THE PERFORMANCE OF VIRTUAL LABORATORY OF MEMBRANE SYNTHESIS VIA PHASE INVERSION AS PRE-PRACTICAL GUIDELINE IN A SEPARATION CHEMISTRY COURSE

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Abstract

The development of virtual laboratory (VL) has been widely used in secondary school teaching, notably science education. However, the development of VL specifically for university-level education remains quite limited. In addition, in some practical disciplines, such as membrane-based separation chemistry, both lecturers and students face restrictions in equipment and resources. As a result, the goal of this study is to develop a VL for membrane synthesis practicum utilizing the phase inversion approach that can also be utilized in separation chemical practicum. In addition, the researchers assessed the amount of legitimacy and user response to VL media, specifically among students. This work follows research and development based on ADDIE (Analysis, Design, Development, Implementation, and Evaluation) framework. The first phase is begun with an analysis (via interviews) to investigate the lecturer's issues and needs. Consequently, the analysis confirmed that the development of VL in separation chemistry is very essential. The researchers used feedback from the lecturer during the design stage, namely while gathering the material and presentation of VL to create the storyboard. Then, three experts confirmed the draft created during the development stage, declaring it highly valid with a proportion more than 85%. Face validity and construct validity took major revision to achieve 100% of highly valid. Following the revision steps of draft I (initial version) based on the validation results, draft II (revised version) was created for restricted testing with users (students), and the results revealed a very good response, with more than 90% of students providing feedback ranging from agree to highly agree. Their responses represent the impact received from VL, particularly in digital literacy, building critical and creative thinking, and learning flexibility. Some suggestions for enhancement, particularly the usage of foreign languages in VL, will be considered in the final stage. Thus, the VL can be recommended for use in membrane synthesis experiments in the separation chemistry course.

Keywords: *Virtual laboratory; membrane synthesis; phase inversion; separation chemistry; ADDIE*

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INTRODUCTION

Creating more implemented techniques, particularly for the industry, has been a growing focus of university-level practical learning in recent years. Particularly in separation chemistry course, a number of separation methods (such membrane technology and adsorption) are turned into straightforward experiments in addition to being taught through instructional lectures. Environmental concerns also form the basis of each topic's development. For instance, in order to address the problem of clean water availability, the separation chemistry practicum aims to offer an effective strategy for enhancing water quality through the use of membrane technology. Cellulose waste can be converted into cellulose acetate, which is then used as a filler or matrix in PVDF and poly (vinylidene fluoride) membranes.

In general, students in the Chemistry Education program receive a very thorough and targeted instruction in chemistry; nonetheless, some of the materials used for experiments are insufficient for laboratory practice. The theory of membrane-based separation, including the synthesis of membranes from polymer materials, has been taught by the lecturer, particularly in the separation chemistry course. This material will be simpler to comprehend if practiced directly in the laboratory. For example, heating a solution, casting it onto a glass plate, and then dipping it in a coagulation bath to create a membrane are all steps in the process. The Sustainable Development Goals (SDGs) environmental pillar, which deals with clean water and proper sanitation, has provided an explanation of water quality and environmental development [1] . Consequently, one tool for producing clean water may be membrane technology. Membranes will facilitate the community's ability to separate pure water from contaminated water that has been contaminated by cow dung, other waste materials, and other contaminants [2].

One of the factors contributing to Indonesia's 7.73% decrease in the water quality index between 2017 and 2019 [3] was the disposal of industrial waste, particularly dyes used in the textile industry up to 5% of which are dumped into the water as garbage [4]. Therefore, additional care is needed to address this issue, especially with regard to water treatment, which helps to raise the water quality index. One of the simplest and least expensive methods is filtering [5]. Membrane technology can be used to increase the process's operational efficiency. Membrane synthesized from PVDF blended with cellulose acetate is effectively remove methylene blue dye higher than 90% from aqueous solution [6], [7]. But, when the membrane applied to learning in practicum learning, the limits of facilities and chemicals reduce the possibility of implementation. As the solution, the virtual laboratory learning media is one of the educational resources that can aid students in comprehending membrane technology [8]. Enhancing students' understanding of membrane production—a technique used to create clean water—is one advantage of having a virtual laboratory. Consequently, the SDGs' environmental pillar will be achieved. By replicating the same procedures and practices as a real laboratory, virtual technology can develop a virtual laboratory that is both interactive and capable of conducting investigations at simultaneously [9].

Virtual laboratories have gained widespread acceptance as a potentially successful alternative to traditional laboratory-based courses, such as science simulations and teaching models [10]. Experience has demonstrated that students can profit from the flexibility of virtual experiments while also improving their imaginative abilities and logical reasoning. However, purely software-based virtual laboratories have essential downsides. For example, students may feel as if they are playing a video game [11].

In recent years, there have been two distinct approaches to developing virtual laboratory systems: web-based remote laboratories and entirely software-based virtual laboratories. A remote laboratory attempts to conduct online tests by using physical equipment from a distance [12]. They are typically sophisticated, need a lot of bandwidth, and have significant demands for sensory-control hardware and software [13]. As a result, this research focuses on virtual laboratories that are entirely software-based. Few virtual platforms try to provide standardized software that may be used across various fields. A virtual chemical vapor deposition (CVD) laboratory focuses training students' experimental design abilities [14].

Previous study developed virtual laboratory (VL) of fermentation experiment. Students like the VL as an additional or preparatory tool, as it takes less time for the fermentation experiment and can be used instead of a physical lab. In the post-VL survey, students were asked if the animations and graphic interface of the VL were pleasant and straightforward to finish within a certain timeframe [15]. All surveyed students believed that the virtual laboratory was a useful learning tool, with both on-campus and off-campus students liking the moderate pace and theory-focused approach [16]. Students who initially attended the virtual laboratory outperformed those who first attended the real laboratory. Furthermore, the best progressive learning and performance for real trials occur when the virtual laboratory precedes paper-based practical investigations [17].

This study aims to identify the validity of the virtual laboratory for membrane synthesis using the phase inversion method. In addition, this work is carried out to address students respond to the virtual laboratory's results. Previous research results support the objective of this study, which is to develop VL not only as a substitute for physical laboratories, but also as pre-experiment activities to increase student engagement when undertaking actual laboratory practices.

METHOD

Laboratory activities help students gain practical understanding of theoretical issues presented in the classroom, making them an important pedagogical tool for science education. Virtual laboratories are a popular e-learning option for higher education due to their advantages over traditional face-to-face laboratories. Creating a virtual laboratory for teaching and learning is a complex task [18].

To move experiments from traditional teaching labs to online environments, technical means are required to simulate the phenomenon’s behaviour in digital form. Furthermore, these tests frequently utilize scientific tools and specialized equipment. These projects demand expertise in interaction design, visualization, and pedagogy to create texts, visuals, environments, and interactivity. They also require programming and animation skills.

Creating an online virtual laboratory is an instructional engineering project that necessitates a clear and tailored plan [19]. Developing an online virtual laboratory is an intricate instructional engineering project that requires a well-defined and carefully customized plan. This involves identifying specific educational objectives, designing user-friendly and interactive interfaces, integrating accurate simulations to replicate real-world laboratory experiments, and ensuring accessibility across various platforms. Additionally, the plan must incorporate robust technical infrastructure, continuous feedback mechanisms, and alignment with curricular standards to effectively support learning outcomes. In this work, We used the ADDIE model (Figure 1) as the major design method. The ADDIE model, a framework for designing instructional systems, is widely recognized in educational engineering [20]. ADDIE is a colloquial word for a systematic approach to instructional development, which is nearly synonymous with instructional systems development. The ADDIE model outlines key things to consider while creating educational content [21].

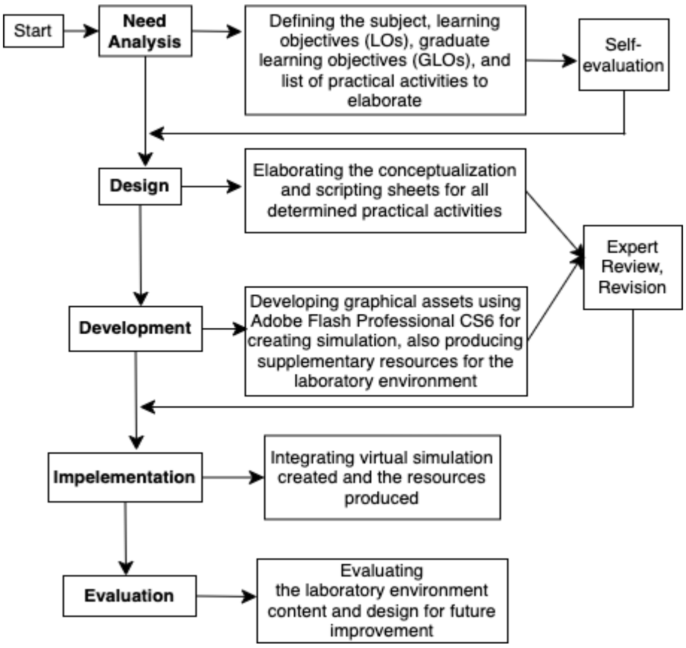

Figure 1. Research flow followed ADDIE framework

The study was carried out in the Chemistry Education Study Program at Ar-Raniry State Islamic University Banda Aceh with 23 students from the 2021 class. They are now enrolled in a separation chemistry course, which is why this sample was selected. They have also carried out practicum in membrane technology. Not every student had the same experience handling materials and equipment because the experiment was a demonstration. These restrictions could lead to bias in this study, for instance, when it comes to employing VL to comprehend each stage of the experimental process. The research sample was chosen specifically because they were taking separation chemistry courses, both theoretical and practical.

The analysis phase is divided into two stages: performance analysis, which identifies and categorizes issues linked to the media to be generated in the Chemistry Education program, and solution development, which involves creating learning media. The needs analysis data was obtained using a questionnaire that included ten questions with answers of strongly agree, agree, disagree, and strongly disagree, each symbolized with a Likert scale of 4, 3, 2, and 1. At the end of analysis phase, the researchers drafted an analysis summary for the consideration of the next phases. The evaluation summary is concluded as performance gap, lecturer gap, and resource gap. The performance gap, resource gap, and resource gap are represented by 3 components illustrated in Figure 2.

The design phase comes after development. During this step, a concept map is created, a virtual laboratory is composed, and an evaluation is conducted. In addition, the researchers created a set of problem questions for formative assessment. In order to maintain all progress with the blueprint concept and to continue working through the design process that follows any significant specifics, this phase is evaluated. The examination also aids developers in finding duplicate or missing components. As a result, the researcher will make sure that the design was the most beneficial for its practical use.

In the development phase, three experts validated the initial version and revised version of VL. The chemistry lecturers with expertise in both designing VL and delivering practicum serve as the validators. The validation sheet, like the needs analysis, was designed as a questionnaire with a Likert scale (a score of 1 indicates highly invalid, 2 indicates invalid, 3 indicates somewhat valid, 4 indicates valid, and 5 indicates highly valid). Following the evaluation of the development, the researchers created the questionnaire. Of all the stages in the ADDIE process, the researchers agree that the development was the most tough and demanding. Because every purpose was carefully examined for the instructional strategy, development needed a lot more work than design.

The questionnaire includes three components: media, material, and language. The assessment towards media, materials, and language represented the face validity, content validity, and construct validity, respectively. The first one, face validity, this component evaluates the virtual laboratory media's fit for the teaching plan, accessibility, and student appeal. Additionally assessed are the layout, graphic design, readability of the text, visual appeal, and the appropriateness of animations and audio for fostering learning. Then, the content's complying with the practical objectives and its readability are both considered material aspects. It is also mentioned how the content may catch attention, increase students' motivation, and improve their knowledge and self-reliance. The last, the construct validity is used to evaluate how well the material is delivered, how well the language complies with EYD guidelines, and how comprehensible it is. Clarity, word choice accuracy, and understandable communication are the primary goals. Each of these features contains eight, twenty-two, and seven statements, respectively. As a result, the researchers assessed each goal in light of the instructional experiences and developed a strategy accordingly. Each score is then converted into a percentage using the equation below [22].

$$P = \frac{\Sigma X}{\Sigma Y}\, x\ 100\%$$

P is score percentage, ΣX is total score given by validator, ΣY is ideal total score. We used the interpretation criteria as presented in Table 1 [23].

Table 1. Criteria of Validation and Students' Response

Percentage	Validation Category	Students' Response
81 – 100	Highly Valid	Strongly Agree
61 – 80	Valid	Agree
41 – 60	Somewhat Valid	Neutral
21 – 40	Invalid	Disagree
0 – 20	Extremely Invalid	Strongly Disagree

In the implementation phase, several tests were conducted to evaluate the practicality of the VL. To investigate how well the students understood the content and the overall practical flow in VL, a comprehension test—a cloze test—was performed. The characteristics and degree of difficulty of this teaching material product were determined based on the comprehension test results. The Guttman Scale was used to process the data for this exam; a correct answer receives a score of 1, while an incorrect answer receives a score of 0. The following equation is then used to apply each question, where N is the total number of students who completed the test, DD is the proportion of students who replied correctly, and Ib is the number of students who answered accurately [24]. The categories of student comprehension are then identified by interpreting the results of this categorization. Three categories can be used to classify the obtained percentage: (1) low or independent (60<DD<100); (2) medium or instructional (40<DD<60); and (3) high or difficult (DD≤40).

$$KK = \frac{Ib}{N}\ x\ 100$$

In addition, the student response form includes written remarks to solicit feedback on the constructed virtual laboratory media. The questionnaire employs a Likert scale with five levels: 5 (strongly agree), 4 (agree), 3 (neutral), 2 (disagree), and 1 (strongly disagree). Each component to which the students answered is likewise translated into a percentage using the algorithm. The percentages are then interpreted according to the criteria outlined in Table 1 [23].

RESULTS AND DISCUSSION

Analysis Stage

The lecturers who taught the separation chemistry course were given a questionnaire to complete as part of the needs analysis. Ten items total, divided into the investigated parts of learning process, learning issues, advantages, and needs, make up the questionnaire. The questions arranged to identify the weakness faced by lecturer in conducting the learning [25]. The responses to the needs analysis are graded on a Likert scale of 1-4 in the following order: strongly disagree, disagree, agree, and strongly agree. The result of needs analysis can be seen in Table 2.

Table 2. Needs Analysis towards Virtual Laboratory Development

Investigated Parts	Questions	Label	Response
Learning Process	Does lecturer frequently appointed to give practical courses?	A1	Strongly Agree
	Does lecturer frequently adjust the learning materials to suit with practical theory?	A2	Strongly Agree
	Does lecturer frequently involved in the process of developing practical modules?	A3	Strongly Agree
	Is there any distinction between the theoretical lecture materials and the practical materials?	A4	Strongly Disagree
Learning Issues	Are issues faced correlated with instruments or materials?	B1	Disagree
	Has the instructor ever used learning media to address the difficulties raised?	B2	Strongly Disagree
Advantages	Will students be interested in virtual lab media?	C1	Strongly Agree
	Will the lecturer be interested in the virtual laboratory materials that will be used during the learning process?	C2	Strongly Agree
Needs	Has the lecturer previously used virtual laboratory media?	D1	Strongly Agree
	Can virtual laboratories be considered an affordable solution?	D2	Strongly Agree

Table 2 illustrates that lecture actively manages instructional and practical classes. Question item A4 demonstrates that practical skills have been tailored to the classroom learning materials. This demonstrates that the content on membrane-based separation is also being used in practical learning. However, due to material and equipment restrictions (as stated in item B2), the experiment remains a demonstration. As a result, additional tools like learning media are required to help students learn independently.

According to Table 2, question item B1 demonstrates that the lecturer has never utilized or created learning materials for membrane-based separation practicum. Virtual labs (VL) are thought to be ideal for developing and implementing practical activities since they help improve students' practical skills [26]. Furthermore, additional research indicates that 90% of participants love using the virtual laboratory (VL) and have improved their virtual practical experience [27]. As a result, the lecture is convinced that students will be interested in VL (item C1) and that it is the best way (item D2) to bridge the gap in membrane-based separation practical learning.

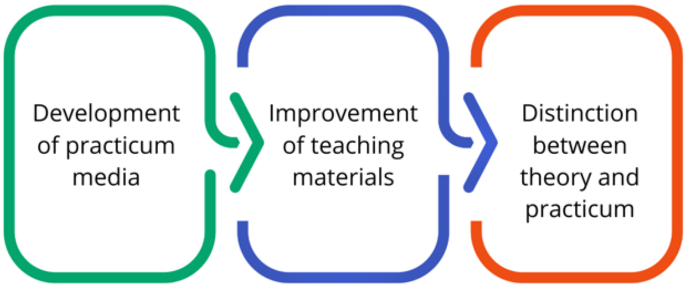

Figure 2. The representation of performance gap, lecturer gap, and resource gap.

Figure 2 exhibits three major groups that must be followed by developers during the next phase. To address the issues come from the first component, the design should overcome the practicality of conduct experiments in membrane separation virtually. The second one is developed to ensure the quality of materials presented in brief theory section. The last, the concept map visualized in virtual lab is generated to be in line with theory given by lecturer in class.

Design Stage

After determining the lecturers' needs during the analysis stage, the researchers moved on to the design step to construct the virtual laboratory media. The design stage must follow the knowledge and practicum activities in order to clarify the storyline for the next development stage. Previous study revealed seven section that must be added into design stage, such as (1) context of practicum; (2) level of study; (3) learning objective; (4) preliminary materials; (5) content; (6) references; and (7) graduate learning objectives [28]. This study covered all sections into three steps conducted during the design phase as follows:

1) Adjusting the practical aims in the membrane technology material to comprehend membrane fabrication, membrane separation, and membrane production employing CA (Cellulose Acetate) and PVDF (Poly(vinylidene) fluoride) compounds.
2) The scope of the discussion material to be offered in the virtual laboratory media has been explained beginning with the first phase, which includes the definition of membranes, membrane principles, membrane production operating principles and methods, and membrane classification based on pore size.
3) After identified the scope of the content, the researcher constructed the media layout, which was divided into numerous sections, some of them are presented in Figure 3.

Figure 3. User interface appearance of the VL

The primary program used by the researcher is Adobe Flash CS6, and Corel Draw X7 and Microsoft PowerPoint are used as auxiliary programs for creating lab tools. It is advisable to create a storyline prior to creating. Researchers primarily employ Adobe Flash CS6 to develop virtual laboratory material. In the Adobe Flash CS6 application, first select the action script to be utilized, and then create a loading screen to access the welcome, main menu, and other features. The designed animation will then be loaded into the Adobe Flash CS6 application. However, Adobe Flash CS6 does not include the words typed in PowerPoint since they are confusing. Therefore, it must be redone in Adobe Flash CS6.

Development Stage

This stage is the process of developing virtual laboratory media based on the design that was created. The developed product will be evaluated by three validators. The validation is carried out to collect the assessment from validators, including their perception and expectation [29]. The validator has made three general revision recommendations for face validity. First, switch "virtual lab" to "*Laboratorium Virtual*". Second, give the virtual laboratory area a menu button. Lastly, using expressions of gratitude like "HOORAY" at the conclusion of the practical session. Some of final revision can be seen in Figure 3. Therefore, the minor revision has been taken to adjust some appearances such as display menu, font size, typography, and background music in order to produce the better VL. Consequently, the face validity index increased to 100% highly valid.

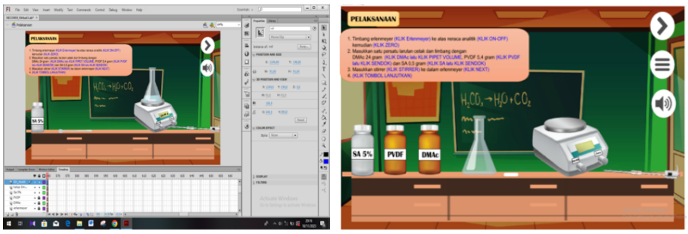

Figure 4. The display of menu button and practical assets before revision (left); and after revision (right)

This validation seeks to determine the final results of the virtual laboratory media production, as well as the validator team's proposals. The findings will be used to assess the validity of the virtual laboratory media generated by the researcher. Validation is performed on three aspects: face validity (20 questions), content validity (10 questions), and construct validity (7questions). The validation results are shown in Figure 5. The media validation focused on media display [30], as concerned more precisely in menus of virtual laboratory. In content (material) section, validators were asked to give feedbacks in pedagogical content [31], where all steps of practicum have been evaluated.

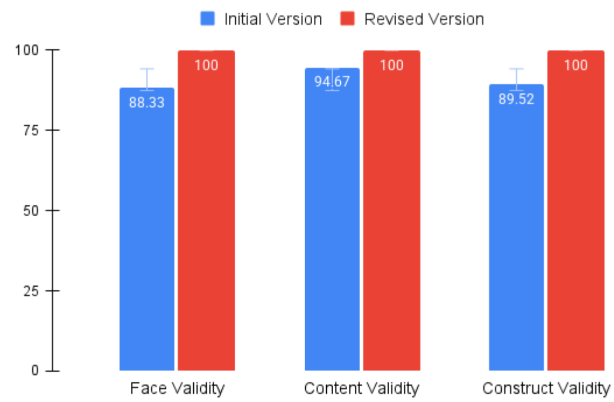

Figure 5. The validation score of virtual laboratory

All aspects obtained validation percentage greater than 80, thus they perform highly valid category. At initial version, the greatest validity index showed by content validity, followed by construct and face validity. Content validity has lack of brief theories related to phase inversion (Figure 5) and filtration types based on membrane pore size (microfiltration, ultrafiltration, and nanofiltration). Therefore, the majority of experts suggest to add description of phase-diagram to visualize the phase inversion during membrane synthesis. Another suggestion is the addition of membrane classification based on membrane pore size. Consequently, the revised version got 100% of highly valid.

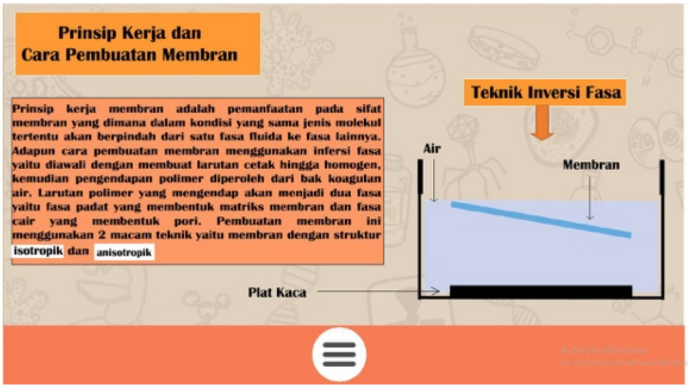

Figure 6. Fundamental theory of inversion phase for membrane formation

The use of language was validated to ensure all information provided into VL can lead students to achieve certain skills [32]. In taking revision towards construct, the researchers adjusted the subtitle presented in additional video to avoid student misunderstanding. Besides that, the procedure of experiment is presented in each section to ensure students follow the right steps (Figure 6). After evaluation and revision, the revised version got 100% of highly valid.

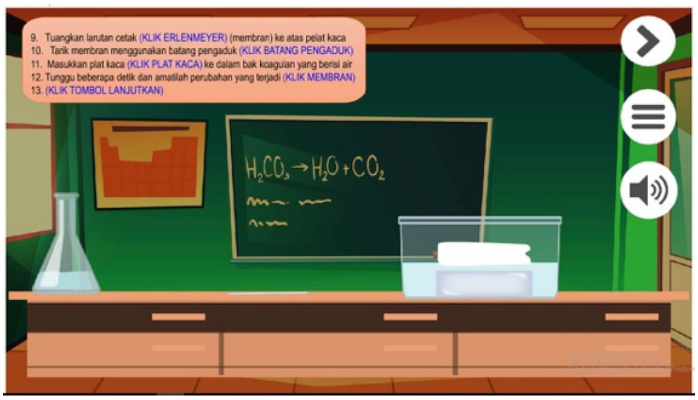

Figure 7. Experiment procedures presented in particular section

Implementation Stage

The implementation step was carried out to assess how students responded to the virtual laboratory media that had been developed. The research instrument, a questionnaire, was distributed to 23 students. The trial process was carried out for 30 minutes for each student, where each student had the opportunity to operate the VL for 20 minutes, and the rest was to answer 14 questions from the questionnaire. The investigation's questionnaire has a Likert scale with response options of 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree), and 5 (strongly agree). Students provide response toward four sections, such as appearance, quality, usefulness, and language. The detail information of students' response can be seen in Table 4 based on their experience of using the VL.

users can use it anywhere, at any time. Additionally, VL offers a number of supplemental videos as extra material to help students comprehend each step in greater detail and with greater guidance.

Although just a few percent of students, approximately 4-7%, provide neutral responses to the quality of language utilized in VL. A 9% regularly respond neutrally to statements

Table 3. Students' responses towards VL quality

No.	Questions	Neutral		Agree		Strongly Agree	
		N	P (%)	N	P (%)	N	P (%)
Appearance							
1	The virtual lab's font choices can help students read membrane technology materials more easily.			16	69.56	7	30.44
2	The colour scheme for the background with words and animations in the virtual lab is already suitable.			15	65.22	8	34.78
3	The design of the virtual laboratory media utilizing Adobe Flash CS6 is already remarkable.			10	43.48	13	56.52
Mean					59.42		40.58
Std. Error					13.97		13.97
Quality							
4	Instructions for using media in the virtual lab assist students with practical work.			5	21.74	18	78.26
5	Membrane technology resources in the virtual lab based on the course objectives.	2	8.69	6	26.09	15	65.22
6	The virtual lab presents membrane technology material in a more simplified approach.	2	8.69	12	52.17	9	39.14
7	Simplifying the information in the virtual lab can improve students' comprehension.	1	4.35	11	47.83	11	47.83
8	Membrane technology materials in the virtual lab can assist students with practical tasks.			5	21.74	18	78.26
Mean			7.24		33.91		61.74
Std. Error			2.51		14.87		17.76
Usefulness							
9	Students are assisted in mastering the practical material of membrane technology by the virtual laboratory media.			17	73.91	6	26.09
10	It is quite simple to use virtual laboratory media on your own.			7	30.43	16	69.57
11	Students' references on the subtopic of membrane technology can be improved by using virtual laboratory media.			13	56.52	9	43.48
Mean					53.62		46.38
Std. Error					21.88		21.88
Language							
12	The virtual lab's terminology already complies with EYD guidelines.	1	4.35	15	65.22	7	30.43
13	The virtual laboratory uses straightforward language that makes it easier to read.	1	4.35	9	39.13	12	56.52
14	The way the virtual lab information is presented uses an effective language pattern that prevents ambiguity.			17	73.91	6	26.09
Mean			4.35		59.42		37.68
Std. Error			0.00		18.10		16.46

Table 3 demonstrates that more than 90% of students agreed or strongly agreed with the four assessed indicators. Because it completed revision based on validation results from the experts during its development stage, it should satisfy very high criteria for appearance and quality when used in practical learning. When compared to other aspects, the quality portion had the greatest response, with 62% of respondents falling into the strongly agree category. With a 95% very valid category, this is very relevant to the validation results. Up to 78% of students strongly agreed with the claim that VL helps students become more independent learners. Students conclude that because VL takes a very straightforward approach, they can easily accomplish the practical learning objectives. As a result, they promote the very basic usage of VL in terms of usability because 70% of

concerning the approach utilized in VL. They believe that because the supplementary resources are supplied in English, a tiny number of them have not been as beneficial to understanding each stage of the practicum. With 4% of respondents giving indifferent answers in the language section, indicating that they think the language used in VL still contains some foreign phrases that are unclear enough to reduce their comprehension, the assessment is relevant. The students' finest response, though, was that the language was excellent and left little chance for interpretation. When students begin the experimental stages, they already understand all of the unfamiliar terms used in the membrane synthesis practical because they were previously explained in the learning material section of the VL.

15 questions have been included in VL to assess students' comprehension following their use of the platform. Up to twenty-three pupils finished the test. The DD percentage, which would indicate the degree of difficulty students encountered when utilizing VL, was then calculated for each question. The average DD in Table 5 is 78.28%, which indicates a very low level of learning difficulty. Therefore, it can be claimed that when students use VL it enhances students' learning independence.

Table 4. Difficulty Degree of Students while using VL

Question Number	Answer		DD (%)
	Correct	Incorrect	
1	21	2	91.30
2	18	5	78.26
3	20	3	86.96
4	15	8	65.22
5	16	7	69.57
6	21	2	91.30
7	20	3	86.96
8	19	4	82.61
9	19	4	82.61
10	20	3	86.96
11	21	2	91.30
12	12	11	52.17
13	18	5	78.26
14	16	7	69.57
15	14	9	60.87
Total Average			78.26
Error			12.19

Students' prior computer program experience also affects how easy it is to use VL. There is no apparent distinction in the learning outcomes of students conducting practical sessions in real and virtual laboratory, according to prior study on a sample with a medium level of computer application skill [33] . The results of the survey also show that, with 60% of respondents agreeing or strongly agreeing, students believe the new classroom design successfully replicates the practical experience of a traditional laboratory setting. Additionally, the study highlights the value of providing students with professional development opportunities and the significance of utilizing practically able virtual laboratories in the context of chemistry education [34].

Evaluation Stage

At every step of the ADDIE framework, the evaluation stage is always conducted. Formative evaluation is an assessment that is carried out to gather information for improvement at each stage. When developing virtual laboratory media using the ADDIE model, evaluation was done formatively, which means that there is an evaluation phase at every stage.

Analyzing the faculty needs, as indicated in Table 2, is the evaluation that was carried out during the analysis stage. Following examination, it was determined that the lecture's requirements analysis questionnaire required revision in accordance with his recommendations. The lecture then presented and double-checked the updated results. The needs analysis was then judged suitable and prepared for evaluation by the course lecturer. The lecturer's assessment of the needs analysis obtained a disagreement response; therefore, it is necessary to examine this response in order to determine why the lecturer disagreed with one of the researcher's questions. According to other research analysis, the assessment stage can be carried out by performing media validation analysis and evaluating the viability of small-scale and large-scale trials.

The supervising lecturer's opinions and recommendations on the created virtual laboratory media are evaluated during the design phase. It was discovered during the consultation with the supervising lecturer that the virtual laboratory media required more materials, a more engaging background change, a volume pipette in the section on solution and solid weighing, reflections at the start and finish of the practicum, definitions for words that students struggle to understand, and images at the phase inversion stage.

The evaluation at the development stage was based on the assessment and recommendations made by the supervising lecturers and validator team regarding the virtual laboratory media. The researchers will then refine the validator team's recommendations to create a better and more appealing product. The validators have suggested adding menu icons in the section on practical implementation, changing the phrase "virtual lab" to "*laboratorium virtual*," and adding a "hooray" icon at the end of the practical to signify its completion. The researcher considered these three recommendations and made the necessary corrections to improve and improve the virtual laboratory media.

Based on how students respond to the virtual laboratory media on the supplied membrane technology material, an assessment of the implementation stages can be made. According to the response results, a number of respondents selected the "neutral" response. This must be assessed in order to determine what is incorrect with the statement and why the provided response is adequate. in order for the researchers to fix any errors and ensure that students can effectively use and comprehend the virtual laboratory media. Selecting the educational media used in the classroom, monitoring its usage, determining if the intended goals of its use have been met, and offering suggestions for enhancing already-developed media are the objectives of media assessment.

CONCLUSION

The ADDIE model was used for developing VL for membrane synthesis practicum in the separation chemistry course. The analysis step with the course lecturers verified that the practical sessions could only be conducted as demonstrations due to equipment and material limitations. As a result, each student does not have the opportunity to participate in all stages of the experiment. Thus, the lecturer believes that developing VL is vital to improve students' learning independence. The VL's composition, both its appearance and content, was determined before of time at the design stage. In addition, the experiment's objectives were confirmed with the course lecturer to verify that the VL content aligns with the learning objectives that students will achieve throughout the practicum. The validation results from the three experts show that all three aspects meet the highly valid criteria at 88%, 95%, and 90%, respectively, for face, content, and construct validity. Several changes were made, particularly within the practical steps, such as the addition of practical assets and display menus to help users follow each step of the experiment. VL was additionally improved with video references as instructions before students carried out the experiments independently. Therefore, the revised version obtained 100% of highly valid. During the trial phase, user responses were extremely high, with more than 90% of students providing positive feedback ranging from agree to highly agree. Although there are approximately 4-7% neutral feedback, they were provided by students who faced difficulties by the foreign language utilized in the reference video Thus, feedback is used to evaluate the final product. Not only based on students' responses, but also the difficulty index represents their independence while using VL. However, VL has not been evaluated in a larger context, therefore it is still limited to study programs and students taking the separation chemistry course solely.

REFERENCES

[1] K. Obaideen, N. Shehata, E. T. Sayed, M. A. Abdelkareem, M. S. Mahmoud, and A. G. Olabi, "The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline," Energy Nexus, vol. 7, p. 100112, 2022.

[2] F. B. Mamba, B. S. Mbuli, and J. Ramontja, "Recent advances in biopolymeric membranes towards the removal of emerging organic pollutants from water.," Membranes (Basel), vol. 11, no. 11, p. 798, 2021.

[3] BPS, Statistik Lingkungan Hidup Indonesia 2020. Badan Pusat Statistik, 2020.

[4] I. M. Sadiana, K. Karelius, R. Agnestisia, and A. H. Fatah, "Studies on Synthesis, Characterization, and Adsorption of Cationic Dyes from Aqueous Solutions Using Magnetic Composite Material from Natural Clay in Central Kalimantan, Indonesia," Molekul, vol. 13, no. 1, p. 63, May 2018, doi: 10.20884/1.jm.2018.13.1.414.

[5] Y. Miyah et al., "Multi-parametric filtration effect of the dyes mixture removal with the low cost materials," Arab J Basic Appl Sci, vol. 27, no. 1, pp. 248–258, Jan. 2020, doi: 10.1080/25765299.2020.1776008.

[6] M. Reza, E. Pramono, and C. L. Radiman, "Improving separation performance of PVDF ultrafiltration membranes by blending with cellulose acetate," Iran. J. Chem. Chem. Eng, vol. 42, no. 3, 2023.

[7] M. Reza, R. F. I. Rahmayani, and C. L. Radiman, "Effects of coagulant bath temperature toward separation performance and antifouling properties of PVDF/CA membranes for filtration of dyes.," Chimica Techno Acta, vol. 11, no. 2, p. 202411201, 2024.

[8] H. Aliyu and C. A. Talib, "A systematic review of 21st-century chemistry laboratory experiments and classroom instructions facilitated/aided with digital technologies and e-resources," International Journal of Current Educational Studies, vol. 2, no. 1, 2023.

[9] A. J. A. Alnagrat, R. C. Ismail, and S. Z. S. Idrus, "The Opportunities and challenges in virtual reality for virtual laboratories," Innovative Teaching and Learning Journal, vol. 6, no. 2, pp. 73–89, 2022.

[10] K. Frady, "Use of virtual labs to support demand-oriented engineering pedagogy in engineering technology and vocational education training programmes: A systematic review of the literature," European Journal of Engineering Education, vol. 48, no. 5, pp. 822–841, 2023.

[11] R. L. Reyes, K. P. Isleta, J. D. Regala, and D. M. R. Bialba, "Enhancing experiential science learning with virtual labs: A narrative account of merits, challenges, and implementation strategies," J Comput Assist Learn, vol. 40, no. 6, pp. 3167–3186, 2024.

[12] K. Achuthan, D. Raghavan, B. Shankar, S. P. Francis, and V. K. Kolil, "Impact of remote experimentation, interactivity and platform effectiveness on laboratory learning outcomes," International Journal of Educational Technology in Higher Education, vol. 18, pp. 1–24, 2021.

[13] V. J. Bhute, P. Inguva, U. Shah, and C. Brechtelsbauer, "Transforming traditional teaching laboratories for effective remote delivery—A review.," Education for Chemical Engineers, vol. 35, pp. 96–104, 2021.

[14] L. J. Hirshfield and M. D. Koretsky, "Cultivating creative thinking in engineering student teams: Can a computer-mediated virtual laboratory help?," J Comput Assist Learn, vol. 37, no. 2, pp. 587–601, 2021.

[15] S. Caño de las Heras et al., "Benefits and challenges of a virtual laboratory in chemical and biochemical engineering: Students' experiences in fermentation," J Chem Educ, vol. 98, no. 3, pp. 866–875, 2021.

[16] A. L. Tauber, S. M. Levonis, and S. S. Schweiker, "Gamified virtual laboratory experience for in-person and distance students," J Chem Educ, vol. 99, no. 3, pp. 1183–1189, 2022.

[17] M. C. Manyilizu, "Effectiveness of virtual laboratory vs. paper-based experiences to the hands-on chemistry practical in Tanzanian secondary schools," Educ Inf Technol (Dordr), vol. 28, no. 5, pp. 4831–4848, 2023.
[18] C. Byukusenge, F. Nsanganwimana, and A. P. Tarmo, "Effectiveness of virtual laboratories in teaching and learning biology: a review of literature," International Journal of Learning, Teaching and Educational Research, vol. 21, no. 6, pp. 1–17, 2022.
[19] D. May, I. Jahnke, and S. Moore, "Online laboratories and virtual experimentation in higher education from a sociotechnical-pedagogical design perspective," J Comput High Educ, vol. 35, no. 2, pp. 203–222, 2023.
[20] H. Abuhassna and S. Alnawajha, "Instructional design made easy! Instructional design models, categories, frameworks, educational context, and recommendations for future work," Eur J Investig Health Psychol Educ, vol. 13, no. 4, pp. 715–735, 2023.
[21] A. Mayasri, M. Reza, M. R. Asyifa, and K. Ulayya, "The impact of experimental researchbased learning modules on students' affective domain: A study on religious moderation in chemistry education," Jurnal Kimia dan Pendidikan Kimia (JKPK), vol. 9, no. 3, pp. 433–456, 2024.
[22] M. Berlian, R. Vebrianto, and M. Thahir, "Development of Webtoon Non-Test Instrument as Education Media," International Journal of Evaluation and Research in Education, vol. 10, no. 1, pp. 185–192, 2021.
[23] K. L. Hsiao, Y. Y. Ku, and Y. T. Lee, "Development and validation of a scale for assessing university students' new online media and reporting literacy," Educ Inf Technol (Dordr), vol. 28, no. 10, pp. 13569–13594, 2023.
[24] M. Agusti, S. M. Ginting, and F. Solikhin, "Pengembangan E-Modul kimia menggunakan eXe-Learning berbasis Learning Cycle 5e pada materi larutan penyangga," ALOTROP, vol. 5, no. 2, pp. 198–205, 2021.
[25] C. C. Ledoh, S. B. Raharjo, and S. Saputro, "The need analysis of guided inquiry-based electronic module using virtual laboratory for chemistry learning," in 6th International Seminar on Science Education (ISSE 2020), Atlantis Press, Mar. 2021, pp. 277–282.
[26] A. H. Y. Asare, J. N. Annan, and E. I. Ngman-Wara, "The effect of virtual laboratory on student teachers' achievement in integrated science in Bagabaga College of Education, Tamale, Ghana," European Journal of Research and Reflection in Educational Sciences, vol. 10, no. 1, pp. 26–39, 2022.
[27] N. Kapilan, P. Vidhya, and X. Z. Gao, "Virtual laboratory: A boon to the mechanical engineering education during covid-19 pandemic," Higher Education for the Future, vol. 8, no. 1, pp. 31–46, 2021.
[28] K. El Kharki, K. Berrada, and D. Burgos, "Design and implementation of a virtual laboratory for physics subjects in Moroccan universities," Sustainability, vol. 13, no. 7, p. 3711, 2021.
[29] M. E. Ahmed and S. Hasegawa, "Development of online virtual laboratory platform for supporting real laboratory experiments in multi domains," Educ Sci (Basel), vol. 11, no. 9, p. 548, 2021.
[30] W. P. Astuti, M. Ramli, and S. Suranto, "Validity and practicality of sangiran site-based virtual laboratory learning media on evolutionary materials to empower science literacy," Jurnal Penelitian Pendidikan IPA, vol. 8, no. 3, pp. 1378–1384, 2022.
[31] A. Giguère et al., "Printed educational materials: effects on professional practice and healthcare outcomes," Cochrane Database of Systematic reviews, 2020.
[32] L. A. Putri, A. Permanasari, N. Winarno, and N. J. Ahmad, "Enhancing Students' Scientific Literacy Using Virtual Lab Activity with Inquiry-Based Learning," Journal of Science Learning, vol. 4, no. 2, pp. 173–184, 2021.
[33] H. Bazie, B. Lemma, A. Workneh, and A. Estifanos, "The Effect of Virtual Laboratories on the Academic Achievement of Undergraduate Chemistry Students: Quasi-Experimental Study," JMIR Form Res, vol. 8, no. 1, p. e64476, 2024.
[34] V. K. Kolil and K. Achuthan, "Virtual labs in chemistry education: A novel approach for increasing student's laboratory educational consciousness and skills," Educ Inf Technol (Dordr), vol. 29, no. 18, pp. 25307–25331, 2024.