Benefits and challenges in the implementation of virtual laboratory simulations (vLABs) for medical biochemistry in Indonesia

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Benefits and challenges in the implementation of virtual laboratory simulations (vLABs) for medical biochemistry in Indonesia

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Abstract

The pandemic caused major shifts in the delivery of education worldwide. In the teaching of medical biochemistry, the greatest impact was towards the delivery of traditional laboratory simulations. In this study, we highlight the benefits and barriers encountered in the use of virtual laboratories (vLABs) to substitute traditional laboratory practicals. The subjects were a class of 271 medical students at the Faculty of Medicine, Hasanuddin University, all freshman undergoing the Biomedicine Block. The study assessed the use of a commercial vLAB on antibodies and blood typing procedures, which were implemented using our four-step model of vLAB implementation. Collected data include the lecturer-assigned pre- and post-test result, built-in vLAB assessment result of the student first and best attempts, a student perception questionnaire based on a 5-point Likert scale, and an open ended questionnaire regarding student perceptions of the advantages and disadvantages of the vLAB. We observed a remarkable increase of lecturer assigned pre- and post-test scores and built-in first and best attempt scores ($p < 0.0001$, Wilcoxon signed rank test). A majority of students reported increased motivation when using the vLABs, and favored the ability of mastery through repetition. However, technical and language barriers were highlighted by students during the vLAB implementation. We demonstrate a successful implementation of commercial vLABs in a cohort of non-native English speakers using our four-step approach. Implementation requires strong support from faculty to address technical and language barriers that arise during use of vLABs.

KEYWORDS

biomedical education, laboratory exercises, medical biochemistry, using simulations and internet resources for teaching, virtual laboratory

1 | INTRODUCTION

The COVID-19 pandemic has caused many abrupt and drastic changes in the delivery of education across all fields. In our higher-education institution, the undergraduate Bachelor of Medicine Programme, Faculty of Medicine, Hasanuddin University, the lockdowns coincided with the initiation of the new academic year of 2020. The first learning block for the freshman cohort was the Biomedicine block, an intensive course that aims to deliver the basic medical sciences required for students in order to comprehend the subsequent clinical science blocks. Under normal circumstances, the biomedicine block is taught through a combination of face-to-face lectures and laboratory practicals. Upon the onset of the pandemic, transition from live lectures to zoom-based lectures were quick, but the laboratory and clinical skill practicals posed a challenge to the programme. This challenge was emphasized by the lack of preparation time between the lockdown initiations to the start of the curriculum.

As one of the main contributors to the Biomedicine Block, the Department of Biochemistry of the Faculty of Medicine aims to provide comprehensive integration of both clinical, theoretical, and laboratory aspects to instill comprehension of physiological and pathological processes, and enhance understanding of health-disease processes and the laboratory principles involved in diagnostics.[1,2] To achieve said aims, we chose to implement virtual laboratories (vLABs) to completely replace traditional laboratory learning during the year 2020–2021. Advances in technology and virtual reality are major driving forces in the increased implementation of vLABs in recent years, particularly in the STEM fields.[3] Studies have been conducted to assess the potential role of vLABs to either supplement or replace laboratory-based learning. Although some have indicated no difference in learning achievement, most of the data supports the notion that virtual learning laboratories provide comparable or greater learning achievement compared to traditional laboratory learning.[4] In addition, vLABs have been shown as a more cost- and time-efficient alternative for laboratory exploration, with greater usage flexibility due to the remote access.[5]

The platform used in this study was Labster, a gamified laboratory learning environment for practical and experimental work in STEM education. The Labster virtual learning environment is equipped with the necessary guidance required to support student inquiry,[6,7] including built-in process constraints, prompts, and heuristics in the form of mission checklists, adequate presentation of information (both theoretical and practical), built-in assessments with instant feedback, and a performance dashboard for students and the lecturer. The platform has been described in previous studies to be as effective as traditional tutorials for the preparation of life science practicals,[8] and has been shown to assist in connecting theory with practice, and increase student motivation.[9] Despite its effectivity, a barrier that has been reported in previous studies includes technical issues.[9] In addition to anticipating the reported barriers of technical difficulty, we also highlight the potential language barrier that may occur as we tried to implement the Labster vLAB platform in our institution that consists of a cohort of non-native English speakers.

In this article, we aim to describe the outcomes, challenges, and benefits of vLABs in our setting. To illustrate said strategies, we provide the approach and evaluation data from one of the simulations used in our first Biomedicine block, which is the antibodies and blood-typing laboratory practical.

2 | METHODS

2.1 | Sampling

The sample cohort was composed of an entire class of first-year undergraduate students in the Bachelor of Medicine Programme, at the Faculty of Medicine Hasanuddin University. All students had no previous experience using the vLAB platform. Prior to commencement, the study attained ethical approval from the Faculty of Medicine Institutional Review Board (IRB Application Number 250/UN.4.6.4.5.31/PP36/2020), and students were notified of the anonymity of their responses.

2.2 | Biomedicine block context and the virtual simulation

The Biomedicine Block is a 5-week course that consists of both theoretical lectures and laboratory practical on fundamental medical sciences. Prior to the practical, the students have received a relevant 2-h online lecture on antibody structure and antibody–antigen interactions, as well as a 2-h online lecture on blood biochemistry which covers the basics of blood-typing. Both theoretical lectures were delivered in the format of blended, task-based learning, with synchronized discussions conducted via zoom.

The vLABs used was the Labster Antibodies Virtual Simulation, which is a commercially available vLAB with license purchased by the faculty prior to

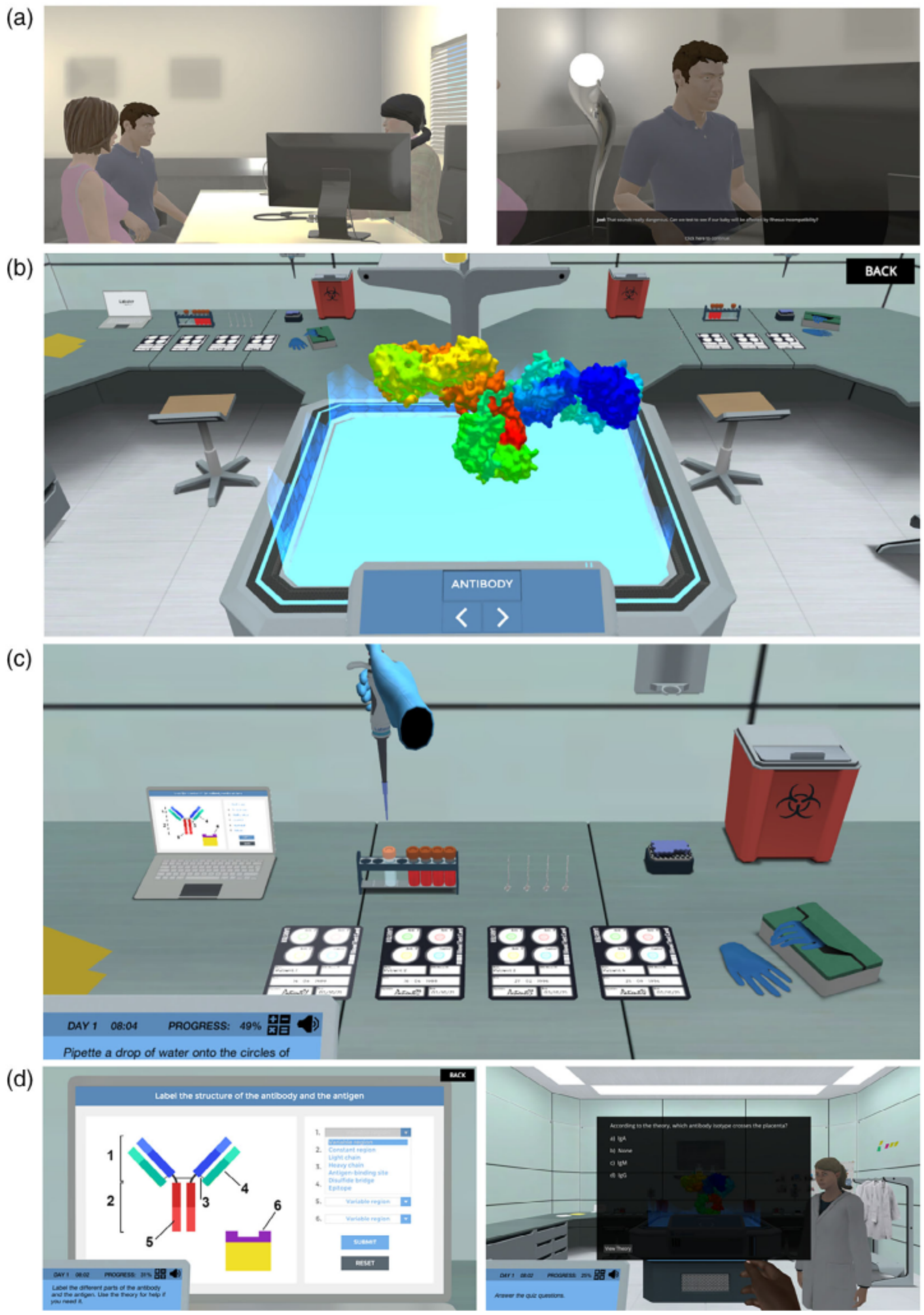
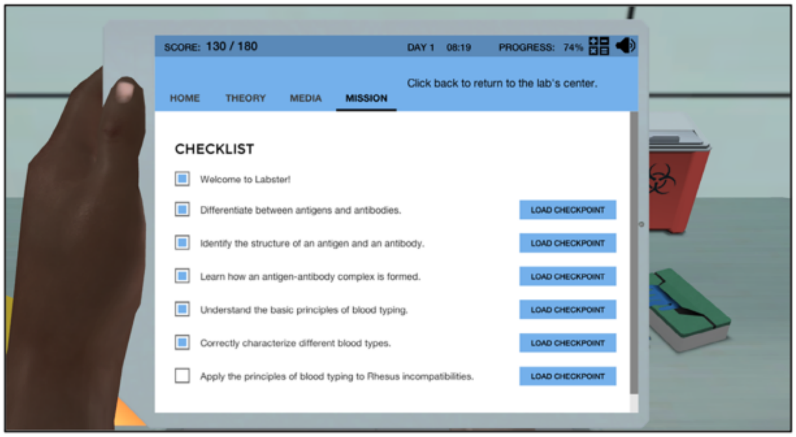
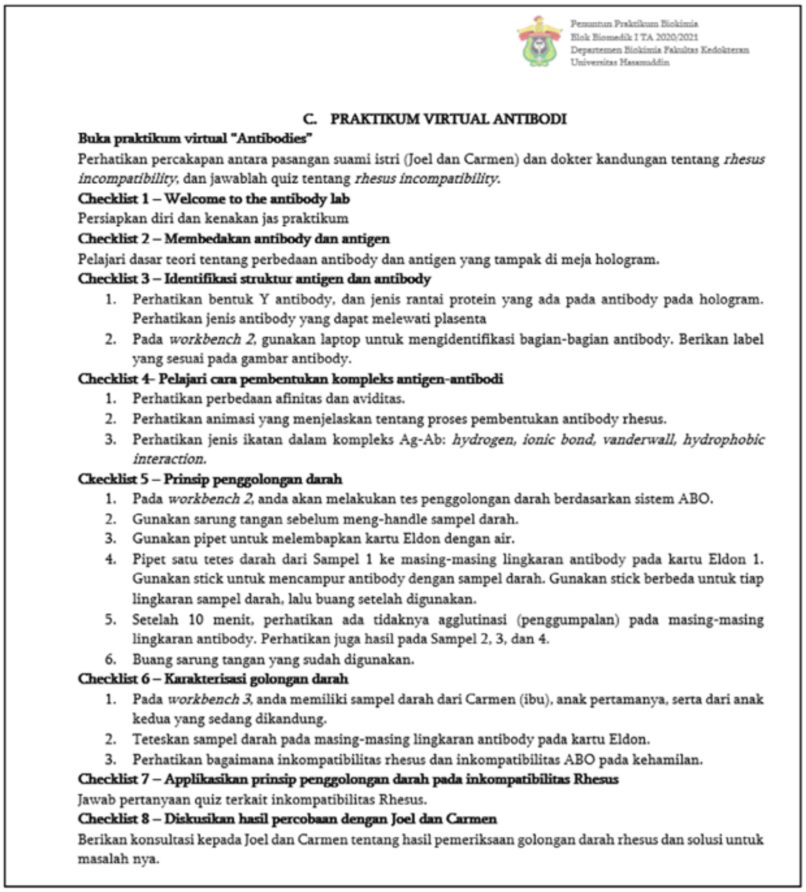


FIGURE 1 Overview of the vLAB simulation utilized in the study. (a) The simulation provided a clinically relevant, problem-based approach on antibodies and blood-typing with real-life scenarios to set the practical. (b) Animations and theoretical reinforcements were provided throughout the simulation to reinforce the previous lectures that were delivered to students through synchronized zoom sessions. (c) Example of the ABO and rhesus blood-typing procedure. (d) Built-in assessments were provided throughout the simulation to assess both completion and comprehension. vLAB, virtual laboratory





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Blok Biomedik I TA 2020/2021
Departemen Biokimia Fakultas Kedokteran
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C. PRAKTIKUM VIRTUAL ANTIBODI

Buka praktikum virtual "Antibodies"

Perhatikan percakapan antara pasangan suami istri (Joel dan Carmen) dan dokter kandungan tentang *rhesus incompatibility*, dan jawablah quiz tentang *rhesus incompatibility*.

Checklist 1 – Welcome to the antibody lab

Persiapkan diri dan kenakan jas praktikum

Checklist 2 – Membedakan antibody dan antigen

Pelajari dasar teori tentang perbedaan antibody dan antigen yang tampak di meja hologram.

Checklist 3 – Identifikasi struktur antigen dan antibody

1. Perhatikan bentuk Y antibody, dan jenis rantai protein yang ada pada antibody pada hologram. Perhatikan jenis antibody yang dapat melewati plasenta
2. Pada *workbench 2*, gunakan laptop untuk mengidentifikasi bagian-bagian antibody. Berikan label yang sesuai pada gambar antibody.

Checklist 4- Pelajari cara pembentukan kompleks antigen-antibodi

1. Perhatikan perbedaan afinitas dan aviditas.
2. Perhatikan animasi yang menjelaskan tentang proses pembentukan antibody rhesus.
3. Perhatikan jenis ikatan dalam kompleks Ag-Ab: *hydrogen, ionic bond, vanderwall, hydrophobic interaction*.

Ckecklist 5 – Prinsip penggolongan darah

1. Pada *workbench 2*, anda akan melakukan tes penggolongan darah berdasarkan sistem ABO.
2. Gunakan sarung tangan sebelum meng-handle sampel darah.
3. Gunakan pipet untuk melembapkan kartu Eldon dengan air.
4. Pipet satu tetes darah dari Sampel 1 ke masing-masing lingkaran antibody pada kartu Eldon 1. Gunakan stick untuk mencampur antibody dengan sampel darah. Gunakan stick berbeda untuk tiap lingkaran sampel darah, lalu buang setelah digunakan.
5. Setelah 10 menit, perhatikan ada tidaknya agglutinasi (penggumpalan) pada masing-masing lingkaran antibody. Perhatikan juga hasil pada Sampel 2, 3, dan 4.
6. Buang sarung tangan yang sudah digunakan.

Checklist 6 – Karakterisasi golongan darah

1. Pada *workbench 3*, anda memiliki sampel darah dari Carmen (ibu), anak pertamanya, serta dari anak kedua yang sedang dikandung.
2. Teteskan sampel darah pada masing-masing lingkaran antibody pada kartu Eldon.
3. Perhatikan bagaimana inkompatibilitas rhesus dan inkompatibilitas ABO pada kehamilan.

Checklist 7 – Applikasikan prinsip penggolongan darah pada inkompatibilitas Rhesus

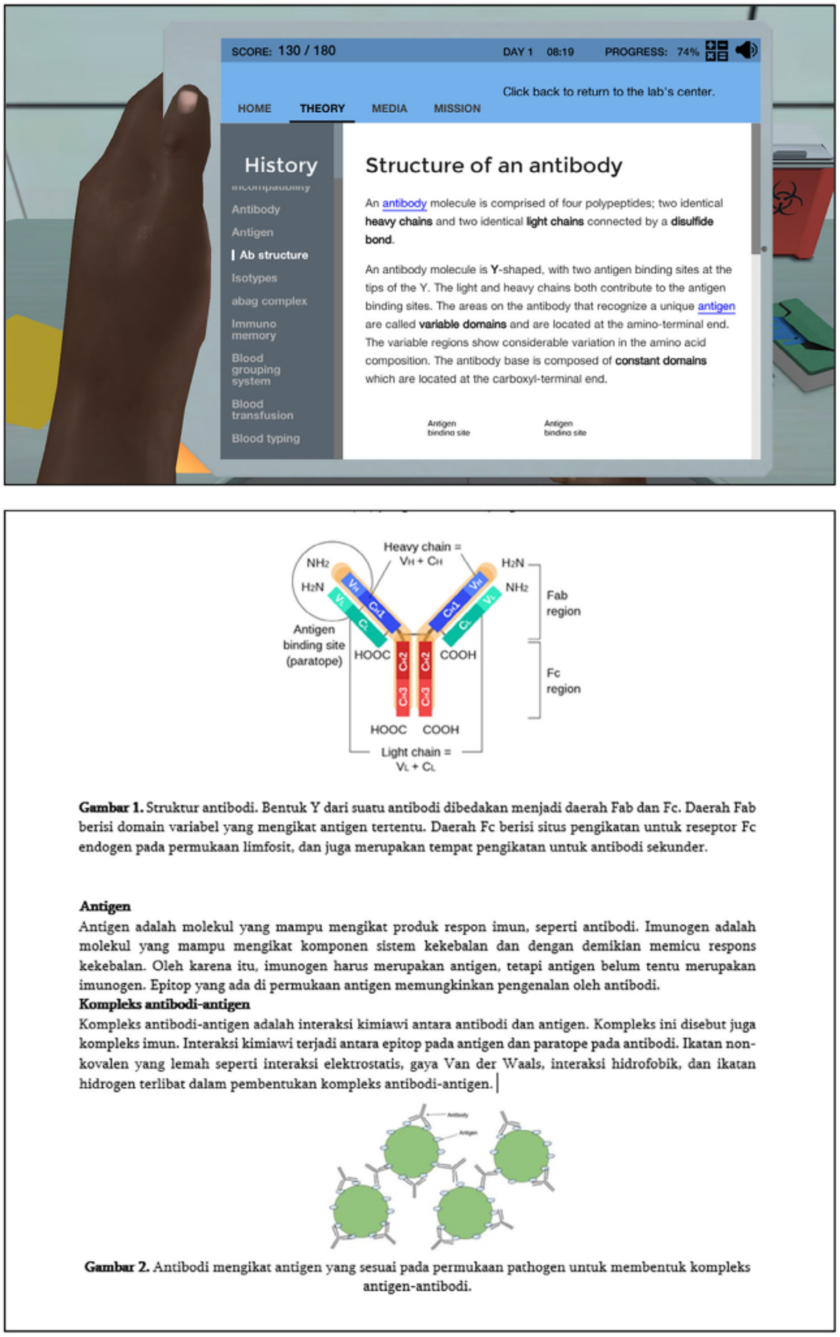
Jawab pertanyaan quiz terkait inkompatibilitas Rhesus.

Checklist 8 – Diskusikan hasil percobaan dengan Joel dan Carmen

Berikan konsultasi kepada Joel dan Carmen tentang hasil pemeriksaan golongan darah rhesus dan solusi untuk masalah nya.

FIGURE 1 (Continued)

commencement. The purpose of the practical is to (1) enhance the theoretical knowledge of antibody structure and antigen–antibody interaction, and (2) to teach the principles and the step-by-step procedures involved in blood typing (ABO and Rhesus) procedure applied in a clinical context. The vLAB was delivered based on a clinical context wherein a couple was shown to consult an obstetrician regarding concerns of Rhesus incompatibility in their unborn child (Figure 1a). This then leads to the vLAB practical component, wherein students receive both theoretical reinforcement (Figure 1b) in addition to performing



Gambar 1. Struktur antibodi. Bentuk Y dari suatu antibodi dibedakan menjadi daerah Fab dan Fc. Daerah Fab berisi domain variabel yang mengikat antigen tertentu. Daerah Fc berisi situs pengikatan untuk reseptor Fc endogen pada permukaan limfosit, dan juga merupakan tempat pengikatan untuk antibodi sekunder.

Antigen
Antigen adalah molekul yang mampu mengikat produk respon imun, seperti antibodi. Imunogen adalah molekul yang mampu mengikat komponen sistem kekebalan dan dengan demikian memicu respons kekebalan. Oleh karena itu, imunogen harus merupakan antigen, tetapi antigen belum tentu merupakan imunogen. Epitop yang ada di permukaan antigen memungkinkan pengenalan oleh antibodi.
Kompleks antibodi-antigen
Kompleks antibodi-antigen adalah interaksi kimiawi antara antibodi dan antigen. Kompleks ini disebut juga kompleks imun. Interaksi kimiawi terjadi antara epitop pada antigen dan paratope pada antibodi. Ikatan non-kovalen yang lemah seperti interaksi elektrostatis, gaya Van der Waals, interaksi hidrofobik, dan ikatan hidrogen terlibat dalam pembentukan kompleks antibodi-antigen.

Gambar 2. Antibodi mengikat antigen yang sesuai pada permukaan pathogen untuk membentuk kompleks antigen-antibodi.

FIGURE 1 (Continued)

gamified and open-ended laboratory work on the ABO and Rhesus blood-typing procedure (Figure 1c). Throughout the vLAB session, students also undergo mandatory built-in assessments with direct feedback (Figure 1d).

2.3 | Delivery of the virtual laboratory practical

The delivery of the virtual laboratory was organized into four steps (Table 1). The first step (orientation) was

TABLE 1 Strategy and timeline for the delivery of virtual laboratory learning

Steps	Step 1 Orientation	Step 2 Conceptualization	Step 3 Clarification	Step 4 Experimentation
Title	Virtual Laboratory Demonstration	Provision of Guidebook	Guidebook Walkthrough	Virtual Laboratory Practical Session
Description	Introduction to the virtual lab practical Familiarization with platform Troubleshooting of technical issues	Theoretical basis of experiments Detailed description of the checklists in the native language of students (Bahasa Indonesia)	Detailed explanation of the guidebook content by the lecturer Clarification of theoretical concepts	Pre and post assessments Structured time (3–4 h) Independent and collaborative learning
Time frame	Start of the Biomedicine Block	2 weeks before the practical session	~3 days before the practical session	Pre-test H1-2: Independent work H3: Group discussion with team and TA H4: Panel discussion with lecturers Post-test
Facilitator	Block Coordinator/ Secretary	Block Coordinator/Secretary	Lecturer	Lecturer and TA

Note: TA = teaching assistant, H1 = first hour, H2 = second hour, H3 = third hour, H4 = fourth hour.

performed at the start of the biomedicine block and consists of an introduction to the virtual platform to ensure familiarization with the vLAB and to allow for troubleshooting of technical difficulties that may arise. In Step 2 (conceptualization), students are provided with the guidebook, which contains both the theoretical basis of the experiment as well as a detailed description of the checklists that need to be completed in the virtual simulation. All contents of the guidebook are in the native language of the students (Bahasa Indonesia) to assist non-English speakers while navigating the virtual laboratory (English). A crucial point in the guidebook development is alignment with the vLAB content, and we have designed the book to supplement the vLAB in order to allow quick and easy comprehension of the checkpoints, theory, procedures and expectations of the vLAB (Figures S1 and S2).

In the third step (clarification), students are provided with a 1 h, guided walkthrough of the guidebook to ensure clarification of theoretical concepts and instructions of the practical. The final step (experimentation), which is the implementation of the practical itself, was conducted as a structured 4-h session with both built-in as well as lecturer-assigned assessments. The session starts with a pre-test, followed by independent exploration of the simulation during the first 2 h of the practical. Students are required to complete all checklists during the 2 h period, during which teaching assistants (TA) are available for any questions or difficulties that may be faced by students through WhatsApp groups formed specifically for the practical sessions. In the third hour, students summarize their findings and prepare for the discussion with TA assistance. In the final hour, a panel discussion is provided with lecturers to discuss the findings and questions given to the students. The session closes with a post-test, and results of the built-in assessments are extracted. All lecturer assigned tests were administered via the Moodle e-learning platform, while built-in assessments were obtained from the Labster teacher dashboard.

2.4 | Data collection

Collected data include the lecturer-administered pre-test and post-test results extracted from the Moodle LMS Platform, and the built-in assessment results from the vLAB teacher dashboard. Student perceptions were assessed with a Likert-scale survey on the three aspects of implementation (learning, language, and technical), with the scale ranging from 1–5 to indicate the following opinions: strongly disagree, disagree, neutral, agree, and strongly agree. An optional, open-ended questionnaire regarding the perceived advantages and disadvantages of the Labster simulation and the practical were also administered to the cohort, with the following questions:

(Q1) What was a positive thing that you experienced with the vLAB practical?
(Q2) What was a negative thing that you experienced with the vLAB practical?

2.5 | Data analysis

Graphpad Prism 9 and Microsoft Excel was used to perform all data analysis. Shapiro–Wilk test was used to assess data distribution, and the Wilcoxon matched-pairs rank test was used to assess the difference between pre- and post-test results. Statistical significance was set to $p < 0.05$. The results of the Likert questionnaire are presented as stacked bar charts. Thematic analysis was performed on the open-ended questionnaire to identify the major themes for the two questions answered by the cohort.

3 | RESULTS

3.1 | Sample characteristics

The total number of students in the freshman cohort of this study was 271 students. All students completed the vLAB and all completed the built-in assessment of the vLAB. The lecturer-assigned pre- and post-test was completed by 269 students, while 266 completed the Likert and open-ended questionnaire. Among the 266 students who completed the optional open-ended questionnaire, 6 of the responses to Q1 were unclear/unanswered, and 22 of the responses to Q2 were unclear/unanswered.

3.2 | Cognitive domain

The lecturer-assigned pre- and post-test results were used to assess the knowledge gain obtained from using the vLABs. As shown in Figure 2a, the average pre-test scores were 6.38 ± 2.56. Following the vLAB session, a statistically significant ($p < 0.0001$) increase in knowledge gain was observed, with an average score of 9.35 ± 1.32. Built-in assessments were also completed by all students, and since we aimed for students to achieve mastery of the practical, reattempts were allowed within the allocated time of the laboratory practical. Herein, Figure 2b indicates the average scores that were observed in the student's first attempt and their best attempt. A significant difference ($p < 0.0001$) was observed between the average first attempt (82.57 ± 29.81) and the average score of the student best attempts (99.48 ± 1.72).

3.3 | Learning and motivation domain

Student perceptions in the learning and motivation domain are presented in Figure 3a. With regard to motivation, 81.57% of students claimed that using the vLAB was more motivational relative to reading the theory alone as they have previously done with the guidebooks during the conceptualization and clarification phases. A total of 75.18% of students felt that the vLAB session increased their knowledge and understanding of both antibodies and blood typing, with 66.54% of the students stating that repetition or reattempts of the simulation helped improve their understanding of the material. A large proportion (81.95%) of the students claimed that they

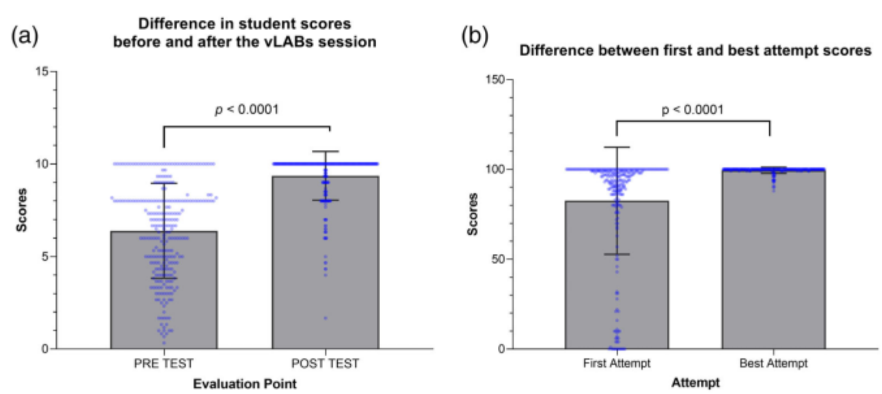


FIGURE 2 Results of the lecturer-assigned and built-in cognitive assessments. (a) Comparison between prevLAB and post-vLAB, lecturer-assigned test scores of students, $n = 269$ students. (b) Comparison between the first and best attempt of the built-in vLAB assessment, $n = 271$ students. This figure shows mean ± standard deviation, p-value calculated with the Wilcoxon matched-pairs signed rank test. vLAB, virtual laboratory

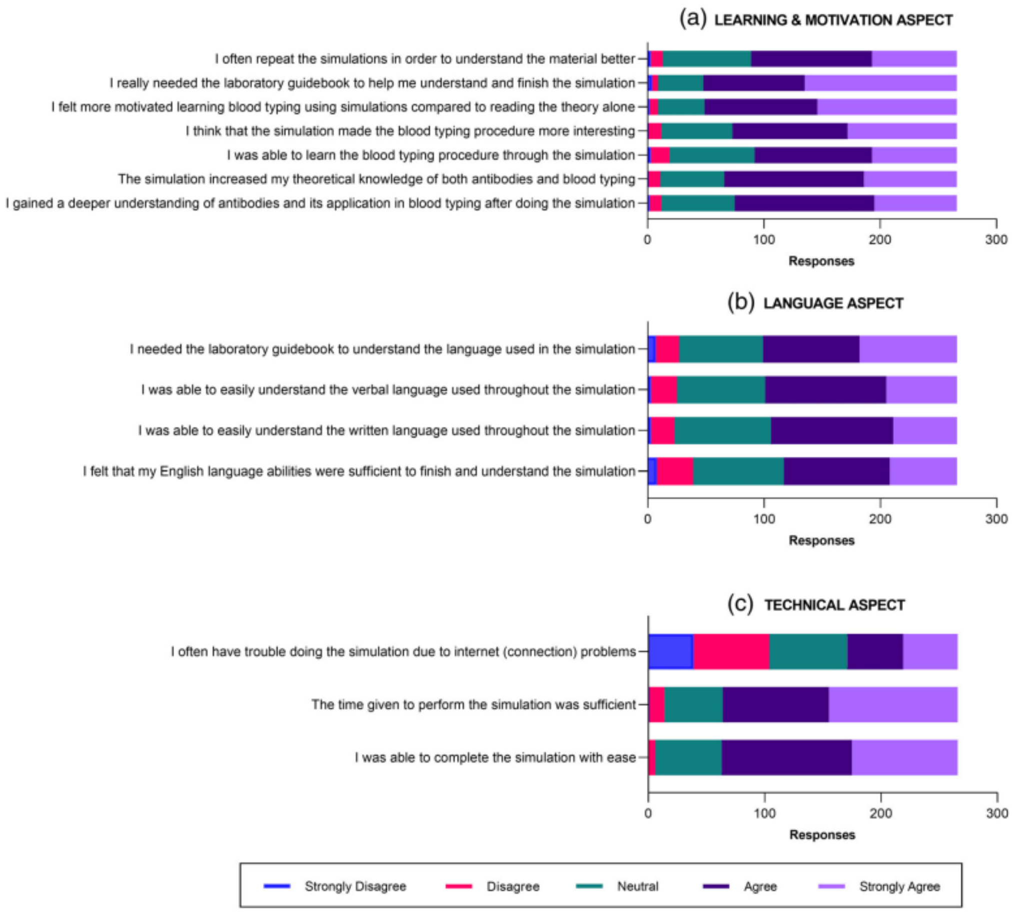


FIGURE 3 Student survey evaluation on the learning of motivation aspect of the vLAB. (a) Evaluation of the learning and motivation aspect. (b) Evaluation of the language aspect. (c) Evaluation of technical aspects. This figure illustrates the student response counts in accordance to the Likert scale (1–5 scale), $n = 266$ students. vLAB, virtual laboratory

depended on the guidebook to help them understand and complete the simulation.

3.4 | Language domain

Student perception results on the language domain is presented in Figure 3b. Only half of the cohort (56.01%) felt that their language abilities were sufficient to finish and understand the simulation. In line with said finding, around 62.78% of the students claimed that the laboratory guidebook was essential to understand the language used.

3.5 | Technical domain

From the technical point of view, most students reported ease of completion, with only six students claiming that they were unable to complete the simulation with ease. Internet connection was an issue for around 35.71% of the students, which caused them some trouble during completion of the simulation. During this course, the pandemic lockdown has been initiated and student locations varied, with some students living in rural or village areas with less stable connection. On the other hand, time was not a problem since most (75.93%) students felt that the 2-h period allocated for simulation completion was sufficient, with only 14 students claiming that the time was not enough.

3.6 | Student perceptions on the positive and negative aspects of the vLAB

Results of the identified themes, corresponding frequency count, and example quotes for each theme is presented in

TABLE 2 Results of thematic coding of the open-ended student questionnaire on the perceived positive and negative aspects of the vLAB

Perceived positive aspects		
Identified themes	**Response *n* (%)**	**Example quotes**
Interesting/Motivational	81 (30.45)	"The simulation was interesting, and I liked how the scenario was about us helping a patient, which made it more appealing" "The simulation was fun to complete, it felt like playing a game" "The antibody simulation made me more enthusiastic in learning about the topic"
Improve understanding	165 (62.03)	"I understood the material very well because of the simulation, guidebook, and discussions" "The simulation made me feel like I was an obstetrician for the day, and more importantly it helped me understand antibodies and blood-typing, especially Rhesus typing" "I was able to understand the topic better after the simulation compared to just reading the guidebook. During the biochemistry classes, I look forward to the Labster simulations the most"
Repeatability	9 (3.38)	"The best thing about the simulation is that I can keep repeating it" "I could repeat the simulation over and over again""The simulation can be repeated until I understood"
Accessibility	5 (1.88)	"I did not have to wait too long to perform a practical, I could avoid dangerous chemicals in the lab, and the instructions were on point" "I had flexibility when working on the simulation because I can access it any time I want" "Its practical, and I can access the simulation anytime and anywhere"
Unclear/not answered	6 (2.25)	–
Perceived negative aspects		
identified themes	**Response *n* (%)**	**Example quotes**
Language difficulties	51 (19.17)	"The English used in the simulation was too advanced for me" "I sometimes encounter terms that I do not know the meaning off, making the explanation difficult to understand" "It took me a while to complete since I had trouble understanding the language and I had to translate it first"
Technical difficulties	38 (14.29)	"The connection in my home is not good, so I had to go to another place to complete the simulation" "Sometimes I have connection problems, and occasionally I encounter errors so I had to reload the page, and that takes up time" "I had trouble accessing because my laptop did not meet the specifications"
Cannot replace real labwork	81 (30.45)	"I do not think I achieved optimal understanding because I did not the perform the practical directly, and I have no hands-on experience" "I still prefer real practicals, I believe that will be more effective because we will perform that directly" "I still do not have the feel of the practical"
Require further elaboration	38 (14.29)	"There were some things that I still did not understand despite completing the simulation" "The explanations in the simulation can be a bit confusing" "I need more explanations"
No perceived negative aspects	36 (13.53)	"There was nothing negative about the simulation" "Nothing, I liked the simulation and the theory" "To be honest, nothing negative"
Unclear/not answered	22 (8.37)	–

Abbreviation: vLAB, virtual laboratory.

Table 2. We identified that the most prominently reported themes for Q1, on the perceived positive aspects of the vLAB practical, in the order of frequency counts were; (1) improved understanding, (2) interesting/motivational, (3) repeatability, and (4) accessibility. Additionally, the most prominently reported themes for Q2 (perceived negative aspects) were (1) cannot replace real labwork, (2) language difficulties, (3) technical difficulties, and (4) require further elaboration. Interestingly, when asked the open-ended Q2, a proportion of students (13.53%) stated that they perceived no negative aspects from the vLAB, rendering this as the 5th theme identified among the Q2 responses.

4 | DISCUSSION

Although traditional offline laboratory sessions are essential for most biomedical subjects, many institutions have been unable to conduct them due to the strict lockdowns occuring in several locations. In this article, we presented the results of implementing a fully online vLAB platform in place of traditional face-to-face laboratory work for the Biomedicine Block of first-year medical students at the Faculty of Medicine, Hasanuddin University. Whilst we implemented multiple vLAB sessions throughout the block, this article presents one of the sessions that we utilized, which was a simulation for antibodies and blood typing. Prior to the pandemic, this topic was taught in two face-to-face lecture (2 h) followed by a 4-h laboratory practical for blood typing. In this study, we demonstrate the transition from the 4-h offline laboratory practical session to a fully online vLAB on antibodies, which not only encompasses simulation on the procedure of ABO and Rhesus typing, but also reinforces the theoretical concepts through 3D and interactive animations on antibody structure and antibody–antigen interactions.

This study demonstrates that vLABs not only improve the comprehension of a medical biochemistry topic but also increases the motivation of students, a finding that was also previously reported in other settings using the same vLAB platform.[10,11] Motivation is a highly crucial, and often overlooked aspect of medical education delivery. As elaborated in a review on motivation among medical students, educators need to encourage intrinsic motivation by addressing the three student needs including autonomy, competence, and relatedness, which can be achieved by providing optimal challenge, feedback, choice and opportunity for self-direction, and by giving a sense of belongingness and connection to medical sciences.[12] We believe that all three aspects were adequately provided in our model of vLAB implementation, wherein students were allowed independent exploration of vLABs, but placed within a structured learning and time framework.

Additionally, results of the built-in assessment also indicate that when given the opportunity, the students showed great self-drive, and were motivated to reattempt the practicals to achieve mastery and improve their scores. This is another additional advantage of vLAB implementation that would otherwise be unfeasible in a traditional laboratory setting, considering reagent costs and the time required to completely repeat an experiment. In relation to this aspect, we highlight some of the student responses on the perceived advantages of the vLAB, stating "*I was able to repeat the simulation until I understood*".

Another interesting thing to note from this study is the language aspect. Language barriers are rarely evaluated in studies concerning vLAB effectivity, but we have predicted from the start of implementation that language may be one of the biggest barriers for successful conduct of the vLAB. This was confirmed by the finding of this study, wherein only half of the students felt that they have the required language capacity and skills to complete the simulation. Several answers from the open-ended student questionnaire also highlighted this issue with comments such as "*what hindered my understanding was the language*", and "*the language used in the simulation can be difficult to understand*", and "*the vocabulary used in the simulation was too advanced for me*". This is important to note for other primarily non-English speaking settings and institutions seeking to adapt commercial laboratory simulations, which are dominantly served in English as the language of instruction. Even if the simulation itself is comprehensive, language barriers can cause a major problem.

Several strategies were employed to overcome said language issues. We found that the guidebook is a crucial component as it not only guides learning, but also alleviates some language issues by students who are unable to comprehensively follow both the written or oral instructions and information provided by the simulation. Additionally, the WhatsApp groups formed specifically for the practical allowed direct communication between the TAs, facilitating lecturers, and the students. Often, language barriers encountered during the independent practical sessions can be clarified through simple communication in these groups. Students were free to clarify any statements or any form of the practical that they had trouble understanding.

In resource limited settings, technical aspects can also prove to be a barrier in the implementation of vLABs. As shown in this study, although most students were able to navigate the simulation without an issue, some still experience difficulties due to poor internet connection. In the vast archipelago of Indonesia, some areas have insufficient internet connection, which becomes an issue for students who are participating from a distance. This may be a consideration for vLAB developers, and for institutions to help provide students with the necessary facilities to successfully complete their studies in the online format. Not much could be done for the internet connection issues experienced by students who resided far from the university. However, for students residing in the same city, IT assistance were provided as drop-in IT clinics in which students can be assisted with any technical difficulties encountered during the practical. Interactions between the IT team and the students were facilitated, with the requirement of strict health protocols during the drop-in IT assistance.

Whether or not vLABs can completely replace traditional labs is a question that requires further critical assessment. In favor of vLABs, a study by Pyatt and Simms emphasize the higher usability and higher degree of open-endedness in vLABs, with most students favoring virtual and online alternatives in inquiry-based lab experiences.[13] But despite its realistic interfaces and advanced open-ended features, vLABs cannot fully replicate benchtop and real hands-on activities provided through traditional laboratory learning.[14] Based on the perceived disadvantages questionnaire, some students also highlighted this issue, stating that "...*I would prefer doing the practical directly, because I cant learn to handle the equipment with the vLAB*" and "*the disadvantage is I am unable to try it out directly*". However, in some under-resourced settings, it is not uncommon to find that vLABs have been used as substitutes for real-life laboratory practicals due to cost and facility constraints,[15,16] therefore helping to bridge the gap between science and technology education in developed and under-developed nations.

Some limitations of this study include our lack of control group wherein we only assessed the differences between the pre- and post-test scores of the same cohort of students. Ideally, a control of the equivalent offline version of the laboratory practical is ideal to truly assess the cognitive and learning benefits of vLAB simulations. However, this was not possible in this current situation, since direct face-to-face learning was prohibited at the time of implementation.

There are many lessons learned from the implementation of vLABs in our primarily non-English speaking institution, where students were instructed and facilitated in a fully online format. Firstly, despite the self-directed nature of simulations itself, the learning process requires active guidance from the lecturer. The role of the lecturer includes smoothing the transition from offline to online laboratory practicals, familiarizing students with the platform, and providing clear and detailed guidebook which elaborates the theoretical and practical aspects of the laboratory session, and ease the use of the platform for students who may find language to be a barrier. Based on these findings, we suggest the that faculties consider language barriers during the implementation of commercial laboratory platforms. Although we have alleviated this barrier partially using the guidebooks, it is likely that some students still lack the skills required to fully comprehend the vLAB. If possible, local development of vLABs in student native languages should be considered when resources allow.

5 | CONCLUSION

We demonstrate the successful implementation of commercial vLABs in a cohort of non-native English speakers using a four-step approach, and have explored the cognitive and motivational benefits in addition to the technical and language barriers. These results emphasize that commercial vLAB implementation requires strong support from faculty to provide the resources required for optimal transition.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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