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Transforming laboratory management learning with e-modules

Ni Pt. Pande Mirah Surya Dewi*)[1], Luh De Liska[2], Ni Putu Yuniarika Parwati[3]
[1]Universitas Lambung Mangkurat, Banjarmasin, Indonesia; mirah@ulm.ac.id
[2]Universitas PGRI Mahadewa Indonesia, Denpasar, Indonesia; luhdeliska86@gmail.com
[3]Universitas PGRI Mahadewa Indonesia, Denpasar, Indonesia; parwatiyuniarika@gmail.com
*)Corresponding author: Ni Pt. Pande Mirah Surya Dewi; E-mail addresses: mirah@ulm.ac.id

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Abstract. Laboratories are crucial in chemistry education; however, in practice, many students still struggle to grasp the concept of laboratory management in an applied way, as reflected in their scores, which remain below the passing grade. This research aimed to develop e-modules based on case-based and project-based learning to improve understanding of laboratory management concepts. This study used a Research and Development (R&D) approach with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). Validation of e-modules was carried out by material and media experts, and tested on 24 FKIP ULM Chemistry Education students. Data collection instruments included validation questionnaires, student response questionnaires, as well as pretests and posttests, which were analysed using the Wilcoxon test. The results showed that the e-module was rated "very valid" from the aspects of content, presentation, language, and media. The Wilcoxon test resulted in a significance value of 0.000 ($p < 0.05$), indicating a significant increase in student concept understanding after the use of e-modules. Recommendations from this study are the wider use of case- and project-based e-modules in learning laboratory management, as well as continuous development to be more adaptive to the development of educational technology.

Introduction

Laboratories serve as essential environments for performing scientific experiments that enhance various aspects of chemistry education (DeKorver & Towns, 2015; Restiana & Djukri, 2021). They offer an optimal setting for meaningful learning, particularly for secondary and undergraduate students. Through laboratory activities, students can develop practical skills, foster creativity, and deepen their understanding of chemical concepts while also enhancing motivation, collaboration, safety awareness, and attentiveness. Laboratories also play a vital role for chemists in presenting evidence and testing scientific hypotheses directly.

The integration of theoretical knowledge with hands-on experimentation is fundamental and inseparable in chemistry education. Experiments function as a key approach to verify scientific principles, acquire new knowledge, and facilitate discovery (Gungor et al., 2022). They involve exploring natural phenomena and conducting tests within controlled environments (Adiningsih et al., 2020). Relying solely on theoretical instruction without experimental practice can hinder students' comprehension. Studies indicate that engaging in chemistry experiments significantly boosts students' motivation, achievement, conceptual grasp, and scientific proficiency (Sartika &

Timan, 2025). Before the e-module was developed, researchers had carried out data collection related to student scores in the learning process with conventional learning models without using e-modules. The data is presented in image 1.

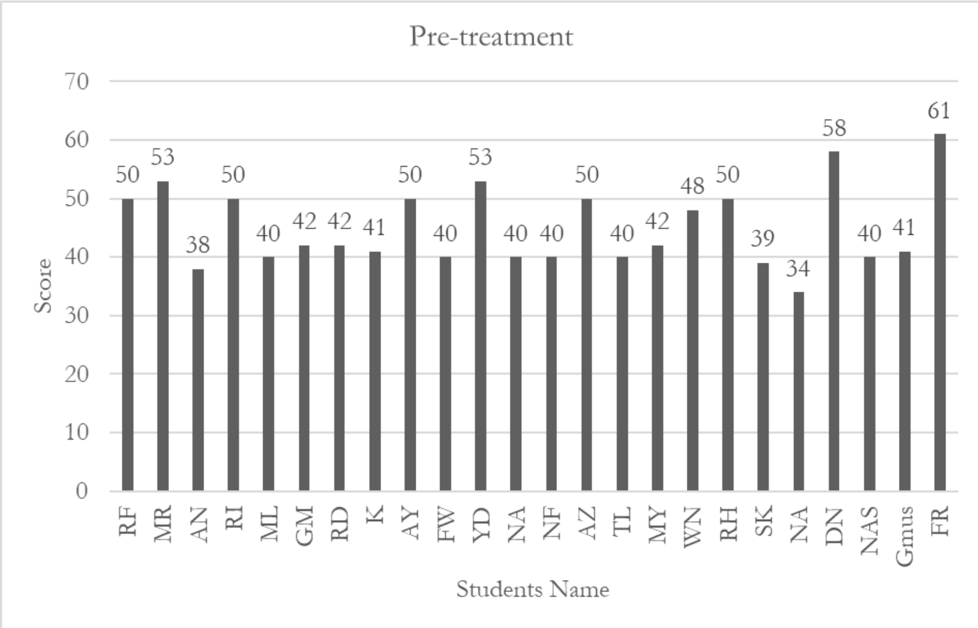

Image 1. Student grades before e-modules were developed

Based on image 1, student scores are still below the passing grade, so a more contextual learning method is needed accompanied by technological applications to facilitate the learning process. This condition indicates a gap between the learning methods applied and the need for mastery of the material by students. This fact emphasises the need for innovation in learning strategies that can increase student involvement, concept understanding, and applicative skills. One relevant innovative approach is the development of e-Modules based on digital technology. E-Modules do not only provide learning flexibility, but also allow the integration of interactive media, formative evaluation, and systematic presentation of material so as to significantly improve student motivation and learning outcomes.

The swift advancement of technology has profoundly transformed the field of education. One of the impacts is the emergence of various learning innovations that are more interactive and effective, one of which is e-modules. In the context of laboratory management, the integration of e-modules with student-centered learning methods such as case-based learning and project-based learning is becoming increasingly relevant. The rapid development of digital technology has enabled the development of e-modules that are feature-rich, interactive, and easily accessible. As emphasised by Abdul Sakti (2023), digital technology has shaped a more interactive learning approach, utilising various multimedia, simulation devices, and software. This can encourage student participation such as direct involvement in problem solving, critical thinking skills, and project development in addressing existing problems (Sukendra et al., 2023).

The world of work today demands graduates who not only have strong theoretical knowledge, but also have practical skills, critical thinking skills, and the ability to work in teams. Case and project-based learning in e-modules can help students develop these skills. The learning paradigm has shifted from a teacher-centered approach to a student-centered approach. Case-and project-based learning is in line with this paradigm as it encourages students to become active and independent learners (Purnadewi & Widana, 2023).

Combining e-modules with case-based learning and project-based learning in the context of laboratory management has great potential to improve the quality of learning. Case-based learning allows students to learn from complex real situations. The case-based method is an active learning approach that places students at the heart of the learning process, promoting exploration within real-world contexts and community-based scenarios. This strategy allows students to concentrate on specific cases, engage in scientific investigation, and collaborate actively with their peers. Throughout the process, they enhance their critical thinking and problem-solving abilities by applying theoretical knowledge to practical situations (Dewi, 2022). Project-based learning motivates students to utilise their knowledge and skills to address real-world problems (Evi Yupani & Widana, 2023). This approach revolves around complex questions that require students to engage in designing, problem-solving, decision-making, and investigative tasks. It provides them with the freedom to create both tangible and intangible outcomes over a set period. At its core, project-based learning emphasises hands-on experience, allowing students to directly apply the theories they have learned to meaningful project (Anggriani et al., 2019).

Although there have been several studies that examine the use of emodules in education, research that specifically combines e-modules with case-based learning and project-based learning in the context of laboratory management is still relatively limited. Based on the urgency, this research focuses on answering several important questions, namely: (1) What is the validity of the developed Laboratory Management e-Module based on aspects of material substance, presentation, language, and media? (2) What is the level of student understanding before and after attending lectures using e-Modules based on case-based learning and project-based learning? Laboratory is a place to conduct an experiment and investigation related to physics, chemistry, and biology or other fields of science (Muhith et al., 2022). Good laboratory management is determined by various interrelated factors. Sophisticated laboratory equipment and skilled professional staff are not necessarily able to operate optimally without the support of effective laboratory management. Therefore, laboratory management is an integral part of daily laboratory activities (Suranto et al., 2020) . This study seeks to address the existing gap by creating an e-module that integrates case-based learning and project-based learning for laboratory management, ensuring its validity in terms of content substance, presentation, language, and media, as well as measuring students' understanding before and after participating in lectures using the e-module.

Method

This study employed a Research and Development (R&D) approach, with the creation of e-modules guided by the ADDIE model. The ADDIE framework included five key phases: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The first stage was Analysis, where researchers conducted a student needs analysis, analysis of the Semester Learning Plan (SSP), and interviews with students to identify the main problems in learning Laboratory Management. The results of this stage were the basis for preparing e-Modules that are relevant and based on real needs in the field. The second stage was Design, at this stage the researcher began to design the e-Module as a solution to the problems that had been identified. The design focused on the integration of case-based learning and project-based learning methods into the e-Module structure, by paying attention to systematic learning stages, starting from course learning outcomes (CPMK), sub-CPMK, to the presentation of material and evaluation.

The third stage was Development, where the product that had been designed was then developed through several main steps, namely: (a) Material Collection, which was the collection of types of material that were in accordance with the characteristics and learning needs. This material was obtained from various reference sources in the form of relevant books and journals. The material in each chapter was supported by multimedia components such as text, images/graphics, and interactive videos, (b) Media Creation, namely making all the components needed and integrating them into the e-Module according to the flowchart that had been designed, starting from the learning model, CPMK, sub-CPMK, to the final competency, (c) Product Validation, which was validation conducted by material experts and media experts. Input from the validators was used to revise the product so as to produce an e-Module that was valid and feasible to implement. The components assessed from the validation stage were related to the content, presentation, grammar, and media used.

The fourth stage was Implementation, where the e-Module that had been developed was tested on a small class from a non-experimental class after which was tested on 24 students of the Chemistry Education Study Program at FKIP Lambung Mangkurat University (ULM). This stage included organising the classroom environment and conducting trials of using the e-Module in learning activities. The fifth stage was Evaluation, which was carried out thoroughly from the beginning to the end of the development process. Evaluation was carried out to measure the effectiveness of e-Module in improving students' understanding before and after attending lectures, as well as to assess the suitability of the product with the learning objectives that had been set.

The data analysis technique used was quantitative using the Wilcoxon test. Data collection consisted of validation questionnaires, student responses, and pretest and posttest instruments (Widana & Muliani, (2020). The validity of the e-module preparation product was obtained from measuring the validation results so that the validity of the e-module and the pretest and posttest instruments for research was known. The test results were further strengthened by a non-parametric statistical test called the Wilcoxon test using the following hypothesis, H0: There is no significant increase in students' concept understanding ability before and after attending lectures using e-modules, H1: There is a significant increase in students' concept understanding ability before and after attending lectures using e-modules, the hypothesis used a significance level of $\alpha = 0.05$. Hypothesis criteria and significance level: if p value $< \alpha$, then H0 is rejected, if p value $\geq \alpha$, then H0 is accepted.

Results and Discussion

Chemistry requires hands on lab activities to help students achieve learning competencies. Theory alone is not sufficient; practical work using proper tools and materials is essential to connect theory with scientific problem-solving. Laboratories enhance learning by allowing students to directly observe and engage in experiments, making chemistry more meaningful. To ensure effective lab activities, proper laboratory management is crucial. This includes having complete equipment, skilled personnel, and clear guidelines. Effective lab management, based on sound management principles, greatly supports efficient teaching and learning in schools (A'yuniah et al., 2022).

This e-module was developed with 5 stages, namely: analysis, design, development, implementation, and evaluation stages. The implementation and evaluation stages can be done simultaneously. The ADDIE model is a widely recognised framework commonly used by instructional designers and training developers. It consists of five key phases: Analysis, Design, Development, Implementation, and Evaluation. Originally developed by Reiser and Mollanda in 1967, the ADDIE model outlines a structured process for instructional design aimed at creating more effective and efficient teaching and learning experiences. This model is adaptable for a wide range of educational product development, including strategies, methods, media, and instructional materials. While traditionally followed in sequence, the ADDIE model also emphasizes the importance of reflection and feedback to support ongoing improvements throughout the design process. To effectively apply the ADDIE model, it should be customized to suit the specific learning context. This includes defining learning goals, understanding the characteristics of the target audience, and considering the learning environment. A successful implementation often involves collaboration among instructional designers, educators, content experts, and other stakeholders, who each contribute to the planning, development, and delivery of instruction.

The first stage is Analysis, which focuses on identifying what learners need to achieve. It involves conducting a needs assessment, identifying existing learning problems or gaps, and conducting a detailed task analysis. The outcomes of this stage include learner profiles, identified learning needs, and task details aligned to those needs. The analysis stage can be broken down into three main components: learner analysis which involves interviewing students in relation to the learning process. Drawing from the interview findings, students said that during the lecture, they found it difficult to acknowledge the concept of laboratory management in an applicable manner. The student added "If there is an assignment, it is usually only a paper or presentation, there are rarely case studies or laboratory management projects that make us learn directly how to make SOPs, manage tools, or arrange work safety." learning content analysis (which includes setting learning objectives based on RPS), The selected CPMKs are CPMK 1, namely mastering the principles of management of tools and materials in chemical laboratories, chemical laboratory work safety and CPMK 2, namely mastering the concepts of chemical packaging, MSDS, and handling laboratory waste, and analysis of offline delivery methods. Activities in this phase include determining learners' characteristics, analysing their learning needs, creating a concept map based on preliminary research, and designing a flow chart to guide product development (Mustadi et al., 2022). This comprehensive analysis provides a solid foundation for the design and development of effective instructional materials.

The second stage is Design, which is a critical step in the development of learning materials. At this stage, the structure and specifics of how the instructional content will be created are carefully planned, taking into account the entire development and implementation process (Hamid et al., 2021). In the Design stage, the following activities are carried out 1) Formulate learning objectives using the SMART principle (Specific, Measurable, Applicable, Realistic) to ensure that each objective is measurable and relevant to student needs. 2) Determine Learning Strategies and Learning Models that are tailored to CPMK 1 and 2. 3) Design the E-Module Structure systematically. 4) Researchers select appropriate learning media and design resource needs such as illustrations, supporting videos, project worksheets, and relevant evaluation tools to support learning effectiveness.

The next stage is Development, where the instructional design created during the previous phase is transformed into actual learning products and activities. This includes developing e-learning content and choosing the appropriate digital platforms to support the learning experience (Ofosu-Asare et al., 2019). At this stage, e-modules were made, e-modules validated, and e-modules revised. The resulting Laboratory Management E-Module is organized into several learning activities, namely 1) Introduction to Chemical Laboratory Design; 2) Safety and Security in the Laboratory; 3) Source of Chemical Information; and 4) Laboratory Waste. The resulting e-module has several parts consisting of a cover page, preface, table of contents, list of figures, list of tables, list of videos, explanation of the contents of the e-module, instructions for using the e-module, course overview, concept map, explanation of learning methods, material description, case study, student project, summary, competency test, glossary, and bibliography.

At this stage of development, it discusses the results of e-module development that have been revised based on suggestions from validators. Material expert validators consist of 1 lecturer and 1 media expert validator. Validators not only provide an assessment, but also provide suggestions as a reference for making revisions to the e-module, including 1) questions on case studies are adjusted to the conditions in the laboratory where we conduct experiment, 2) adjust the level of difficulty on competency test questions, 3) add a glossary, and 4) adjust the bakcground so that the text remains clearly visible. The following is an analysis of the assessment by material and media expert validators can be seen in table 1.

Table 1. Assessment Results by Material and Media Expert Validators

Assessment Aspect	Average Percentage (%)		Average (%)	Validity Criteria
	Validator 1	Validator 2		
Content eligibility	96.36	85.45	90.91	Very Valid
Presentation feasibility	100	98.33	99.17	Very Valid
Linguistic appropriateness	100	98	99	Very Valid
Media feasibility	88.57	94.28	91.43	Very Valid
Average	96.23	94.01	95.12	Very Valid

The analysis results indicated that the validation of the e-module's material and media achieved an average percentage of 95.12%, falling into the "very valid" category. Therefore, the e-module was deemed valid in terms of content eligibility, presentation feasibility, linguistic appropriateness, and media feasibility, making it suitable for use in the learning process. The developed e-module is illustrated in image 2.

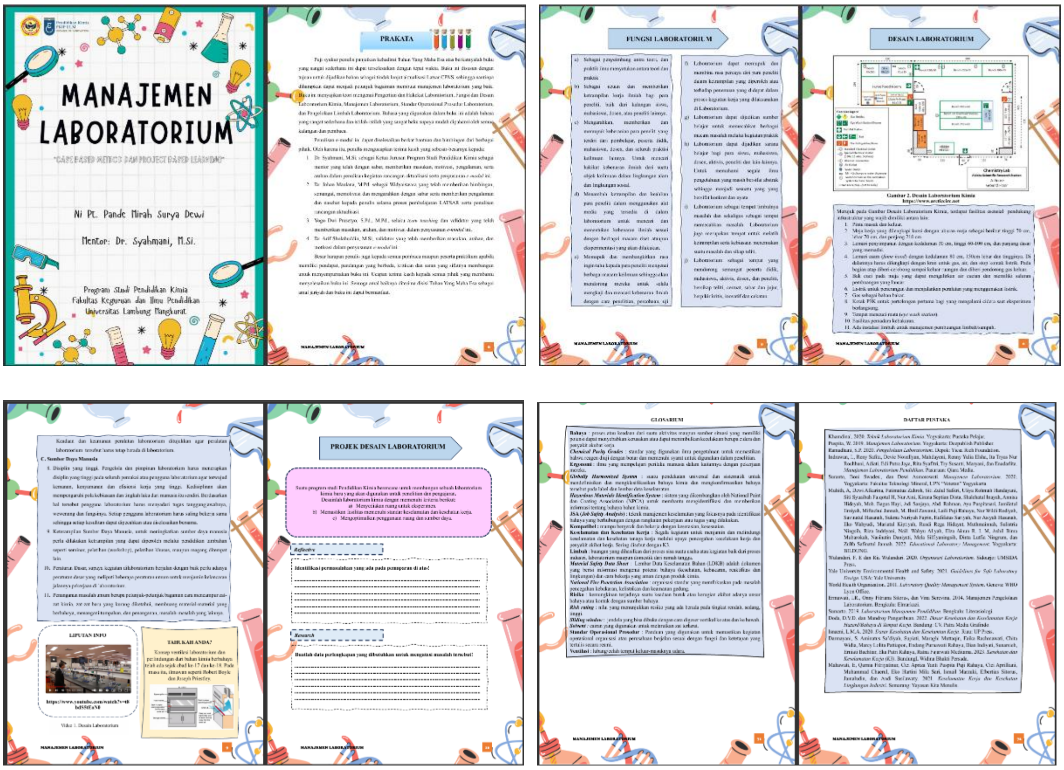

Image 2. E-modules of Laboratory Management

After obtaining a valid e-module, proceed to the small class trial stage with 12 students. Students responded to the e-module that had been produced.

Table 2. Student Response Result

Student	Student Response	
	Value	Category
1	4.4	Good
2	3.8	Good
3	4.9	Very good
4	5.0	Very good
5	4.1	Good
6	4.8	Very good
7	4.3	Good
8	4.2	Good
9	4.7	Very good
10	4.8	Very good
11	4.8	Very good
12	5.0	Very good
Average	4.5	Very good

The result of the student response questionnaire to the developed e-module received a positive response from students because it was included in the "very good" category so it was very good to use in learning.

The fourth stage of the ADDIE model is Implementation, which involves putting the developed learning system into actual practice (Hafni et al., 2022; Sarwa et al., 2021). At this stage, all components that have been created are arranged and configured according to their intended roles and functions, ensuring they are ready for use in the learning process.

Implementation of Project Based Learning Model

The stages of learning activities with project based learning model consists of 5 (five) stage according to Laboy-Rush as follows.

Table 3. Syntax of Project-based Learning Model

Project-based Learning Syntax	Objective	Learning Activity	
		Lecturer Activity	Student Activity
Reflection	This stage brings students into the context of the problem and inspires them to start investigating.	Provide general insight into the importance of good laboratory design and the safety aspects that must be considered	Discuss in groups to reflect on their knowledge of the safety aspects, layout and standards required in a chemistry laboratory. List the main issues often faces in laboratories, such as chemical, storage, safety, ergonomics, and efficiency.
Research	This stage facilitates students to find and collect relevant information about	Provide resources or references that can be accessed by students and provide guidance on	Collect data on modern laboratory design and consider special needs

Project-based Learning Syntax	Objective	Learning Activity	
		Lecturer Activity	Student Activity
	chemistry laboratory design,	what aspects need to be considered in research.	such as ventilation, lighting and storage.
Discovery	This stage leads students to identify potential solutions based on the information they have gathered	Encourage students to think creatively in developing solutions and provide input and clarification on the initial concepts prepared by students.	Create a sketch or initial concept of a laboratory design based on their findings.
Application	This stage applies their discoveries and solutions in the form of concrete designs.	Provide specific feedback on the application of the chosen solution, ensuring the design meets standards and addresses all identified issues.	Create a model or digital representation of the laboratory design to demonstrate the real-world application of the solution.
Communication	This stage encourages students to present their final design and practice professional communication skills.	Provide a final reflection that includes suggestions for improvement and appreciation for the students' efforts in the project,	Deliver presentations in front of lecturers and peers, receive feedback, and answer questions from the audience.

The five stages of the project-based learning model were implemented to measure the extent of improvement in student learning outcomes within the Chemistry Education Study Program. Data collection was conducted through pre-tests and post-tests to assess the enhancement of students' performance. Alongside the project-based learning model, the researchers also applied the case-based learning model following specific syntax.

Table 4. Syntax of Case-based Method Learning Model

Case-based Method Syntax	Objective	Learning Activities	
		Lecturer Activity	Student Activity
Preparation	Provides an initial understanding of the importance of SOPs in chemistry laboratories and prepares students with the necessary basic information.	Explain the main components of the SOP that must be considered, such as procedures for using chemicals, handling waste, and using safety equipment.	Students read basic materials covering laboratory safety principles, important elements of SOPs, and various examples of laboratory accident cases due to ineffective SOPs.
Implementation	Students apply their acquired knowledge to analyse and design realistic case-based SOPs.	Provide feedback during the discussion and SOP development process, ensuring the SOPs meet safety standards.	Students are given a case that contains problems or incidents in the laboratory caused by the lack of SOPs or ineffective SOPs 9for example: chemical leaks,

Case-based Method Syntax	Objective	Learning Activities	
		Lecturer Activity	Student Activity
			unsafe use of equipment, etc). Based on the results of the case analysis, each group drafts an SOP that includes a description of safety measures, personal protective equipment that must be used, and procedures for handling chemicals or equipment.
Closing	Provide opportunities for students to reflect on the learning outcomes and evaluate the effectiveness of the SOPs that have been made.	Provide a final assessment of the quality of the SOPs developed by each group based on completeness, compliance with safety standards, and ability to prevent risks.	Each group presents their SOP to the class, explaining the background of the case and how their SOP can prevent similar incidents in the future.

Recapitulation of Effectiveness Test Results

Data on student learning outcomes were obtained through pre-test activities at the beginning of the study before being given a treatment model, then given a post-test at the end of the study. The data obtained is presented in the image below.

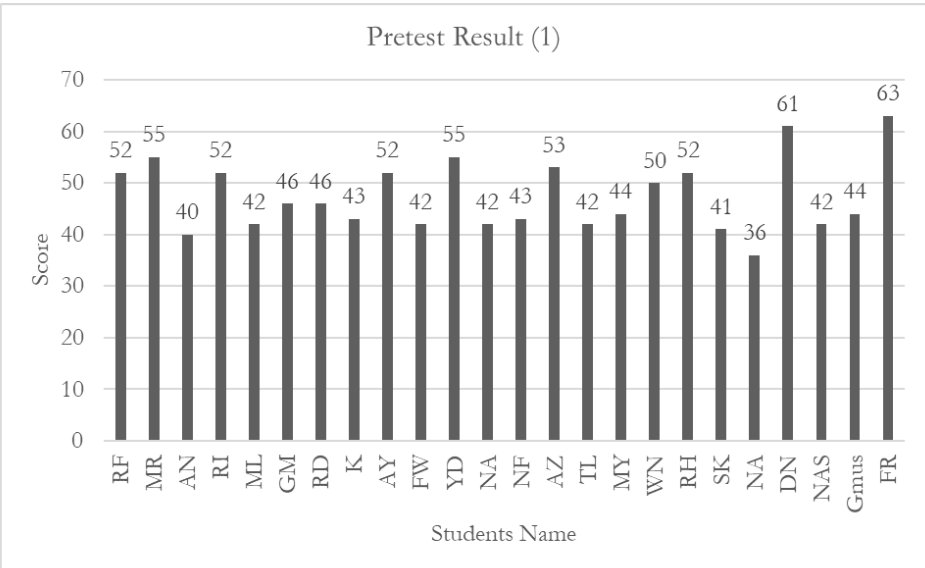

Image 3. CPMK-1 Pre-test Result

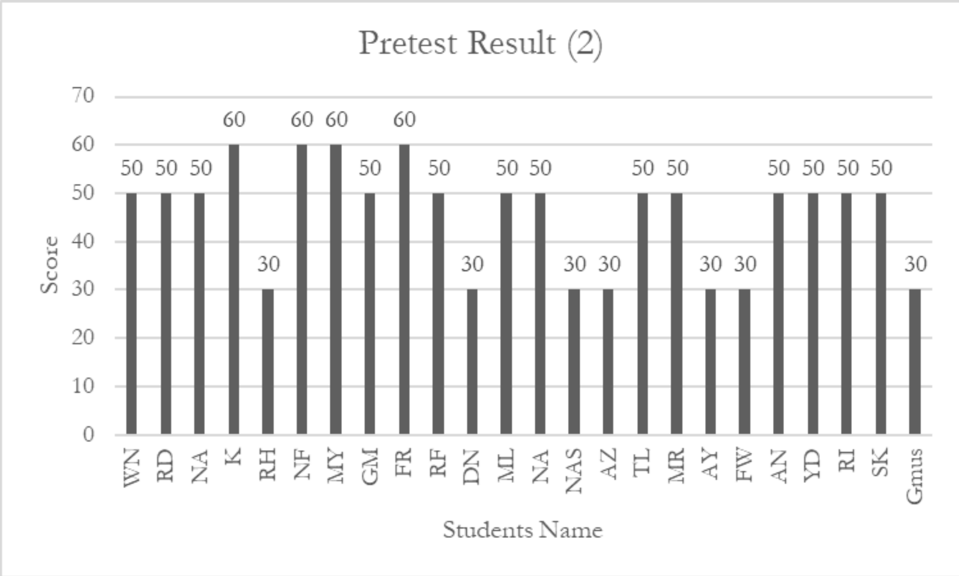

Image 4. CPMK-2 Pre-test Result

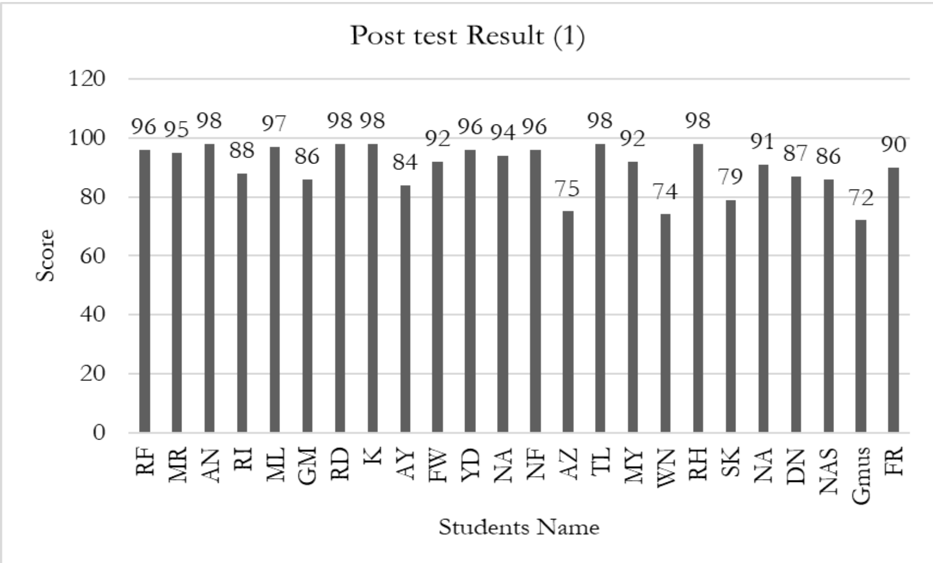

Image 5. CPMK-1 Post-test Result

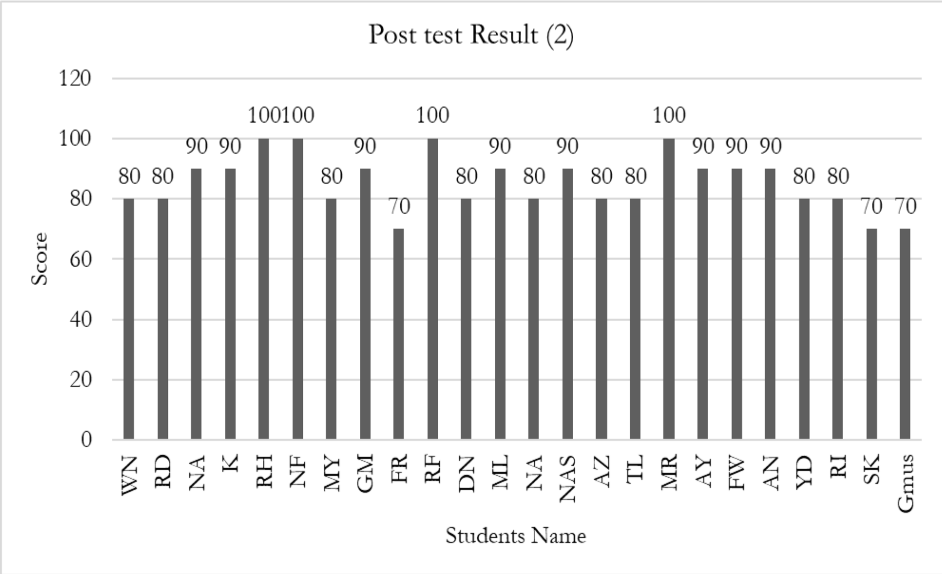

Image 6. CPMK-2 Post-test Result

The data above were then tested for normality using Shapiro-Wilk, data with less than 50. The following is an analysis of the pretest and posttest results on CPMK-1.

Table 5. Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-test	.189	24	.026	.922	24	.065
Post-test	.164	24	.096	.864	24	.004

a. Lilliefors Significance Correction

The pretest results showed a significance value of 0.065, indicating that sig. > 0.05, which means the pretest data is normally distributed. In contrast, the posttest results had a significance value of 0.004, meaning sig. < 0.05, so the data is not normally distributed. To test the hypothesis regarding the use of the e-module, the researcher applied the Wilcoxon Signed Rank Test using the SPSS 25.0 software. The Wilcoxon Signed Rank Test is a nonparametric method used to determine the significance of differences between two sets of paired data on an ordinal or interval scale when the data is not normally distributed. It serves as an alternative to the paired t-test when the assumption of normality is not met. The results of the Wilcoxon test are presented below.

Table 6. Ranks

		N	Mean Rank	Sum of Ranks
Posttest - Pretest	Negative Ranks	0[a]	.00	.00
	Positive Ranks	24[b]	12.50	300.00
	Ties	0[c]		
	Total	24		

a. Posttest < Pretest
b. Posttest > Pretest
c. Posttest = Pretest

Table 7. Test Statistics[a]

	Posttest - Pretest
Z	-4.287[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks

Positive ranks indicate an increase from pretest to posttest scores. The statistical test results show Asymp. Sig. 2 (-tailed) of 0.000, the result of Asymp. Sig. (2-tailed) <0.05 means H0 is rejected, then H1 is accepted, or there is a significant difference between pretest and posttest scores. The following is an analysis of pretest and posttest results on CPMK-2.

Table 8. Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-test	.232	24	.002	.831	24	.001
Post-test	.229	24	.002	.863	24	.004

a. Lilliefors Significance Correction

Based on the data presented above, since the sample size is less than 50, the Shapiro-Wilk test was used to assess normality. The pretest yielded a significance value of 0.001, indicating sig. < 0.05, which means the data is not normally distributed. Similarly, the posttest showed a significance value of 0.004, also indicating non-normal distribution. To evaluate the hypothesis regarding the implementation of the e-module, the researchers employed the Wilcoxon Signed Rank Test using SPSS version 25.0. This test is a nonparametric method used to determine the significance of differences between two sets of paired data on ordinal or interval scales that are not normally distributed. It serves as an alternative to the paired t-test when the normality assumption is not met. The results of the Wilcoxon test are presented below.

Table 9. Ranks

		N	Mean Rank	Sum of Ranks
Post-test – Pre-test	Negative Ranks	0[a]	.00	.00
	Positive Ranks	24[b]	12.50	300.00
	Ties	0[c]		
	Total	24		

a. Post-test < Pre-test
b. Post-test > Pre-test
c. Post-test = Pre-test

Table 10. Test Statistics[a]

	Post-test – Pre-test
Z	-4.318[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

Positive ranks indicate an increase from pretest to posttest scores. The statistical test results show Asymp. Sig. 2 (-tailed) of 0.000, the result of Asymp. Sig. (2-tailed) < 0.05 means that H0 is rejected, then H1 is accepted, or there is a significant difference between pretest scores and posttest scores.

The fifth and final stage in the ADDIE model is Evaluation. This stage is conducted continuously, particularly through formative evaluation, with the goal of identifying areas for revision and improvement (Mustadi et al., 2022). Evaluation results from the validation stage and small class trials showed that the laboratory management e-modules produced were valid with a good category. Students' scores after the implementation of the e-module also increased, which shows that it is effective to improve students' understanding of concepts related to laboratory management.

In learning activities, students are given case-based and projectbased problem solving exercises to apply concepts regarding laboratory management in real situations, increase understanding, and skills in solving problems (I. M. Dewi & Siregar, 2024) . Case-based method learning aims to shape character and improve the quality of student learning through mastery of life skills, including personal, social, intellectual, and vocational skills, as well as the ability to learn throughout life. The characteristics of case-based method include 1) it is decision-oriented, meaning the case presents a managerial situation that requires immediate decision-making without revealing the outcome; 2) it involves active student engagement in analyzing the situatuion; 3) It encourages the development of written discussions to explore various perspectives and analyses generated by students; 4) The content of the case includes a main section that outlines the issues and provides relevant information; and 5) Typically, cases do not include explicit questions, as identifying the key questions is a vital part of the analytical process (C. A. Dewi et al., 2022). The use of case-based learning aims to 1)Illustrate theoretical concepts through practical examples; 2) Support problem-solving and decision-making by offering a contextual framework for applying models, tools, and techniques; 3) Promote critical thinking and active discussion; 4) Enhance students' critical and creative thinking abilities; and 5) Improve real-world competencies and provide practice in realistic skill applications. Implementing case-based learning requires thorough preparation and clear guidance regarding student responsibilities in case discussions. This approach enables students to formulate solutions based on the given scenarios. Well-prepared cases also help instructors assess how well students apply their knowledge and principles to real-world situations, aiding in the identification of key concepts (Bernardi & Pazinato, 2022).

With this approach, students are expected to be able to collaborate in discussing related data and information, and conclude various alternative solutions. Students are also given the opportunity to test the chosen solution through comprehensive discussions, sketching, writing, and mapping the proposed solution (Andayani et al., 2021). Learning to solve cases is the application of the scientific method by thinking systematically and logically, aiming to develop cognitive abilities as well as rational, simple, and structured problem solving skills (Mahdi et al., 2020; Wu et al., 2019). According to Günther et al. (2019), an understanding of the case study method shows that learning that connects various cases in the material makes the learning process more effective and interesting. This method allows students to stay active as well as think critically and creatively when discussing cases that relate to real life. Therefore, this approach is suitable to be applied to expand knowledge and thinking skills in solving problems faced by students.

The application of the project-based learning model has a significant effect on student learning evaluation results from cognitive, affective, and psychomotor aspects (Wijayanto et al., 2020). In addition, the application of project-based learning also gives students the opportunity to explore their abilities and provide an optimal learning environment so that learning becomes fun and lasting (Afriana, 2022). This approach offers the potential to create meaningful and engaging learning experiences for students (Ernawati et al., 2023). Through PjBL, students are encouraged to actively investigate real-world challenges and issues found in their environment. The model involves learners in solving problems and carrying out meaningful, hands-on tasks. It also allows students to take ownership of their learning by independently constructing knowledge and creating tangible products. As a result, PjBL enhances students' cognitive abilities, including their capacity for analysis and critical thinking in the classroom (Lestari et al., 2024). In addition to the above, the PjBL model has advantages including 1) Train students to broaden their understanding of the problems in life that must be faced; 2) Provide direct experience to students by getting them used to thinking critically and honing their daily life skills; 3) Adjust to modern principles whose implementation needs to be done by developing student expertise, both through practice, theory, and application (Anggraini & Wulandari, 2020).

Conclusion

The e-module that has been prepared and developed is valid and effective so that it is feasible to use to improve understanding of concepts related to laboratory management by applying case-based method and project-based learning models so that it can be seen significantly from the post-test results which have positive ranks values that show an increase from the pre-test value.

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