

## Exploring Student Learning Experiences in a PowerPoint-Based Open-Ended Virtual Laboratory for Environmental Engineering Education

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### Abstract

Virtual laboratory technology can provide students with the same learning outcome through a simulated experiment without accessing a physical laboratory. It can also be designed to be open-ended, allowing students to develop the methodology to solve a given problem. This is in-line with Outcomes-Based Education as required by the Engineering Accreditation Council of Malaysia. Therefore, the development of an open-ended virtual laboratory and understanding of how it impacts learning outcomes and student engagement are important. This study developed an interactive, animated, open-ended virtual laboratory for an undergraduate environmental engineering water treatment course using the PowerPoint platform, and its effectiveness in delivering hands-on laboratory instruction was measured from students' perspectives. Students' attainment of the learning outcome was analysed through their laboratory assessment, and their engagement with the virtual laboratory was measured using a survey. The results showed that students successfully navigated the open-ended laboratory assessment and achieved the intended learning outcome. In terms of learning engagement, 90% of students agreed that the virtual laboratory was easy to operate and understand, flexible, stimulating, satisfying, and good for distance learning. However, only 20% of students agreed that they learned and understood more in a virtual laboratory than in a physical one, and only 10% reported gaining hands-on skills through the virtual laboratory.

**Keywords:** virtual laboratory, open-ended laboratory, learning engagement, open distance learning, engineering education

### Introduction

The educational landscape has changed significantly due to the COVID-19 pandemic, with a dramatic increase in the adoption of educational technology by institutions worldwide. It has necessitated adapting teaching methods, including laboratory-based exercises, by developing ways for students to perform experiments (Vasiliadou, 2020). As such, virtual laboratories provide an interactive platform for students to learn from simulated experiments and are a viable alternative to physical experiments from the perspectives of both students and instructors (Hanine et al., 2025). It allows students to practice in a risk-free environment and provides a more flexible learning opportunity (Formella-Zimmermann et al., 2022) and greater inclusivity (Zhou et al., 2024). Moreover, these features enable repeated experimentation, encouraging active learning among students prioritising hands-on engagement and investigation, thereby fostering a so-called Exploratory

Learning Environment (ELE) (Papalazarou et al., 2024). Váraljai (2016) indicated that an ELE supported by virtual laboratories enhances learning effectiveness by improving preparedness and reducing anxiety, enabling well-supported self-exploration of conceptual understanding. In this context, virtual laboratories can also work in tandem with physical laboratories to cater to the needs and experiences of a broad range of learners (Reeves et al., 2021). In general, studies involving virtual laboratories strongly align with learner-centred and activity-oriented pedagogical frameworks (Yindeemak, et al. 2026), alongside experiential and inquiry-based learning approaches, which emphasise active engagement, exploration and problem-solving in the context of the virtual laboratory environment.

Further, the pedagogical approach of constructivism, which describes learners actively constructing knowledge through interaction with their environment, engaging in experimentation, inquiry and problem-solving applies to the implementation of

virtual laboratories; as virtual laboratories are part of online engineering education (Sertu, et al. 2025). Eliza, et al. (2024) state that constructivist thinking is relevant in the context of virtual laboratories, as it provides a platform to allow students to experience engineering practice interactively and independently, where they can construct their own knowledge about the phenomenon they are studying. Sertu et al. (2025) go on to describe that constructivism addresses the loss of active experiential learning in virtual laboratories by designing simulations that enable students to manipulate and study the sensitivity of certain parameters to the outcomes.

In Malaysia, the implementation of Outcome-Based Education (OBE) in engineering education requires pedagogical approaches that prioritise the determination and measurement of student learning outcomes across cognitive, affective, and psychomotor domains, moving beyond content delivery to promote active student engagement in the learning activities (Mistamiruddin et al., 2024). An essential component in the curriculum of engineering courses with OBE implementation is open-ended laboratory (OEL) assignments (Roslia and Sadikinb, 2025). In conventional laboratory approaches, students are guided to attain the expected results. In contrast, students are only given the project purpose or problem in OELs, and are free to develop their own experiments to develop solutions (Hamid and Sakdun, 2024). Through the OEL approach, students are encouraged to think critically and to incorporate theory and logical justification in formulating objectives, procedures, and analytical methods, thereby requiring higher-order critical thinking and complex problem-solving skills (Zaini et al., 2026). In particular, OEL may help increase independent learning by fostering the development of these skills and moulding students to exercise their creativity and innovation (Hamid and Sakdun, 2024). As a result, it allows the students to not only apply theories in laboratory assessments but also to work practically as professionals (Persano Adorno et al., 2023). Due to the complexity of implementing an OEL, students typically work in groups to complete the assigned tasks. Persano Adorno et al. (2023) also suggested that an OEL project enhances communication skills among students, as the exploratory activity of formulating the experimental objectives and methodology encourages comprehensive discussion and active sharing. However, several challenges remain in implementing OEL and ensuring learning outcome attainment, including the limited availability of consumables and restricted access to the laboratory, which constrain students' ability to fully engage in exploratory experimentation and iterative experimental design refinement (Roslia and Sadikinb, 2025). Therefore, it is worthwhile to explore whether the OEL can be effectively delivered in a virtual environment without compromising the attainment of learning outcomes.

Although cloud-based virtual laboratory platforms are recognised for extensive simulations and high pedagogical values in converting OELs into a virtual mode for remote learning, the implementation is constrained by the need for institution-wide subscription, limited user accounts, and high computational and stable internet requirements for students' devices (Narwal, R., & Joyti, 2024). Moreover, most virtual laboratories are designed as virtual versions of conventional laboratories with fixed objectives, variables, and procedures, and thus their application to the OEL is limited (Hanine et al., 2025). Therefore, a degree of flexibility needs to be embedded in virtual laboratories to create an effective ELE for students (Gal et al., 2015). It is beneficial to design appropriate open-ended virtual laboratories (OEVL) using a universally available platform for engineering programmes in Malaysia to meet the Engineering Accreditation Council's requirements as well as to enhance students' learning experience. Microsoft PowerPoint is one of the most commonly used presentation and content-authoring tools in higher education, as it is easy to use and integrates flexibly with institutional learning management systems, while requiring no additional licensing (Wanner, 2015). The development of an interactive OEVL using PowerPoint is a practical and inclusive alternative, owing to its pedagogical flexibility when the priority is learning outcome attainment rather than visually rich simulation.

There are two research questions in this study, namely (1) What are the design considerations in developing a PowerPoint-based OEVL to support students' attainment of the intended learning outcomes in an undergraduate environmental engineering course? and (2) What are the perceptions of students on the PowerPoint-based OEVL in terms of flexibility and engagement? This paper presents a case study of an interactive, animated virtual laboratory developed for an undergraduate environmental engineering water treatment course using PowerPoint, providing students with an opportunity to achieve the same learning outcome through a simulated experiment without accessing the physical laboratory. In addition, the effectiveness of technology adoption in delivering a hands-on laboratory exercise was measured through students' attainment of the intended learning outcome and gauged from the students' perspective.

## Methodology

An OEVL was developed for an undergraduate water treatment course, where the students were in their third year of study in an undergraduate environmental engineering course. This class consisted of 10 students. Due to its potential for facilitating students' investigation, the Jar Test experiment was selected as the experiment to be simulated as an OEVL.

Within the water treatment process, the jar test is an important experiment to investigate the effectiveness of the coagulation and flocculation process with respect to variation in some parameters, including coagulation type, pH, coagulant dosage and others (Joo et al., 2000). For instance, variation in the pH with a constant dosage of coagulant will result in variation in the coagulation effectiveness, denoted by the water turbidity levels. The key learning outcome from the jar test experiment is understanding the coagulation and flocculation process and how parameters such as pH and coagulant dosage affect the water turbidity, and therefore could be designed for optimisation of the process.

To create an OEL, the students were given a real-world scenario related to water quality issues. The students were asked to complete a report to optimise the water treatment process with the data collected from the virtual laboratory. The OEVL addresses the learning outcome “Apply principles of environmental engineering to water resources management” within the course, which emphasises the application of theory in a practical setting to optimise the water treatment process.

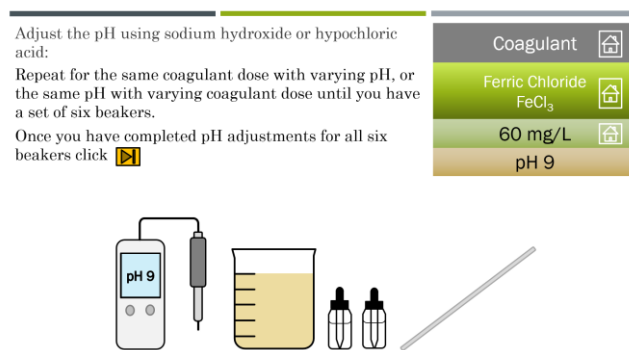
This study was divided into two stages, namely the development and application of the OEVL (Stage 1) and the evaluation of the effectiveness of the OEVL (Stage 2).

#### Stage 1: Development and application of the OEVL

The interactive virtual laboratory was developed using the PowerPoint platform to simulate the jar test experiment according to the ASTM D2035-19 Standard Practice for Coagulation-Flocculation Jar Test of Water (ASTM International, 2019). Developing the virtual laboratory using PowerPoint is both pragmatic and achievable with relatively little coding expertise. Moreover, it can be easily used or manipulated by students with little or no prior training.

The virtual laboratory was designed with an introduction and videos, which were made available to students, to demonstrate the operation of measurement instruments. Users were able to manipulate parameters in the simulated experiment to collect data. To achieve this, a database of experimental data consisting of water turbidity levels was created based on a combination of several variables for the jar test simulation. These variables consisted of types of coagulants, the dosage of the coagulant, and the pH of the mixture. Figure 1 shows an example of the pH adjustment in the virtual laboratory. Students were able to select the type of coagulant they wanted to use, the coagulant dose, and adjust the pH of the mixture to obtain the experimental result. In this study, the experimental result database was established from previous experiments carried out in the same laboratory, as well as from published data from the literature. The OEVL, which was created on the

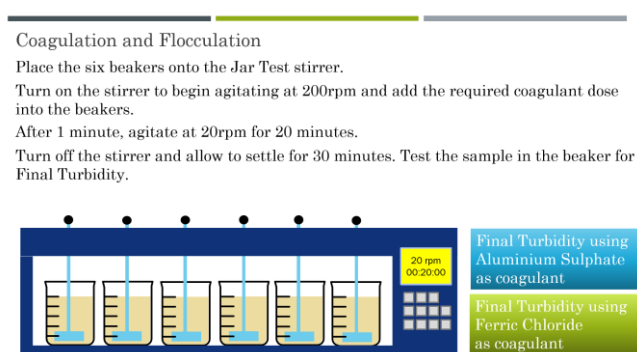
PowerPoint software, was made available as a file to students through their Learning Management System.



**Figure 1. Screenshot of pH adjustment in the PowerPoint-based OEVL**

The workflow for this laboratory assessment is as follows. In this OEL, the students conducted a literature review on optimising the coagulation and flocculation process for water treatment, and based on their literature review, developed the objectives and methodology (i.e. designing for different combinations of variables to test) as part of the pre-laboratory preparation.

In the virtual laboratory, the students selected the appropriate variables based on their pre-laboratory preparation and performed a simulated jar test to collect data virtually, as shown in Figure 2. The result was the final turbidity of the water, which varied according to the combination of variables they selected. The data was then analysed and discussed to complete the tasks of the OEL assessment. Students were grouped into groups of two to three students and given 4 weeks to complete the assessment.



**Figure 2. Example of Jar Test in OEVL**

#### Stage 2: Evaluation of the effectiveness of the OEVL

The OEVL addresses the learning outcome “Apply principles of environmental engineering to water resources management” within the course, which emphasises the application of theory in a practical setting to optimise the water treatment process. In the assessment, students are required to evaluate the coagulation and flocculation process and to recommend optimum conditions (coagulant and pH

dosage) for turbidity removal through a jar test experiment. Students are assessed based on their experimental design, analysis and evaluation of the lab results and their understanding and insight into the coagulation and flocculation process. Students are also expected to validate the values obtained from the lab against appropriately sourced references and demonstrate that the data obtained is reliable. These items form the basis of the assessment rubric. Students' attainment of the learning outcome addressed by this assessment was measured through their submission of a lab report marked against performance criteria differentiating "Below standard", "Meet standard" and "Excellent standard". Where students are able to present their analysis and evaluation of the laboratory results in sufficient detail, recommend optimum conditions and validate their data successfully, they either meet or exceed the standard.

The effectiveness of the OEVL as a learning tool was evaluated through students' attainment of the learning outcome as described above, as well as a survey. A set of survey questionnaires was distributed to the students to collect feedback regarding the suitability of the virtual laboratory, which was developed based on Naidoo and Govender's framework (Naidoo and Govender, 2014) to assess productive online learning through three key components, namely suitability of online technology, self-regulated learning, and learner-centred activity.

Table 1 summarises the questionnaire items, and students were asked to rate their agreement on a 5-point Likert scale, ranging from 1 (Strongly Agree) to 5 (Strongly Disagree) for 10 questionnaire items, and an additional 4 questionnaire items that were open-ended were also included. The students' perception of the effectiveness of the OEVL is assessed based on ease of operation and understanding, flexibility in terms of time and location, its ability to stimulate effective engagement in the learning activities, and the overall learning satisfaction. These evaluations provided fundamental insights into the feasibility of using a virtual laboratory as an alternative to hands-on laboratory exercises from the students' perspective, with particular emphasis on its suitability for learners. The survey also explored whether the OEVL is more suitable for more advanced students, in their second year and above, given concerns that first-year students may lack the fundamental knowledge and skills required for in-depth investigation to complete the tasks. In addition, the survey covered students' perceptions of virtual and physical laboratories by comparing their level of understanding, opportunities for extended learning, suitability of distance learning, and impact on hands-on skills. The open-ended questions in the survey invite the students to reflect on their perceptions of learning outcome attainment and understanding of the experiment, as well as identifying the strengths and weaknesses of the PowerPoint-based OEVL. Ethical approval for conducting the

student survey was granted by the Curtin Human Research Ethics Office (HRE2020-0674).

**Table 1. Questionnaire items to evaluate the effectiveness of the OEVL**

I found the virtual laboratory easy to operate.
I found the virtual laboratory easy to understand.
I found the virtual laboratory flexible to use in relation to time and place.
I found the virtual laboratory stimulating.
I found the virtual laboratory satisfying.
I think the virtual laboratory is more suitable for senior students (2nd-year students and above).
I think that I learn and understand more in a virtual laboratory environment than in a conventional laboratory.
The virtual laboratory is good because I can perform the laboratory exercise outside the laboratory operating hours.
The virtual laboratory is good because it can be used for distance learning, i.e. by students who are away from campus.
I gain hands-on skills through the virtual laboratory.
Learning outcomes are the outcomes (skills or experience) you will achieve upon completion of this laboratory. Do you think you have achieved the relevant learning outcomes for this laboratory exercise? (For your information, the learning outcomes for this lab are stated in the marking rubrics/assignment brief)
After completing this virtual laboratory, do you think you fully understand the coagulation process, and how turbidity varies with pH and coagulant dosage?
Which aspects of this virtual laboratory work well?
Which aspects of this virtual laboratory needs improvement?

## Results and Discussions

This study is conducted as an exploratory study to explore the possibility of implementing OEVLs in engineering programmes. As such, Stage 2 of the study is focused on determining students' perceptions of the suitability of the OEVL for learners, which would inform the development and refinement of the OEVL tool moving forward. Then, the tool may be implemented with a larger sample of students taking the course. Nonetheless, in the present study, all students taking the water treatment course (n = 10) participated in the study.

The assessment rubric associated with the OEVL is mapped against the learning outcome "Apply principles of environmental engineering to water resources management". Students' successful achievement of the learning outcome is dependent on whether their laboratory report achieves the "Meet standard" performance criteria in the marking rubric. Meanwhile, the overall learning outcome attainment for this student cohort is determined by calculating the percentage of students who successfully achieve this learning outcome.

Assessment result showed that attainment for the learning outcome was 96%, indicating that students were able to attain the intended learning outcome by successfully navigating the OEL assessment. Students were able to design appropriate parameter values to obtain experimental results from the virtual laboratory and analyse the results to arrive at a reasonable solution to the problem.

The administered survey achieved a 100% response rate (n=10), with all students in the class providing feedback on the implementation of the OEVL for the jar test experiment. Table 2 presents the results of the statements appraised on a Likert scale by the students, which evaluate students' perception of the effectiveness of the OEVL carried out.

Based on the survey outcomes, 90% (or 9 students) agreed that the virtual laboratory was easy to operate and good for distance learning, while all ten (10) students (or 100%) agreed that the virtual laboratory was easy to understand and was flexible. A total of 80% (or 8 students) agreed that they found the virtual laboratory stimulating and that the virtual laboratory was good because they could perform the laboratory exercise outside the laboratory operating times. Further, 70% (or 7 students) were satisfied with the virtual laboratory. From the open-ended survey question, a student emphasised that there were no safety issues with conducting a virtual laboratory, and the wastage of chemicals was also avoided. These outcomes aligned with the findings in Van den Beemt et al. (2023), where the remote laboratory, incorporating active learning pedagogy, allowed flexibility for the students to plan and organise their learning activities, subsequently achieving the goal of self-regulated learning. In terms of improvement, five (5) students commented that the OEVL did not need

improvement, but two (2) students suggested that more explanation should be given as to the operation of the virtual laboratory. In contrast, one (1) student suggested that the virtual laboratory could be simplified. Six (6) students found that the presentation of the virtual laboratory was very detailed, interactive, and easy to use, and they could easily understand the concept of the jar test.

However, only 20% (or 2 students) agreed that they learned and understood more in a virtual laboratory than in a physical laboratory. Additionally, from the open-ended survey question, six (6) students believe that they understood the theory of the coagulation process through the OEVL. However, only 10% (or 1 student) perceived that they gained hands-on skills through the virtual laboratory. A student also reflected in the open-ended survey question that the virtual laboratory could not replace actual participation in a physical laboratory environment. The findings aligned with the literature, where Poo et al. (2023) highlighted that a virtual laboratory is less effective in providing hands-on and haptic experience essential for embodied learning and developing practical skills compared to physical labs.

Despite a 96% attainment in their learning outcome, only four (4) of the students perceived that they had achieved the learning outcomes through the OEVL. This perception can be explained by the challenges that are posed by self-regulated learning to their motivation, commitment, and desire to learn (Reginald, 2023). The OEVL in this study supports self-regulated learning, as the assessment requires students to construct their learning environment through designing the experiment, carrying out the analysis and verifying their findings independently.

**Table 2. Estimate on Likert scale on how many respondents agreed with the statements (N = 10)**

Statement	1 = Strongly agree	2 = Agree	3 = Neutral	4 = Disagree	5 = Strongly Disagree
I found the virtual laboratory easy to operate.	40%	50%	0%	10%	0%
I found the virtual laboratory easy to understand.	30%	70%	0%	0%	0%
I found the virtual laboratory flexible to use in relation to time and place.	60%	40%	0%	0%	0%
I found the virtual laboratory stimulating.	20%	60%	20%	0%	0%
I found the virtual laboratory satisfying.	20%	50%	20%	10%	0%
I think the virtual laboratory is more suitable for senior students (2 <sup>nd</sup> year students and above).	10%	50%	20%	20%	0%
I think that I learn and understand more in a virtual laboratory environment than a conventional laboratory.	10%	10%	40%	30%	10%
The virtual laboratory is good because I can perform the laboratory exercise outside the laboratory operating hours.	20%	60%	20%	0%	0%
The virtual laboratory is good because it can be used for distance learning, i.e. by students who are away from campus.	50%	40%	10%	0%	0%
I gain hands-on skills through the virtual laboratory.	0%	10%	40%	30%	20%

This is consistent with Reginald (2023), which proposed that virtual labs have the ability to initiate self-regulation and promote meaningful learning. To improve the learning experience and ensure better navigation and understanding of lab procedures, the design of online learning activities should incorporate scaffolded support through video demonstrations and a built-in help system. Additional modules could be developed to specifically focus on imparting practical skills that students might otherwise miss in a virtual environment by including virtual demonstrations of hands-on techniques or interactive modules that simulate practical skill application.

## Conclusions

This study developed a virtual laboratory for the jar test using the PowerPoint platform in an undergraduate environmental engineering water treatment course. The effectiveness of the OEVL was evaluated through the attainment of learning outcomes and students' satisfaction. The high attainment of the learning outcome implies that the students were able to achieve the intended learning outcomes. As for the students' satisfaction, majority of students agreed that the virtual laboratory was easy to operate and understand, flexible, stimulating, satisfying, and good for distance learning. However, only 20% of students agreed that they learned and understood more in a virtual laboratory than in a physical laboratory, and only 10% of students perceived that they had gained hands-on skills through the virtual laboratory. This suggests that further development is required to address the hands-on skills gap, such as the use of augmented reality (AR) to improve students' learning experience.

This study shows that environmental engineering students do not think that this type of virtual laboratory could replace physical laboratory exercises. However, the students showed a very positive response towards the virtual learning experience.

The findings of this project would support the implementation of virtual laboratories in Malaysia, and around the region, should remote/online learning become a necessity due to resource limitations, or where access to a physical laboratory is not possible. In addition, developing the virtual laboratory using PowerPoint is both pragmatic and achievable with relatively little coding expertise, hence it can be implemented with ease to meet the Outcomes-Based Education expectations for engineering programmes.

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## Conflict of Interest

The authors declare no conflict of interest regarding this paper.

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