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# Flipped Laboratories: Engaging Experiences in Virtual, Real, and Open-Ended Labs

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**ABSTRACT**

The flipped classroom instructional approach, known for inverting classroom and homework activities, has gained traction in practical laboratory classes. However, engaging students during the pre-lab activities remains a challenge. To tackle this issue, a gamified pre-lab activity was implemented in a second-year undergraduate engineering course. This innovative approach included an escape room-style game and a virtual laboratory simulator. Students immersed themselves in the game and conducted virtual experiments before participating in the open-ended hands-on lab session, following the flipped approach. Survey results using a Likert scale demonstrated a significant improvement in student engagement due to the gamified pre-lab activity. The flipped approach not only shows promise in motivating students to grasp key concepts, but also provides valuable insights for educators in designing interactive pre-lab activities that can be adapted across various disciplines.

## 1. Introduction

Laboratory teaching has long existed in engineering curricula as a method to facilitate the connection between technical fundamentals and practical hands-on experience. Nevertheless, traditional laboratory settings often focus on following prescribed procedures without allowing for autonomous learning, resulting in difficulties for learners to connect the laboratory content with practical applications [1]. However, the flipped classroom approach has emerged as a promising solution to meet learner expectations in the new normal. In the flipped classroom, the traditional roles of classroom and homework activities are inverted, with learners being introduced to knowledge content as homework and engaging in hands-on activities and discussions during class time, replacing the conventional lecture delivery [2]. The effectiveness of the flipped classroom method in bridging the gap between theoretical and practical learning components has been widely acknowledged [3,4]. In the context of laboratory teaching, it is also recognized that lab classes often focus on disseminating instructions and checking students' understanding, which can result in a perception of learning without significant challenges for the learners [5].

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Virtual laboratories, which simulate real laboratory activities, have gained significant attention in science and engineering curricula, particularly due to the COVID-19 lockdown [6,7]. Previous studies have highlighted the importance of simulation learning tools in enhancing learners' performance and developing their digital literacy skills, which are crucial for their future careers [8,9]. One of the most notable advantages of a virtual laboratory is its inherent flexibility and easy accessibility. Compared to the traditional physical counterpart, virtual laboratory enables remote access, scalability to accommodate large class sizes, and freedom from physical resource constraint typical of most institutions [19,20]. Virtual laboratories can be utilized either as a substitute for physical laboratory work [10] or as a complement to existing face-to-face activities [9]. When employed as a standalone activity to replace physical labs entirely, a drawback becomes evident in the lack of face-to-face interaction between instructors and learners [10]. Moreover, virtual tools were used in delivering safety training and promising results have been reported [21]. Conversely, when used as a supplementary activity conducted after the physical laboratory session, students tend to be motivated to engage in post-experiment analysis [9]. Therefore, there is a great potential to reinforce key concepts, facilitate deeper understanding by complementing hands-on experiences with virtual simulations.

The concept of gamification in learning involves the integration of game elements into the learning activities to promote learner engagement in the learning process. Specifically, commonly used game elements in learning activities include points, leader boards, competitions, avatar, and rewards [11]. Apart from the application of gamification within conventional classroom settings, the concept can be extended to laboratory related activities. Gamification in learning extends to engaging students in pre-lab activities as well. By incorporating game elements into the pre-lab phase, educators could enhance student engagement and motivation before the actual hands-on laboratory session. For example, incorporating gamified quizzes, simulations, or interactive challenges prior to the hands-on laboratory session improve learning experience significantly.

Simultaneously, open-ended laboratories have become a recent trend in engineering education. This is partly due to the mandate set by the professional engineering accreditation body, as mentioned in previous studies [12]. In this approach, laboratory objectives and methodologies are intentionally left vague to foster open-endedness in the task. Learners have to create or establish their own objectives and techniques for completing laboratory assignments [13]. Incorporating an open-ended lab, particularly in a blended learning environment, poses a significant challenge for instructors. It entails a longer time commitment to complete the task and necessitates more detailed instructor-student briefings when conveying instructions, requirements, and intended learning outcomes. This can potentially overwhelm students with excessive information, leading to disengagement. Furthermore, resource constraints such as limited specialized equipment and limited scheduling especially dealing with large class size could prevent the implementation of open-ended lab [22]. On the other hand, safety and hazard concern needs to be addressed, if learners are allowed to operate equipment without prescribed procedures. Nevertheless, open-ended lab could potentially enhance learning outcomes due to its easy adaptability to authentic complex engineering practice. Having the learners to expose to such learning experience could develop skills such as critical thinking, problem solving, project management, communication and teamwork. Due to the real-world relevance and professional skill development, the effect of open-ended lab has been explored in a few reported studies [22]. Thus, there is a need to consider innovative methods including the use of virtual laboratory combining with actual experimental tasks when initiating open-ended laboratory teaching or transforming an existing laboratory work into an open-ended version.

While instructors may assign pre-lab tasks to help students connect their understanding to the real laboratory work, the usefulness of these resources can have an impact on the quality of teaching and learning if learners remain unable to visualize the experimental process. As a result, the purpose of this research is to present a laboratory teaching method that incorporates components of the flipped classroom approach, the challenges of the emerging norm in education, gamification, virtual laboratories, and open-ended laboratories. Additionally, the study seeks to evaluate students' virtual laboratory experiences and how these experiences prepare them for their actual laboratory work.

## 2. Method

The flipped-classroom pedagogy was implemented in the course “Structural Mechanics” which is part of the second-year engineering curriculum. The course MEE20004 Structural Mechanics is shared among three engineering programs offered at Swinburne University of Technology Sarawak. It serves as a prerequisite for advanced studies in Civil, Mechanical, and Robotics & Mechatronics Engineering. Within this course, students are tasked with completing an open-ended activity known as the “Deflection of Beam”. The primary objective of this lab activity is to explore the behaviour of beam deflection under external loads. It aims to enable students to visualize beam deformation, reinforce theoretical concepts covered in lectures, develop practical skills in operating equipment, and enhance problem-solving, teamwork, and report writing abilities.

Instead of relying on prescribed or manual-based laboratory instructions, an open-ended laboratory assessment approach was implemented so that complex problem-solving skills can be fostered.

### *2.1 Open-Ended Laboratory Activity*

Students worked in teams of four in the “Deflection of Beam” laboratory activity. The student teams were required to explore and conduct experiments with various parameters that affects a flat beam deflection behaviour. The parameters included the loading position, incremental magnitude of the load, beam's cross-sectional dimensions, and the beam's stiffness (i.e. modulus of elasticity). In order to organize their experiments, students were asked to define the technical objectives using the structure of “to determine the effect of (what has been changed) on the beam deflection,” which was previously used in a similar study [14]. Then, student teams were required to structure their methodological plan which could possibly achieve their intended technical objectives. Students could simulate their intended methodological plan using a virtual lab tool provided. The process should involve in-depth discussions among team members to ensure a successful execution of the required experiments.

### *2.2 Design of the Pre-laboratory Activity*

Due to the intricacy of the open-ended lab requirement, the task is divided into two phases. The first phase involves a pre-lab activity, which takes place two weeks before the actual hands-on lab class. The purposes of the pre-lab are not limited to understand the lab requirement and the relevant subject content, but also to develop the methodological plan. In this phase, students receive a description of the forthcoming hands-on open-ended lab activity and the report composition guidelines. They are expected to engage in discussions with their peers, collaboratively construct their technical objectives, and decide upon their intended methodology. In order to enhance students’ interaction, the first part of the pre-lab activity is a gamified quiz, designed to help students connect the upcoming lab task with the technical content they have learned. Upon completing the quiz, students receive a pass that grants them access to a virtual lab, which serves as the second part of the pre-lab activity.

### *2.3 Design of Virtual Laboratory*

The virtual lab has been developed using Adobe Animate CC, along with HTML5 codes, Adobe Illustrator CC, and Adobe Photoshop CC. It is designed to operate in both online (web-based) and offline modes, offering flexibility to users. Fig. 1 showcases a screenshot of the virtual lab alongside the actual laboratory equipment. Within the virtual lab, animated graphics are incorporated to demonstrate the setup and operation of the equipment, as shown in Fig. 2. It also visualizes the deflected state of the beam based on user inputs for loading parameters and generates output values that emulate real experiments, even accounting for deviations caused by experimental errors. These features allow users to simulate an open-ended laboratory assessment by specifying various input parameters, such as the beam's dimensions, properties, applied force magnitude, and loading conditions. This interactive environment enables users to perform experiments akin to those conducted in an actual lab setting.

### *2.4 Design of Escape Room-Style Gamified Quiz*

Fig. 3 displays a screenshot of the gamified quiz, which was created using Genially, an interactive learning content platform. The quiz adopts an escape room-style gaming approach, where students engage with problems related to the underlying concept and theory of the upcoming lab assignment. The quiz interface includes interactive elements, designed to help students establish connections between the upcoming lab task and the technical content they have learned.

(a)
(b)

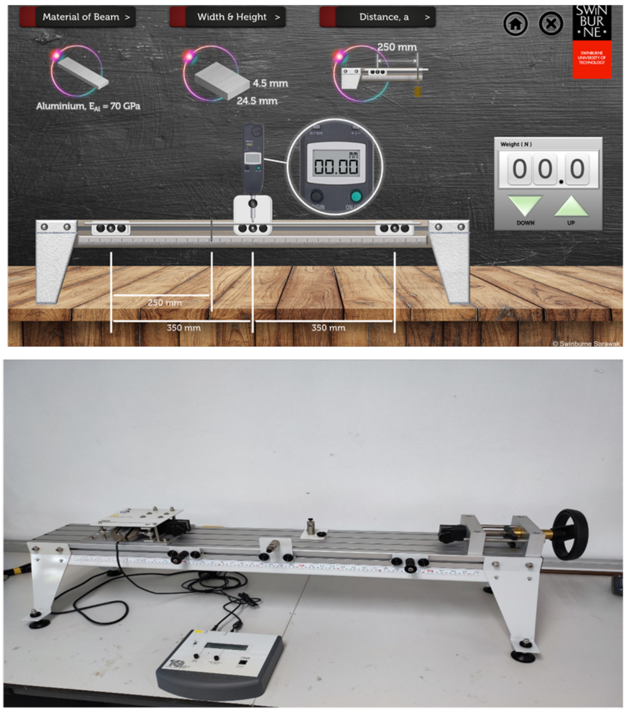


**Fig. 1.** (a) Virtual laboratory interface, (b) actual lab equipment

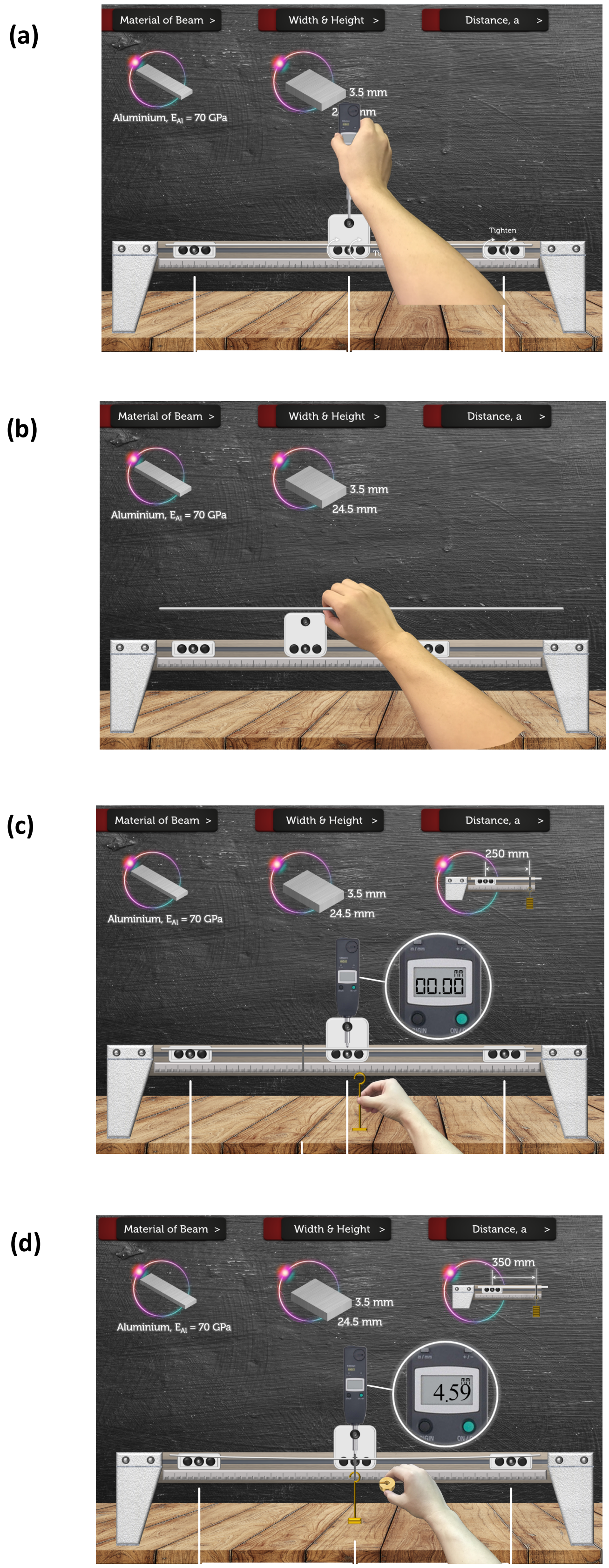


**Fig. 2.** Animated graphics showing (a) fixing a deflection indicator, (b) positioning the beam, (c) setting up a weight holder, (d) loading the beam with the specific weight on the virtual test rig

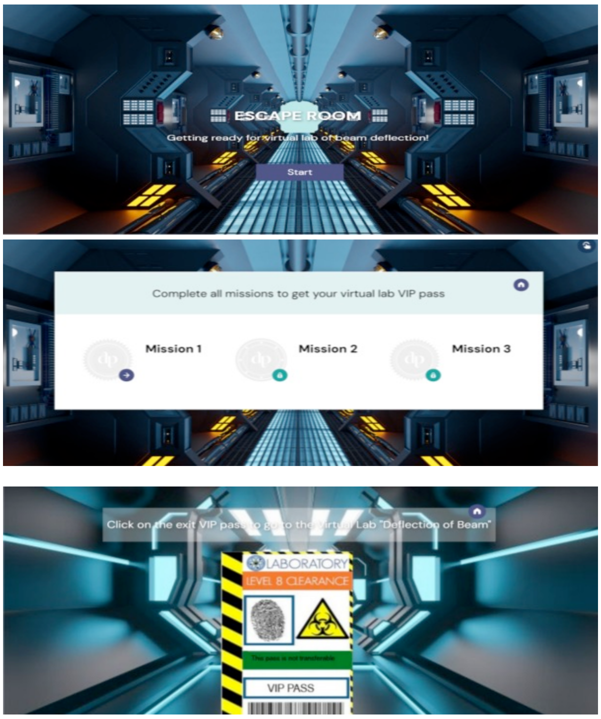


**Fig. 3.** Screenshot of the gamified quiz in pre- laboratory activity

### *2.5 Design of Actual Laboratory Activity*

Student teams are tasked with conducting the actual experiments according to the methodological plan they determined during the pre-laboratory activity. The required experimental equipment is depicted in Figure 1 (b), and it is the same equipment that students operated in the virtual lab. During this session, the instructor does not need to provide a detailed explanation of the activity; instead, students are expected to begin the experiment on their own. However, the instructor will be available to offer assistance and support to students in configuring the equipment the equipment as needed.

### *2.6 Survey Administration*

An online survey with 5-point Likert scale was conducted after the physical laboratory session. Ethical approval for the survey was obtained from Swinburne's Human Research Ethics Committee at Swinburne University of Technology. Prior to participation, all respondents were provided with comprehensive information regarding the survey's purpose, the anonymous nature of their responses, voluntary participation, their right to withdraw at any point, and assurance that their grades would remain unaffected by their participation. Students were asked to rate the effectiveness of the virtual lab in supporting them to complete the lab assignment. A total of 25 students responded anonymously to the survey.

## 3. Results and Discussion

### *3.1 Overall Learning Experience*

The overall students' satisfaction with the virtual lab is depicted in Fig. 4. According to the 5-point Likert scale survey, 32% of the students strongly agree, and 44% agree with their overall experience using the virtual lab. Notably, none of the students expressed disagreement or strong disagreement. This indicates that students are highly satisfied with the virtual lab, finding it effective and engaging. The virtual lab tool has the potential to enhance the learning experience, aligning with the findings of previous studies [8]. It is believed that incorporating interactive elements and animated graphics in the virtual lab aids in better visualizing and comprehending complex concepts. Additionally, the ability to simulate real experiments and analyse data helps students develop crucial practical skills in a risk-free virtual environment.

Moreover, through observation and interaction between the instructor and students, it became evident that many students appreciated the opportunity to engage in hands-on experimentation within a controlled digital environment. They found this environment conducive to exploring and testing hypotheses without the constraints of time or resources present in traditional physical labs. Additionally, the flexibility of the virtual lab platform allowed students to revisit experiments, repeat trials, and iterate on their methodologies. This iterative process reinforced their learning and problem-solving skills, contributing to a deeper understanding of the concepts. Furthermore, the virtual lab experience proved invaluable in assisting students during the transition to real laboratory settings. While there were minor differences between the virtual and real versions of the experiment, such as the exact dimensions of the flat beams and the non-ideal conditions of the beams due to years of usage (e.g., slight curvature, imperfections from manual setup), students were able to adapt and adjust their methods effectively. This adaptability was largely attributed to the solid foundation of understanding they had built through the virtual lab experience. Despite encountering the variations in the real lab environment, students demonstrated their ability to troubleshoot issues, refine their approaches, and collected the required results.

### *3.2 Student Engagement and Motivation*

As depicted in Fig. 4, a significant number of students expressed positive responses regarding the impact of the virtual lab tool on their motivation and engagement during the activity. Specifically, 21% of the students chose "strongly agree," while an additional 32% selected "agree" on the Likert scale, acknowledging that the virtual lab tool enhanced their motivation in completing the activity. Moreover, a considerable proportion of students, 21%, strongly agreed that they were engaged during the virtual lab activity, with an additional 46% responding with an "agree" on the Likert scale. This high level of engagement can be attributed to the active learning approach implemented through the virtual lab tool. The interactive nature of the Virtual lab tool, featuring animated graphics and its close relation to the actual hands-on experimentation that followed, encourages students to actively participate in the exploring the virtual tool and physical equipment. This, in turn, fosters a positive learning environment that promotes motivation and engagement among the students.

In addition, the inclusion of a gamified quiz within the pre-lab activity can have a direct impact on students’ interest in the learning process. As the students progressed through the quiz, and achieving milestones, they were motivated to continue their efforts and perform well. Previous research Gressick *et al*., [15] has demonstrated that incorporating elements of gamification into educational activities can increase students' enjoyment of learning, thereby leading to higher levels of engagement. This positive experience reflected by the survey result showing high level of engagement.

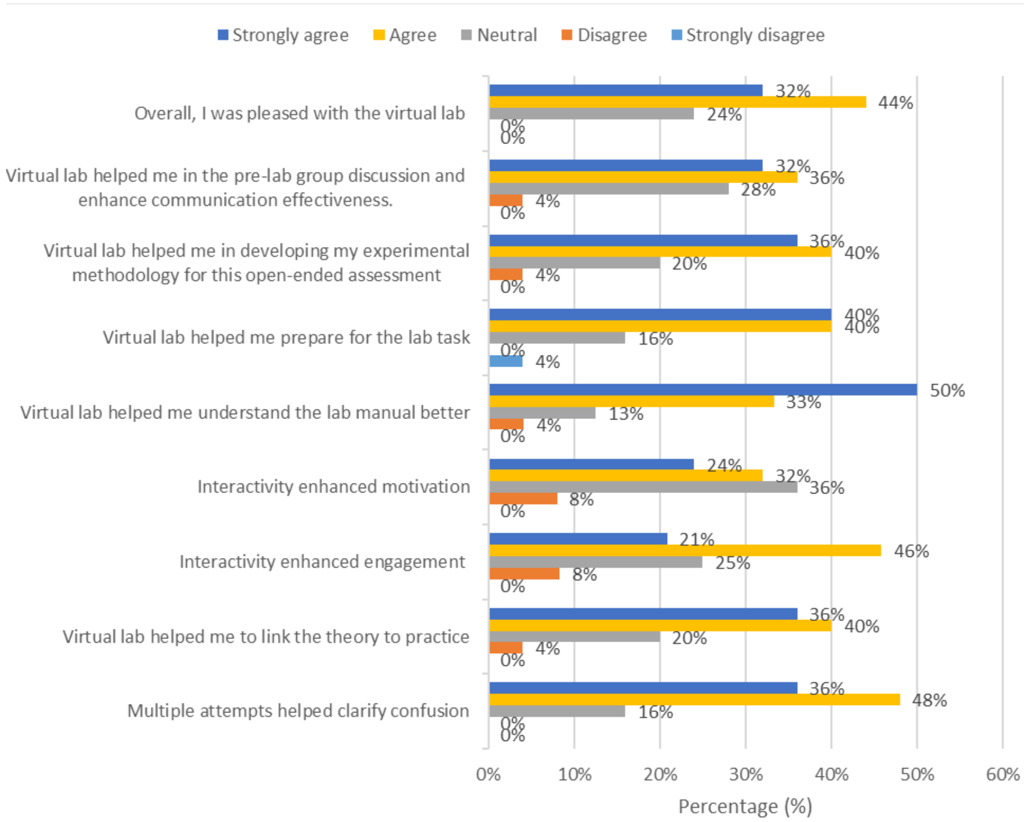


**Fig. 4.** Survey result on students' learning experience

### *3.3 Improved understanding in the subject matter*

According to the Likert scale survey (Fig. 4), a significant portion of students found the virtual lab tool beneficial for completing the lab assignment, with 36% strongly agreeing and 40% agreeing that it helped them develop their own methodology to achieve specific outcomes in the open-ended assignment. Moreover, a total of 80% of students either strongly agreed or agreed that the virtual lab activity prepared them well for the actual physical lab task. Furthermore, 50% of the students stated that the virtual lab activity helped them better understand the requirements of the lab assignment. Moreover, students were attempt the virtual lab multiple times, and resulted in a better comprehension to the assignment requirements feature.

The survey indicated that a total of 84% of students responded either "strongly agree" or "agree" that multiple attempts with the virtual lab effectively clarified any confusion they had. Additionally, most students (36% strongly agreed, and 40% agreed) felt that they were able to link the theoretical concepts taught in class to the practical application in the lab. The high level of preparedness resulting from the virtual lab experience seems to have positively impacted the students' comprehension of the lab assignment's purpose and significance. During the pre-lab phase, students had the opportunity to explore, virtually attempt, and engage in discussions with their peers, which contributed to a better understanding of the underlying principles of the subject matter.

In this study, the combination of a virtual lab as a pre-lab activity followed by a physical lab represents a flipped-classroom approach. Previous research in tertiary education has suggested that the flipped-classroom approach can be beneficial for students who may not excel academically [16], [17]. The results of our survey align with this perception, indicating that students found this approach favourable.

### *3.4 Improved Collaborative Learning*

The virtual lab activity played a significant role in enhancing students' ability to communicate their ideas during pre-lab discussions, with 60% of students expressing agreement on this point (Fig. 4). The survey results demonstrated a positive learning experience for students. Students were expected to encounter challenges during the pre-laboratory preparation because they lacked a visual understanding of the specific experiment process. As a result, peer collaboration in this phase might be less fruitful, as students could feel hesitant to express their ideas due to the lack of visualization during the planning stage. Engaging students with open-ended problems can lead to increased collaborative learning, creativity, and communication skills [18]. In this context, the virtual lab provided to the students served as a valuable tool, enabling them to illustrate the intended experiment setup and predict results. This helped avoid ambiguity in communication during the pre-lab discussions when students shared their ideas. Therefore, it can be concluded that the implementation of the flipped classroom approach, combined with the use of virtual lab support, effectively enhances the learning experience when completing open-ended laboratory tasks.

## 4. Conclusion

In conclusion, the combination of the virtual lab pre-lab activity with the actual physical lab in a flipped-classroom approach positively impacted students' learning experience, facilitating communication, comprehension, and confidence in completing open-ended laboratory tasks.

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## References

[1] Makransky, Guido, Mads T. Bonde, Julie SG Wulff, Jakob Wandall, Michelle Hood, Peter A. Creed, Iben Bache, Asli Silahtaroglu, and Anne Nørremølle. "Simulation based virtual learning environment in medical genetics counseling: an example of bridging the gap between theory and practice in medical education." *BMC medical education* 16, no. 1 (2016): 98. https://doi.org/10.1186/s12909-016-0620-6

[2] Akçayır, Gökçe, and Murat Akçayır. "The flipped classroom: A review of its advantages and challenges." *Computers & Education* 126 (2018): 334-345. https://doi.org/10.1016/j.compedu.2018.07.021

[3] Awidi, Isaiah T., and Mark Paynter. "The impact of a flipped classroom approach on student learning experience." *Computers & education* 128 (2019): 269-283. https://doi.org/10.1016/j.compedu.2018.09.013

[4] Loveys, Beth R., and Karina M. Riggs. "Flipping the laboratory: improving student engagement and learning outcomes in second year science courses." *International Journal of Science Education* 41, no. 1 (2019): 64-79. https://doi.org/10.1080/09500693.2018.1533663

[5] Kim, Minkyoung, Eulho Jung, Amaury de Siqueira, and Lesa Huber. "An investigation into effective pedagogies in a flipped classroom: A case study." *International Journal of E-Learning & Distance Education* (2016).

[6] Ali, Wahab. "Online and remote learning in higher education institutes: A necessity in light of COVID-19 pandemic." *Higher education studies* 10, no. 3 (2020): 16-25. https://doi.org/10.5539/hes.v10n3p16

[7] Radhamani, Rakhi, Dhanush Kumar, Nijin Nizar, Krishnashree Achuthan, Bipin Nair, and Shyam Diwakar. "What virtual laboratory usage tells us about laboratory skill education pre-and post-COVID-19: Focus on usage, behavior, intention and adoption." *Education and information technologies* 26, no. 6 (2021): 7477-7495. https://doi.org/10.1007/s10639-021-10583-3

[8] Colak, Ilhami, Sevki Demirbas, Seref Sagiroglu, and Erdal Irmak. "A novel web-based laboratory for DC motor experiments." *Computer Applications in Engineering Education* 19, no. 1 (2011): 125-135. https://doi.org/10.1002/cae.20298

[9] Domínguez, J. C., R. Miranda, E. J. González, M. Oliet, and M. V. Alonso. "A virtual lab as a complement to traditional hands-on labs: Characterization of an alkaline electrolyzer for hydrogen production." *Education for Chemical Engineers* 23 (2018): 7-17. https://doi.org/10.1016/j.ece.2018.03.002

[10] Bhargava, Peeyush, John Antonakakis, Christine Cunningham, and Alan T. Zehnder. "Web-based virtual torsion laboratory." *Computer Applications in Engineering Education* 14, no. 1 (2006): 1-8. https://doi.org/10.1002/cae.20061

[11] Kalogiannakis, Michail, Stamatios Papadakis, and Alkinoos-Ioannis Zourmpakis. "Gamification in science education. A systematic review of the literature." *Education sciences* 11, no. 1 (2021): 22. https://doi.org/10.3390/educsci11010022

[12] Haron, Zaiton, Shahrin Mohammad, and Abdul RahmanMohd Sam. "The implementation of an open-ended experiment in the civil engineering laboratory." *Procedia-Social and Behavioral Sciences* 102 (2013): 548-559. https://doi.org/10.1016/j.sbspro.2013.10.771

[13] Basir, Nor Irwin, Zainal Ahmad, and Syamsul Rizal Abd Shukor. "Experiential learning via open-ended laboratory initiatives." *Laboratory Unit Operations and Experimental Methods in Chemical Engineering* 23 (2018). https://doi.org/10.5772/intechopen.77015

[14] Smith, Natasha. "Teaching engineering reasoning using a beam deflection lab." In *2010 Annual Conference & Exposition*, pp. 15-1173. 2010. https://doi.org/10.18260/1-2--16908

[15] Gressick, Julia, and Joel B. Langston. "The guilded classroom: Using gamification to engage and motivate undergraduates." *Journal of the Scholarship of Teaching and Learning* 17, no. 3 (2017): 109-123. https://doi.org/10.14434/v17i3.22119

[16] Hibbard, Lisa, Shannon Sung, and Breche Wells. "Examining the effectiveness of a semi-self-paced flipped learning format in a college general chemistry sequence." *Journal of Chemical Education* 93, no. 1 (2016): 24-30. https://doi.org/10.1021/acs.jchemed.5b00592

[17] Reid, Scott A. "A flipped classroom redesign in general chemistry." *Chemistry Education Research and Practice* 17, no. 4 (2016): 914-922. https://doi.org/10.1039/C6RP00129G

[18] Fadhil, Siti Sarah Ain Binti, Muhammad Fairuz Bin Abdul Jalal, and Nuraslinda Binti Anuar. "Effectiveness of open-ended learning method in fluid mechanics laboratory course." In *2016 IEEE 8th International Conference on Engineering Education (ICEED)*, pp. 1-5. IEEE, 2016. https://doi.org/10.1109/ICEED.2016.7856050

[19] Setiawati, Anita, Devira Nur Ajizah, Nela Nur Anisa, Pristiningtyas Ambarwati, Zakiyah Ayu Noor Izzati, and Farah Erika. "The 21st century skills on chemistry learning based on virtual lab in senior high school." *JPPS (Jurnal Penelitian Pendidikan Sains)* (2021): 27-39. https://doi.org/10.26740/jpps.v11n1.p27-39

[20] Mayoz, Cándido Aramburu, Ana Lúcia da Silva Beraldo, Aitor Villar-Martinez, Luis Rodriguez-Gil, Wilson F. Moreira de Souza Seron, and Pablo Orduña. "FPGA remote laboratory: experience of a shared laboratory between UPNA and UNIFESP." In *2020 XIV technologies applied to electronics teaching conference (TAEE)*, pp. 1-8. IEEE, 2020. https://doi.org/10.1109/TAEE46915.2020.9163773

[21] Seo, Hyun Jeong, Gyu Mi Park, Minjie Son, and Ah-Jeong Hong. "Establishment of virtual-reality-based safety education and training system for safety engagement." *Education Sciences* 11, no. 12 (2021): 786. https://doi.org/10.3390/educsci11120786

[22] Vaez Ghaemi, Roza, and Gabriel Potvin. "Experimenting with labs: Practical and pedagogical considerations for the integration of problem-based lab instruction in chemical engineering." *The Canadian Journal of Chemical Engineering* 99, no. 10 (2021): 2163-2172. https://doi.org/10.1002/cjce.24136