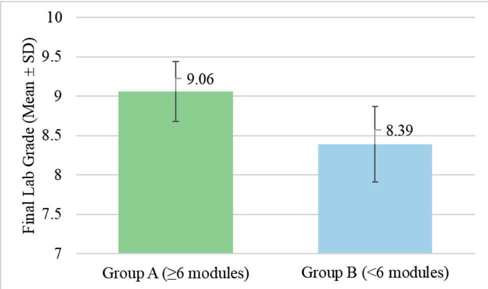

Figure 3. Final laboratory grades by virtual laboratory usage

Summary of findings

Overall, students rated the HybridPraxisLab modules positively across all dimensions. High mean scores (5.64-6.36) indicated strong perceived value, supported by qualitative comments that highlighted increased clarity and preparedness. The flexibility of the platform benefited especially remote and part-time learners, as also shown by Abdelmoneim et al. (2022) and Cao (2023). The statistically significant relationship between platform engagement and academic outcomes reinforces conclusions from broader research in STEM education (Murillo-Zamorano et al., 2021; Schnieder et al., 2022).

Limitations and future research

This study has several limitations that should be acknowledged. First, the sample size was relatively small (N = 36), and all participants were enrolled in a single engineering program at one institution. As such, the findings may not be generalizable across disciplines, academic levels, or institutional contexts.

Second, the virtual lab modules were designed primarily to support preparation for physical lab sessions. While this format proved effective, the study did not evaluate whether simulations could fully replace hands-on labs in a stand-alone virtual setting. Further comparative studies are needed to assess learning outcomes in fully remote versus blended formats.

Third, the evaluation relied primarily on self-reported perceptions and one summative performance metric (final lab grade). Although significant correlations were observed, additionnal data such as practical skill assessments, long-term retention measures, or behavioral analytics (e.g., time spent per module) could provide more nuanced insights into learning effectiveness.

Finally, technical design elements such as the level of interactivity, feedback in quizzes, and simulation realism were not systematically evaluated. Future iterations of the platform would benefit from user-centered design research, incorporating iterative testing and interface improvements based on both student and instructor feedback.

Future research should focus on expanding the range of available modules to cover a broader set of engineering topics and to test the scalability of the platform across larger, more diverse student populations. Additionally, integrating adaptive learning elements or real-time feedback systems could further enhance the effectiveness of virtual laboratory instruction.

CONCLUSIONS

This study investigated the impact of HybridPraxisLab - a virtual laboratory platform - on students' perceptions, engagement, and academic performance within an environmental engineering course. The findings demonstrate consistently positive feedback across all evaluated dimensions: usability and accessibility, engagement and motivation, and confidence and learning outcomes. Students rated all 14 items highly, with mean scores ranging from 5.64 to 6.36 on a 7-point Likert scale, indicating strong acceptance of the virtual modules as effective educational tools.

Qualitative responses further supported these findings. Students emphasized increased confidence before entering the physical lab, greater clarity of procedures, and the value of self-paced exploration. The virtual format was particularly appreciated by part-time and remote learners, who benefited from its flexibility and accessibility.

Moreover, a statistically significant difference in final lab grades was observed between students who completed most of the modules and those who engaged with the platform less frequently. This suggests a strong association between virtual lab engagement and improved academic outcomes, especially in terms of procedural readiness and conceptual understanding.

The results suggest that virtual labs can:

- Enhance student engagement and motivation through inquiry-based and interactive learning.
- Support procedural readiness and safety awareness before entering the physical lab.
- Reduce access barriers for part-time and remote learners.
- Serve as an effective supplement - not a replacement - for hands-on laboratory experiences.

Given these outcomes, several recommendations emerge for educators and institutions:

1. **Curriculum design**: integrate virtual laboratories as preparatory modules to maximize the effectiveness of in-person sessions.
2. **Assessment strategies**: combine self-assessment tools in virtual modules with in-person evaluations to assess procedural, conceptual, and reflective skills.
3. **Teacher training**: provide instructors with pedagogical and technical support for implementing blended learning approaches.
4. **Equity and accessibility**: expand the availability of virtual labs to support inclusive and flexible learning environments.
5. **Ongoing evaluation**: use learning analytics and regular student feedback to refine content and ensure alignment with course objectives.

While HybridPraxisLab proved to be an asset in this course, further research across other subjects and educational contexts is necessary to fully understand its broader impact. Future work should explore long-term retention, cost-effectiveness, and students' ability to transfer virtual learning experiences to real-world engineering tasks.

In summary, virtual laboratories represent a powerful and scalable tool for fostering active, inclusive, and effective learning in environmental engineering - and beyond. The observed correlation between simulation engagement and lab performance suggests that structured virtual components could be embedded into standard laboratory curricula, particularly as preparatory modules.

To guide future development and institutional decisions, a SWOT analysis of HybridPraxisLab's implementation is presented in Tabel 1.

Tabel 1. SWOT analysis of the HybridPraxisLab's implementation

Strengths	Weaknesses
High student satisfaction and engagement	Limited to one course and institution
Improved academic performance and confidence	Not yet validated across disciplines
Flexible access for diverse student profiles	Some modules lack advanced or complex lab procedures
Supports procedural readiness and safety awareness	Not designed as a full replacement for hands-on experimentation
Opportunities	**Threats**
Expansion to other engineering or science domains	Institutional resistance to pedagogical change
Integration with adaptive learning and analytics	Uneven access to infrastructure across student populations
Alignment with blended and inclusive learning policies	Risk of over-reliance in contexts without proper physical labs
Potential for scalable deployment across programs/universities	Platform maintenance and technological dependencies

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REFERENCES

Abdelmoneim, R., Hassounah, E., & Radwan, E. (2022). Effectiveness of virtual laboratories on developing expert thinking and decision-making skills among female school students in Palestine. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(12), em2199. https://doi.org/10.29333/ejmste/12708

Anjos, F. E. V. D., Martins, A. D. O., Rodrigues, G. S., Sellitto, M. A., & Silva, D. O. D. (2024). Boosting Engineering Education with Virtual Reality: An Experiment to Enhance Student Knowledge Retention. *Applied System Innovation*, *7*(3), 50. https://doi.org/10.3390/asi7030050

Asiksoy, G. (2023). Effects of Virtual Lab Experiences on Students' Achievement and Perceptions of Learning Physics. *International Journal of Online and Biomedical Engineering (iJOE)*, *19*(11). https://doi.org/10.3991/ijoe.v19i11.39049

Balamuralithara, B., & Woods, P. C. (2009). Virtual laboratories in engineering education: The simulation lab and remote lab. *Computer Applications in Engineering Education*, *17*(1), 108–118. https://doi.org/10.1002/cae.20186

Bonfield, C. A., Salter, M., Longmuir, A., Benson, M., & Adachi, C. (2020). Transformation or evolution?: Education 4.0, teaching and learning in the digital age. *Higher Education Pedagogies*, *5*(1), 223–246. https://doi.org/10.1080/23752696.2020.1816847

Cao, W. (2023). A meta-analysis of effects of blended learning on performance, attitude, achievement, and engagement across different countries. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1212056

Faour, M. A., & Ayoubi, Z. (2018). The effect of using virtual laboratory on grade 10students' conceptual understanding and their attitudes towards physics. *Journal of Educationin Science, Environment and Health (JESEH)*, *4*(1), 54–68. https://doi.org/10.21891/jeseh.387482

Feisel, L. D., & Rosa, A. J. (2005). The Role of the Laboratory in Undergraduate Engineering Education. *Journal of Engineering Education*, *94*(1), 121–130. https://doi.org/10.1002/j.2168-9830.2005.tb00833.x

Garrison, D. R., & Vaughan, N. D. (2008). *Blended Learning in Higher Education: Framework, Principles, and Guidelines*. Jossey-Bass.

Gungor, A., Avraamidou, L., Kool, D., Lee, M., Eisink, N., Albada, B., Van Der Kolk, K., Tromp, M., & Bitter, J. H. (2022). The Use of Virtual Reality in A Chemistry Lab and Its Impact on Students' Self-Efficacy, Interest, Self-Concept and Laboratory Anxiety. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(3), em2090. https://doi.org/10.29333/ejmste/11814

Kapilan, N., Vidhya, P., & Gao, X.-Z. (2021). Virtual Laboratory: A Boon to the Mechanical Engineering Education During Covid-19 Pandemic. *Higher Education for the Future*, *8*(1), 31–46. https://doi.org/10.1177/2347631120970757

Lage, M. J., Platt, G. J., & Treglia, M. (2000). Inverting the Classroom: A Gateway to Creating an Inclusive Learning Environment. *The Journal of Economic Education*, *31*(1), 30–43. https://doi.org/10.1080/00220480009596759

Li, J., & Liang, W. (2024). Effectiveness of virtual laboratory in engineering education: A meta-analysis. *PLOS ONE*, *19*(12), e0316269. https://doi.org/10.1371/journal.pone.0316269

Murillo-Zamorano, L. R., López Sánchez, J. Á., Godoy-Caballero, A. L., & Bueno Muñoz, C. (2021). Gamification and active learning in higher education: Is it possible to match digital society, academia and students' interests? *International Journal of Educational Technology in Higher Education*, *18*(1). https://doi.org/10.1186/s41239-021-00249-y

Perales, M., Pedraza, L., & Moreno-Ger, P. (2019, aprilie). Work-In-Progress: Improving Online Higher Education with Virtual and Remote Labs. *2019 IEEE Global Engineering Education Conference (EDUCON)*. 2019 IEEE Global Engineering Education Conference (EDUCON), Dubai, United Arab Emirates. https://doi.org/10.1109/educon.2019.8725272

Raman, R., Achuthan, K., Nair, V. K., & Nedungadi, P. (2022). Virtual Laboratories- A historical review and bibliometric analysis of the past three decades. *Education and Information Technologies*, *27*(8), 11055–11087. https://doi.org/10.1007/s10639-022-11058-9

Reeves, S. M., & Crippen, K. J. (2021). Virtual Laboratories in Undergraduate Science and Engineering Courses: A Systematic Review, 2009-2019. *Journal of Science Education and Technology*, *30*(1), 16–30. https://doi.org/10.1007/s10956-020-09866-0

Revilla, M. A., Saris, W. E., & Krosnick, J. A. (2014). Choosing the Number of Categories in Agree-Disagree Scales. *Sociological Methods & Research*, *43*(1), 73–97. https://doi.org/10.1177/0049124113509605

Schnieder, M., Williams, S., & Ghosh, S. (2022). Comparison of In-Person and Virtual Labs/Tutorials for Engineering Students Using Blended Learning Principles. *Education Sciences*, *12*(3), 153. https://doi.org/10.3390/educsci12030153

Wahyudi, M. N. A., Budiyanto, C. W., Widiastuti, I., Hatta, P., & Bakar, Mohd. S. B. (2024). Understanding Virtual Laboratories in Engineering Education: A Systematic Literature Review. *International Journal of Pedagogy and Teacher Education*, *7*(2), 102. https://doi.org/10.20961/ijpte.v7i2.85271