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Home-Based Microbiology Laboratory: Perceptions and Experience among Diploma in Pharmacy Students

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Abstract

Due to the COVID-19 pandemic, an online home-based microbiology laboratory has been developed to replace the gap for psychomotor aspect and to enrich the online learning experience. This study was conducted to assess students' perceptions of online and distance learning (ODL) for microbiology laboratory learning experiences among diploma in pharmacy students. A total of 130 students participated in this newly designed ODL home-based laboratory whereby an online survey was used to collect their opinions. Overall, students' perceptions towards ODL laboratory experience were positive whereby they believed to have gained new knowledge from the laboratory sessions. Students stated that the practical was satisfying (64.4%) and convenient to their schedules (58.7%). Almost three quarter of the students (71%) enjoyed the practical sessions whilst 37.5% of them thought the hands-on kit enhanced their understanding of the laboratory experiments. Nevertheless, 85.6% of them encountered problems with observations of their experiments while others had difficulties with aseptic techniques and hands-on kits. Undoubtedly, 77.9% of them still favour face-to-face compared to ODL laboratory sessions. Our findings suggest that our ODL home-based laboratory have improved students' understanding of the laboratory experiments leading to positive ODL experiences.

Keywords: Hands-on Kit, Home-Based, Microbiology, Online Learning, Perception

Introduction

The COVID-19 pandemic has impacted the world and most aspects of life. The outbreak which started in Wuhan, China Zhu et al (2020), reached Malaysia on the 25th of January 2020, with the first (three) cases originating from 3 Chinese nationals who entered the country from Singapore (New Strait Times, 2020). Two months following the mentioned cases, the Movement Control Order (MCO) was announced on the 18th of March 2020 (Tang, 2020). The MCO forces most sectors in the country to limit, if not stop all face-to-face engagement (Tang, 2020). All levels of education in the country were forced to adopt the

online method, cramping all manner of different aspects of conventional education to the electronic approach. Whilst the teaching and learning process has been evolving and adapting to the online approach via the implementation of blended learning and such, its growth hit a sudden spurt recently due to the restriction following the pandemic. Some universities, including Universiti Teknologi MARA (UiTM) had been using the e-blended learning management system (LMS) as an additional method to the traditional approach in the past 10 years prior to the pandemic (Sabri et al., 2010), but most universities were unprepared for a comprehensive online experience (Coman et al., 2020). However, following the sudden and forced situation, education providers have no other option than to resort for the e-approach Lemay et al (2021), and as a result, a lot of new teaching and learning practices emerged, with the majority opting for a full online experience utilising platforms such as UFUTURE - UiTM home grown online LMS Othman et al (2022a), Google Meet, Microsoft Teams and Webex.

Whilst theory-based subjects such as pharmacology, has reported satisfactory transition Ezeala et al (2020), issues arise with courses which are associated with the psychomotor or technical skill as their core and important criteria. Under normal conditions, most conventional tertiary higher education health science courses necessitate laboratory sessions, that is essential in providing hands-on experience and abilities which are otherwise unachievable through lectures and passive reading solely (Brockman et al., 2020). With regards to microbiology, safe working techniques and microbe manipulation are among the hands-on laboratory skills that educators believed should be taught in-person (Horak, 2020). There are a variety of methods available to help with online course delivery, such as digital content that presents microbiological learning objects or lab-related and (or) data-driven tasks. The most common strategy used in distant learning is the use of virtual laboratory simulators. However, these lab simulations limit students with the opportunity to engage in hands-on science activities. This approach frequently restricts the use of divergent or experimental lab work because the learner is guided by a particular software tool (Santiago et al., 2022). The failure to provide a typical in-person microbiology laboratory experience is said to be a major source of worry among microbiology educators (Noel et al., 2020).

Therefore, an alternative approach is needed to fill the deficiency created by the lack of wet-lab or hands-on sessions due to the current constraint. The microbiology laboratory practical for Diploma in Pharmacy students have implemented a mixed/balanced between hands-on and online approach to counter said deficiencies and improve the overall online distance education laboratory experiences. The improvement is achieved by re-constructing 5 experiments utilising a hands-on laboratory kit which was prepared and mailed to each student. The ODL for the laboratory sessions require the students to use the mailed kits and household items throughout the experiments. A step-by step guide was provided via a pre-recorded video and text instructions. Likewise, students were required to submit a lab report for each of the experiments. Lecturers used an LMS to implement both synchronous and asynchronous strategies. Synchronous learning was offered as pre-lab interactive lectures, while asynchronous components include videos, external links for websites and other additional online resources (Zalat et al., 2021). It is critical that students' learning experiences include connections between culture and their surroundings; the opportunity, casual contacts that form bonds with peers and enjoyable learning sessions do not deteriorate and continue to play an important role in any excellent programme, albeit in a new form (Gamage et al.,

2020). It has been reported that lab work that emphasises problem-solving and discovery can improve learning (Mahmoudet al., 2020).

This report assesses the Diploma in Pharmacy students' perceptions and experiences on the conducted ODL microbiology lab. The findings of this study will help in improving the ODL teaching and learning laboratory activities in near future. In order to adapt to the ODL environment, the results will also be utilised to examine the microbiology component of the Diploma in Pharmacy curriculum.

Methodology

Study Design

The practical activities presented here were created in collaboration with students enrolled in the Microbiology course during their third semester of Diploma in Pharmacy at UiTM Cawangan Pulau Pinang Kampus Bertam. A total of 5 experiments were created based on the traditional lab experiments. However, a microbiology hands-on laboratory kit was only prepared and mailed to each student for 3 experiments which include the topic of basic laboratory techniques for isolation, identification, cultivation of microorganisms and control of microbial growth. The lecturer gave an online pre-lab lecture at the beginning of each lab session, which lasted around 20 to 40 minutes depending on the experiment to be conducted. Pre-lab videos were also designed to cover the pre-lab lecture material. The students were given instructions in the form of a lab manual that specified the aims, materials and methods of each experiment to enable them to conduct it on their own. Students conducted the experiments unsupervised using the hands-on laboratory kits and other home-based materials. Students also need to use household items such as soap, detergent or hand sanitizer and disinfectant to minimize contamination. Students prepare laboratory reports and answer evaluation questions based on their observations.

Data Collection

A survey was developed to find out how students felt about their microbiology lab experiences. All students were asked to complete the same survey while reflecting on their own experience in the ODL microbiology lab. The questionnaire was sent through email and WhatsApp to students with request letters for their responses (Othman et al., 2022b). A survey questionnaire with both closed and open-ended questions was designed and data were collected to investigate students' perceptions and their experiences. It consisted of basic demographic, perception and experience questions of the ODL lab practice. The demographic data consisted of gender, age, area of residence and learning style. Three questions for evaluating student perception of ODL laboratories whereby two questions used a 5-point Likert scale (where scores of 1-5 were used to indicate levels of agreement with the statements) and a closed ended with multiple choice questions for students' perception. Meanwhile five close-ended and open-ended questions were used to evaluate students' experience of the ODL lab practices.

Data Analysis

The data obtained were analysed qualitatively and presented in descriptive form. Mean and standard deviation (SD) were presented for numerical data, while frequency and percentage were presented for the categorical data. The responses for overall perception of

the microbiology lab practice (5-point Likert scale) were transformed into scores using the following rule: five points and one point for very good and very poor, respectively.

Ethical Aspect

Prior to collecting the data reported in this study, the survey and methods were approved by Universiti Teknologi MARA's (UiTM) Research Ethics Committee (REC) reference number REC/04/2021(MR178).

Results

Out of 130 students registered for microbiology course, a total of 104 have responded to the survey with the age range between 19 to 21 years old. Majority of the respondents were females (83.7%) compared to males (16.3%). A total of 60.6% of the students lived in sub-urban areass whilst 23.1% from urban areas sand 16.3% from rural areas. Students were asked to report their desired current learning style and were given the choices of visual, auditory or kinesthetics. As shown in Figure 1, students who attended the microbiology labs reported a greater preference towards a visual learning style (68.3%) whilst kinesthetic learners were the least preferred (8.7%).

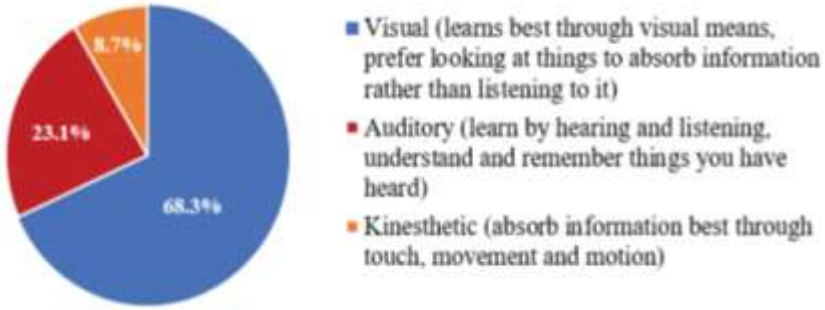

Figure 1: Respondents' learning style

Students were asked for their perception regarding the overall experience of online distance learning in their microbiology lab practice, with five Likert scale choices from 1 to 5 with 1 being 'very poor' and 5 being 'very good' (Table 1, question 1). A sum of 18.3% rated their ODL experience as very good followed by 65.4% rated good and 16.3% rated fair. The median perception score among the students was 4 (range: 3 to 5), which indicates that the students have a good perception and experience with their home-based microbiology laboratory experiments. Students were also asked how much new information they believed they had gained from their microbiology lab experience, using a five-point Likert scale ranging from 1 to 5, with 1 denoting "no new information" and 5 denoting "essentially all new information was learned" (Table 1, question 2). A total of 17.3% felt they had learned new essential information whilst 58.7% gained mostly new information and 24% felt they had gained some information during the ODL microbiology lab practice. The current study also solicited participants' perception regarding the implementation of ODL in their microbiology lab session (Table 1, question 3). A sum of 64.4% reported that the ODL microbiology lab was satisfying whilst 41.3% felt it was stimulating. Next, 58.7% respondent felt the ODL microbiology lab was flexible and convenient in relation to time and space. Likewise, 45.2% of the respondents felt that the ODL lab practice was easy to understand, but 22.1% felt that it was difficult to conduct. Only 2.9% of students thought that the ODL microbiology lab was boring.

Table 1
Student's perception regarding ODL microbiology lab practice.

Description		N (%)
1.	Overall perception of the microbiology lab practice.	
	Very poor	0 (0.0)
	Poor	0 (0.0)
	Fair	17 (16.3)
	Good	68 (65.4)
	Very Good	19 (18.3)
2.	How much new information they felt they had learned via ODL microbiology lab experience.	
	No new information	0 (0.0)
	Small amount of new information	0 (0.0)
	Some new information	25 (24.0)
	Mostly new information	61 (58.7)
	Essentially all new information	18 (17.3)
3.	Perception on the implementation of ODL lab sessions*	
	I found the ODL microbiology laboratory satisfying.	67 (64.4)
	I found the ODL microbiology laboratory stimulating.	43 (41.3)
	The ODL microbiology laboratory is flexible in relation to time and place.	61 (58.7)
	The ODL microbiology laboratory is easy to understand.	47 (45.2)
	I found the ODL microbiology laboratory difficult to conduct.	23 (22.1)
	The ODL microbiology laboratory is boring.	3 (2.9)

Notes: *Multiple responses possible. Therefore, the total may exceed 100%

The close-ended question data identified whether respondents had a positive, negative or indifferent experience while conducting ODL experiments (Table 2). Majority of the students agreed that they enjoyed microbiology lab experiments (75%). In addition, 85.6% of the students felt that the pre-lab lecture, slides and lab manual helped them to understand the purpose of the lab experiment. Moreover, 70.2% of the students agreed that the time given for each lab experiment was adequate. Nevertheless, 8.7% of the students reported that it took a long time for them to complete the lab experiments. Likewise, 43.3% of the

students expressed that they felt lonely in completing the lab experiment. This may be due to the lack of interactions with friends and lecturers while conducting the experiments. Lastly, 68.3% agreed that the laboratory experiments helped them understand topics from lecture and text.

Table 2
Student's experience while conducting ODL experiments.

Description	N (%)		
	Agree	Neutral	Disagree
I felt lonely completing the lab experiments	45 (43.3)	46 (44.2)	13 (12.5)
Time given for each experiment is adequate.	73 (70.2)	23 (22.1)	8 (7.7)
I did not learn anything from the lab experiments	0 (0.0)	19 (19.2)	84 (80.8)
It took me too long to complete the lab experiments	9 (8.7)	51 (49.0)	44 (42.3)
I enjoyed conducting the microbiology lab experiments	78 (75.0)	26 (25.0)	0 (0.0)
The pre-lab lecture, slides and lab manual helped me understand the purpose of the lab experiment	89 (85.6)	14 (14.4)	0 (0.0)
The laboratory experiments helped me with the understanding of topics from lecture and text.	71 (68.3)	31 (29.8)	2 (1.9)

Students were asked about the type of lab experience they felt most effectively enhanced their understanding of the purpose of the lab experiments and were given the choices of the hands-on kit, lab manual, pre-recorded video and pre-laboratory lecture. As shown in Figure 2, majority of the students felt that the hands-on kit (37.5%) was the most effective experience in enhancing their understanding of the lab experiment, followed by the pre-recorded video (27.9%), the pre-lab lecture (25.0%) and the lab manual (9.6%).

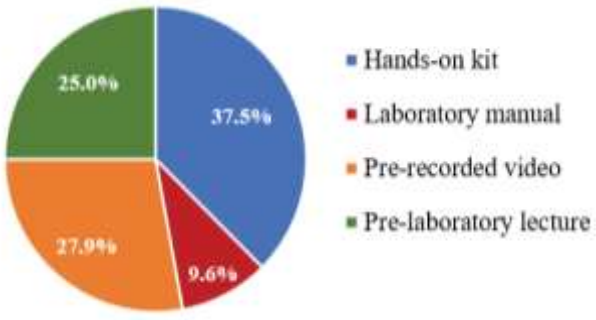

Figure 2: Most effective lab experience that enhances students' understanding of the lab experiments' purposes.

The close-ended question data identified whether respondents had a positive, negative or indifferent experience concerning the pre-recorded videos (Table 3). Most of the students reported that the pre-recorded video helped students to be better prepared for their lab experiments (93.3%) and understand the purpose of the experiments (80.8%). Almost all students would preview the pre-recorded videos before conducting their experiments (94.2%). The pre-recorded videos also allow the students to conduct practical work at their own time and pace.

Table 3
Student's experience using the pre-recorded video on conducting lab experiments.

Description	**N (%)**		
	Agree	**Neutral**	**Disagree**
The videos were not useful for my self-learning	2 (1.9)	20 (19.2)	82 (78.8)
The videos allow me to work at my own pace.	87 (83.7)	16 16.3)	0 (0.0)
I did not preview the video-guides before conducting the experiment.	1 (1.0)	5 (4.8)	98 (94.2)
The videos help students to be better prepared for the laboratory.	97 (93.3)	7 (6.7)	0 (0.0)
I understand more from printed instructions compared to the video-guides.	8 (7.7)	56 (53.8)	40 (38.5)
The videos helped me understand the purpose of the lab experiment	84 (80.8)	19 (19.2)	0 (0.0)
I was able to apply the skills learned from the videos lab to my lab work	80 (76.9)	24 23.1)	0 (0.0)
The videos help students to better understand the experiment and how it connects to topics covered in lecture.	82 (78.8)	22 (21.2)	0 (0.0)

Students were also asked about which experiment they like most. As shown in Figure 3, most of the students liked the experiment of growing microorganisms using three different types of agars. Likewise, 31.7% preferred the experiment on preparing agar and cultivation of microorganisms. Only 1 student (1%) liked completing microscopy and common staining technique worksheets.

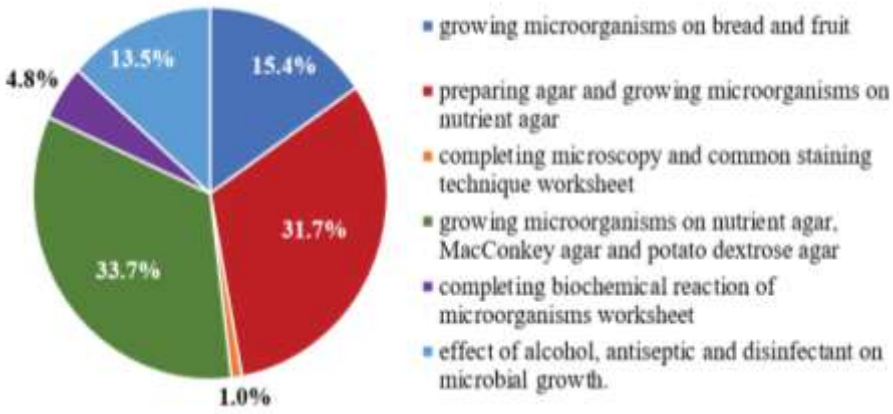

Figure 3: Experiments the students like the most.

However, students identified some difficulties while conducting their experiments especially with their observations, aseptic techniques and hands-on kit. Majority of the students reported that their observations were not as what they expected. Some students reported having lack of proper equipment at home to melt their nutrient agar, therefore they have problems in solidifying their agar plates. Students also have problems maintaining their sterile working area; therefore, it was difficult for them to exercise aseptic technique accordingly. Other problems encountered by students were delayed arrival of the hands-on kit (more than 5 days) and damaged petri plates or materials. These responses are summarized in Table 4. Most of the students reported that they have problems with their results and observations which were not as expected (85.6%). One of the students mentioned that it was difficult to analyse the observations whether it was good or not. Students also reported that they have problems conducting the experiment in sterile conditions. Next, 76% of the students felt that their working areas were not sterile since they do not have proper equipment or condition for aseptic technique, therefore it was difficult to minimise the contamination. Moreover, 59.6% of the students reported the failure of using correct aseptic technique while conducting the experiment. Students also reported that they faced problems with the hands-on kit. More than half of the students (51.9%) reported that they have received damaged petri plates. Students also reported that some of the agar powder spilled upon arrival, leading to insufficient material (18.3%). Likewise, 11.5 % of students reported that it took more than five days to receive their hands-on kit. Other problems reported by students include the agar did not solidify accordingly (47.1%) and distraction from family members (1.9%).

Table 4
Difficulties faced by students while conducting ODL microbiology lab experiments.

Description	N (%) *
Hands-on kit arrived late (>5 days)	12 (11.5)
Received damaged petri plates	54 (51.9)
Agar powder spilled causing not enough materials	19 (18.3)
Working area is not sterile/ difficult to minimize contamination	79 (76.0)
Failure to perform proper aseptic technique	62 (59.6)
The agar did not solidify accordingly	49 (47.1)
Result is not as expected	89 (85.6)
Other external factors that may influence the result or process such as family or environment.	2 (1.9)
None	1 (1.0)

*Multiple responses possible. Therefore, the total may exceed 100%

Our findings revealed that, while students are greatly supportive of the ODL microbiology lab activities, many students (77.9%) still seek physical hands-on laboratory experiences. Students lamented the lack of peer-to-peer and student-instructor interactions. Some students mentioned the advantage of having direct interactions with both peers and the lecturers in the traditional microbiology laboratory setting. In an open-ended question regarding their opinion on the microbiological laboratory, students expressed their hope to return to campus again for the face-to-face laboratory sessions. They stated that an in-person lab session is better than ODL in terms of facilities, equipment and interaction with peers and lecturers.

Discussion

Traditionally, microbiology laboratory practical for students has taken place in the laboratory, led by lecturers in a face-to-face context. However, since the onset of the pandemic, students have been affected by the COVID-19 closures and subsequent educational changes. When the MCO was implemented by the Malaysian government, all the students were forced to attend classes remotely. Since then, all classes were conducted via e-learning including lab practical sessions. Laboratory activities play an important role in teaching and learning science courses. Many science-based courses require the development of core "hands-on" abilities, therefore finding the effective teaching techniques is not a unique issue. There is a basic set of skills in microbiology needed in order to perform safely and efficiently in laboratory settings. These skills include hands-on laboratory competencies that represent best practises for handling and viewing microorganisms (Noel et al., 2020).

The home-based laboratory was designed to provide hands-on experiences using the hands-on kit, lab manual, pre-lab videos of experiments and pre-lab lectures to develop

practical skills and knowledge for the student. Overall, students' responses regarding their perception towards home-based laboratory experience were positive. Some students perceived the microbiology lab experience as satisfying and stimulating while some felt that it was convenient for their schedules due its innate adaptability of time and space. The incorporation of different methodologies into the lab session seems to be appreciated by our students. Combining visual (lab manual and discussion), auditory (pre-lecture and pre-recorded video) and kinaesthetic effects from the hands-on kit were perceived positively by our students in accordance with previously published articles by (Brockman et al., 2020). As reported by Brockman et al (2020) in his study, hands-on microbiology laboratory activities were valued by medical students and the same is likely to be true for our students. As discussed by Joshi (2021), teaching that is both engaging and innovative is essential in educating microbiologists with the skills they need to tackle healthcare concerns, especially in light of the COVID-19 pandemic.

Based on the survey of student perceptions and experience, this study provides support for the notion that microbiology laboratory practical can be taught using an online or distance education platform using hands-on lab kits for at-home convenience. Most of the students like experiments that involve the use of the hands-on kit provided by the faculty such as growing microorganisms using different types of agars, preparing agar plates and cultivation of microorganisms. The hands-on kit provides a stimulating learning experience and opportunity for students to develop practical skills. Students were able to experience hands-on manipulation of materials from the kit, learn microbiological techniques and understand the purpose of the experiments. As discussed by Noel et al (2020), home-labs and delivering kits to students via mail have the potential to stimulate students' interest in microbiology. According to a case study by Santiago et al (2022), the optimal distance learning method for subjects like chemistry or chemical engineering is the usage of home laboratory kits. Additionally, it has been claimed that take-home experiments have improved students' attitudes toward science (Zulirfan et al., 2017).

Majority of students reported that the pre-recorded video helped them comprehend the goal of the experiments and be better prepared for their lab experiments. These findings are consistent with those of Lewandowski et al (2020), who found that a high percentage of the class (approximately 80%) felt the pre-lab videos prepared them well, was more interesting and allowed them to complete the experiment at their own pace. The intention of pre-recorded video was for the students to view prior to performing any specific experiment, thus eliminating the need for an extensive pre-lab lecture, improve students' preparation and increase their understanding of the experiments. According to Kestin et al (2020), videos could provide students with an equally effective learning experience when live lecture demonstration are unavailable. The use of pre-recorded video to explain essential skills within the laboratory, where the educator is filmed practising tailored microbiological methods, such as preparing agar medium and using aseptic technique, is an attempt to replace in-person instruction. While there is no substitute for hands-on learning, students might be encouraged to practise basic techniques at home using common household items (Joshi, 2021).

Almost all students (99%) reported that they had experienced at least one of the following issues: hands-on kit arrived late (>5 days), damaged petri plates, spilled agar powder, working areas were not sterile or difficult to minimize contamination, failure to

perform proper aseptic technique, agar did not solidify accordingly, results were not as expected or other external factors that may influence the result or process such as family or environment. Many students reported having issues with their results and observations. According to Rowe et al (2018), students can gain valuable experience and confidence when their experiments did not go as planned as they will learn from their mistakes and will improve themselves in their next experiments. Even though the study demonstrated a favourable opinion of a home-based laboratory by the students, they still considered that laboratory practising was best done in a physical set up with suitable equipment tailored to deliver this experience. A study from Salter and Gardener (2016) suggested that the reason students perceived the in-person lab as more beneficial and enjoyable is because they felt more engaged in the learning process when they were able to physically interact with an instructor.

Conclusion

The study findings reveal that, Diploma in Pharmacy students had a positive perception of their online distance learning (ODL) laboratory experience in a home-based microbiology laboratory. Most students believed they gained new knowledge from the laboratory sessions and found them satisfying and convenient to their schedules. A significant proportion of students enjoyed the practical sessions and felt that the hands-on kit enhanced their understanding of the experiments. However, some students encountered difficulties with observations, aseptic techniques, and hands-on kits. Despite the positive perceptions, a large percentage of students still preferred face-to-face laboratory sessions over ODL. These findings provide evidence that ODL in microbiology laboratories is feasible, particularly during the pandemic. The majority of students found the ODL laboratory sessions satisfying and stimulating, highlighting the effectiveness of the provided hands-on kit and pre-lab videos in enhancing their understanding and preparedness. However, considering the expressed preference for face-to-face sessions, a blended approach that combines traditional face-to-face learning with online components could be more beneficial in improving students' laboratory skills. Overall, this study highlights the potential of ODL in microbiology laboratories while acknowledging the importance of incorporating face-to-face elements to cater to students' preferences. Further research and exploration of innovative approaches in combining online and traditional laboratory experiences can contribute to the continuous improvement of distance learning in the field of pharmacy education.

Co-Author Contribution

The authors declared that there is no conflict of interest in this article. Suraya Sulaiman involved in conceptualisation, data curation, statistical, research methodology and managed the write-up of the whole article. Mohd Izani Othman was involved in conceptualisation, interpretation of the results and reviewing the whole article. Mohd Nadzri Mohd Najib prepared the literature, interpretation of the results and reviewing the whole article. Wan Nordini Hasnor Wan Ismail involved in reviewing and editing the whole article.

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References

Brockman, R. M., Taylor, J. M., Segars, L. W., Selke, V., & Taylor, T. A. (2020). Student perceptions of online and in-person microbiology laboratory experiences in undergraduate medical education. *Medical education online*, *25*(1), 1710324. https://doi.org/10.1080/10872981.2019.1710324

Coman, C., Țiru, L. G., Meseșan-Schmitz, L., Stanciu, C., & Bularca, M. C. (2020). Online teaching and learning in higher education during the coronavirus pandemic: Students' perspective. *Sustainability*, 12(24), 10367. https://doi.org/10.3390/su122410367

Ezeala, C. C., Ezeala, M. O., & Akapelwa, T. M. (2020). A Survey of Medical Students' Experiences with Online Practical Pharmacology Classes during Covid19 Lockdown. *Medical Journal of Zambia*, *48*(1), 25-30. https://www.ajol.info/index.php/mjz/article/view/206233

Gamage, K. A., Wijesuriya, D. I., Ekanayake, S. Y., Rennie, A. E., Lambert, C. G., & Gunawardhana, N. (2020). Online delivery of teaching and laboratory practices: continuity of university programmes during COVID-19 pandemic. *Education Sciences*, *10*(10), 291.

Horak, R. (2020). Virtual Resources to Teach Microbiology Techniques and Experiments.. https://asm.org/Articles/2020/December/Virtual-Resources-to-Teach-Microbiology-Techniques Accessed 08 Oct 2021.

Joshi, L. T. (2021). Using alternative teaching and learning approaches to deliver clinical microbiology during the COVID-19 pandemic. *FEMS Microbiology Letters*, *368*(16), fnab103.

Kestin, G., Miller, K., McCarty, L. S., Callaghan, K., & Deslauriers, L. (2020). Comparing the effectiveness of online versus live lecture demonstrations. *Physical Review Physics Education Research*, *16*(1), 013101.

Lemay, J. D., Doleck, T., & Bazelais, P. (2021). Transition to online teaching during the COVID-19 pandemic. *Interactive Learning Environments*, 1-12. https://doi:10.1080/10494820.2021.1871633.

Lewandowski, H. J., Pollard, B., & West, C. G. (2020, January). Using custom interactive video prelab activities in a large introductory lab course. In *PERC Proceedings*. https://

Mahmoud, A., Hashim, S. S., Sunarso, J. (2020). Learning permeability and fluidisation concepts via open-ended laboratory experiments. Educ. Chem. Eng. 32, 72–81. https://doi.org/10.1016/j.ece.2020.05.008. Makransky, G., Thisgaard, M.W., Gadegaard, H.,

Noel, T. C., Rubin, J. E., Acebo Guerrero, Y., Davis, M. C., Dietz, H., Libertucci, J., & Sukdeo, N. (2020). Keeping the microbiology lab alive: essential microbiology lab skill development in the wake of COVID-19. *Canadian Journal of Microbiology*, 66: 603–604 (2020) dx.doi.org/10.1139/cjm-2020-0373

Othman, M., Sulaiman, S., Najib, M., & Wan Ismail, W. (2022a). Forced Online and Distance Learning (ODL) During COVID-19 Pandemic: Revealing Students' Perceptions and Experiences. *Asian Journal of University Education, 18*(4), 894-905. doi:10.24191/ajue.v18i4.19994

Othman, M. I., Sulaiman, S., Najib, M. N. M., Ismail, W. N. H. W. (2022b). Covid-19 Transmission and Prevention: Knowledge and Awareness Among Diploma in Pharmacy Students. International Journal of Education, Psychology and Counseling, 7 (46), 430-448. doi: 10.35631/IJEPC.746033

Rowe, R. J., Koban, L., Davidoff, A. J., & Thompson, K. H. (2018). Efficacy of online laboratory science courses. *Journal of Formative Design in Learning*, *2*(1), 56-67. https://doi:10.11120/ened.2009.04020070

Sabri, N. M., Isa, N., Daud, N. M. N., & Aziz, A. A. (2010). Lecturers' experiences in implementing blended learning using i-Learn. In *2010 International Conference on Science and Social Research (CSSR 2010)* (pp. 580-585). IEEE. doi: 10.1109/CSSR.2010.5773845.

Salter, S., & Gardner, C. (2016). Online or face-to-face microbiology laboratory sessions? First year higher education student perspectives and preferences. *Creative Education*, *7*(14), 1869.

Santiago, D. E., Melian, E. P., & Reboso, J. V. (2022). Lab at home in distance learning: A case study. *Education for Chemical Engineers*, 40, 37-44.

Tang, K. H. D. (2020). Movement control as an effective measure against Covid-19 spread in Malaysia: An overview. *Jornal of Public Health.* 2020:1–4. doi: 10.1007/s10389-020-01316-w

Zalat, M. M., Hamed, M. S., Bolbol, S. A. (2021) The experiences, challenges, and acceptance of e-learning as a tool for teaching during the COVID-19 pandemic among university medical staff. *PLOS ONE*, 16(3): e0248758. https://doi.org/10.1371/journal.pone.0248758

Zhu, H., Wei, L. & Niu, P. (2020). The novel coronavirus outbreak in Wuhan, China. *Global Health Research and Policy,* 5, 6 (2020). https://doi.org/10.1186/s41256-020-00135-6

Zulirfan, I., Osman, K., & Salehudin, S. N. M. (2018). Take-home-experiment: Enhancing students' scientific attitude. *Journal of Baltic Science Education*, 17(5), 828.