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DEVELOPMENT OF PBL-BASED CHEMISTRY E-MODULES FOR COLLOIDAL SYSTEMS

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ABSTRACT

Integrating digital learning tools has become increasingly important for enhancing student engagement and learning outcomes in the rapidly evolving educational landscape. This research aimed to assess the feasibility of a developed e-module and its impact on student learning outcomes. The development process followed the ADDIE Model, comprising five stages: Analysis, Design, Development, Implementation, and Evaluation. The instruments used included interview sheets, e-module validation sheets, student response questionnaires, and a 20-item test instrument. The e-module was validated by experts based on content, presentation, language, and graphic criteria, achieving an average validity score of 91.6%, indicating strong validity. Following validation, the e-module was implemented with 36 eleventh-grade Science Program (XI MIA) students at a high Islamic school in Medan during the 2023/2024 academic year. The results demonstrated a significant improvement in student learning outcomes, as evidenced by an N-gain score of 0.76, which falls within the high criteria. Additionally, student responses to the e-module were overwhelmingly positive, with an average approval rating of 87%, categorising their feedback as "very good." The findings suggest that the developed e-module is feasible and effective in enhancing student learning outcomes. The high validation scores and positive student feedback indicate that the e-module is well-designed and meets educational standards. It is a valuable tool for improving student engagement and achievement in the classroom.

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INTRODUCTION

Chemistry is pivotal in promoting sustainable development and achieving sustainability goals, supported by four key indicators: policy, technology, industry, and education [1]. Education, in particular, is evolving to equip students with the skills necessary to make informed decisions, understand the consequences of their actions, and connect these insights with their knowledge and abilities. Modern learning emphases the integration of technological proficiency and practical skills, with the 21st century marked by the rapid dissemination of information through digital media and technology, enhancing both knowledge and skills [2]. One critical area in chemistry education is the understanding of colloidal systems. While colloidal topics may seem straightforward, many students need help grasping their concepts due to the tendency to memorize rather than meaningfully engage with the content. This challenge is compounded by traditional teaching models focusing on transferring information from educators to students. This leads to superficial learning, where students must understand concepts, principles, laws, and formulas. This approach needs to meet the demands of 21st-century learning, which calls for more interactive and student-centered methods [3].

There is a need for appropriate strategies and teaching concepts tailored to the complexities of colloidal systems to address this gap. Previous studies have highlighted the lack of specific media for teaching chemistry, particularly in areas like thermochemistry, and the need for digital media-based learning tools to improve the quality of education [4]. Teachers are expected to identify suitable learning models and methods to motivate students, enhance learning outcomes, and foster creativity during teaching [5]. Incorporating learning media into the educational process can spark new interests, generate motivation, and stimulate active learning, making the experience more engaging and less monotonous [6]. However, students often face challenges finding innovative alternative learning media that serve as independent learning resources, particularly in understanding complex chemistry topics [7].

Modules, particularly e-modules, offer a solution by enabling students to learn independently, catering to individual learning paces and abilities. With their numerous benefits, E-modules have become increasingly important in modern education. They provide versatility, allowing access from any location, and offer a practical alternative to traditional print instructional media. E-modules empower students to learn autonomously, reducing the need for constant teacher guidance and facilitating learning beyond scheduled class hours [8]. Furthermore, e-modules are an effective alternative source of information, encouraging interactive, student-centered learning that resonates more with today's tech-savvy students than traditional textbooks [9]. Additionally, the ease of access to information via electronic devices enhances students' ability to master the concept and increases motivation [10].

Integrating appropriate learning models, such as e-modules based on PBL, can significantly enhance the effectiveness of chemistry instruction. The chemistry e-module based on PBL is a digital teaching content designed around real-world problems. PBL-based modules have positively impacted students' independence, motivation, interest, concept reinforcement, and cognitive and affective development [11]. These e-modules encourage students to think critically, connect with real-world contexts, and analyze problems independently, leading to discovering and understanding concepts applicable to everyday life. Encouraging students to solve problems effectively fosters higher-order thinking skills, which can improve learning outcomes. The effectiveness of e-modules in learning is evident through increased student performance [12]. Furthermore, the interactive features of e-modules, such as videos, images, and animations, motivate students to use them as valuable learning resources [13]. This aligns with studies that demonstrate the effectiveness of e-modules in enhancing student achievement [14].

However, the success of PBL depends on correctly presenting the initial problem and ensuring students fully understand the task at hand. The problem should be a real, authentic issue from students' lives rather than just a question. Presenting such real-world problems in the module helps students discover concepts and build knowledge, making the learning process more student-centered [15]. Implementing problem-based e-modules in chemistry consistently shows positive results in improving student achievement.

This research aimed to evaluate the feasibility of the developed e-module and its impact on student learning outcomes. Previous research suggests that PBL-based e-modules in chemistry are effective, as evidenced by improved student learning outcomes. Additionally, another study found that using PBL-based e-modules enhanced student achievement and helped students exceed the Minimum Competency Standards [17].

METHODS

1. Research Design

This study utilized the ADDIE development model, comprising five stages: Analysis, Design, Development, Implementation, and Evaluation, as illustrated in Figure 1. The ADDIE model was selected for its systematic, clear, and efficient approach to instructional design. The research focused on the design, feasibility, student learning outcomes, and student responses to developing a PBL e-module on colloidal systems. The study employed a one-group pre-test post-test design to assess the effectiveness of the e-module during the trial phase.

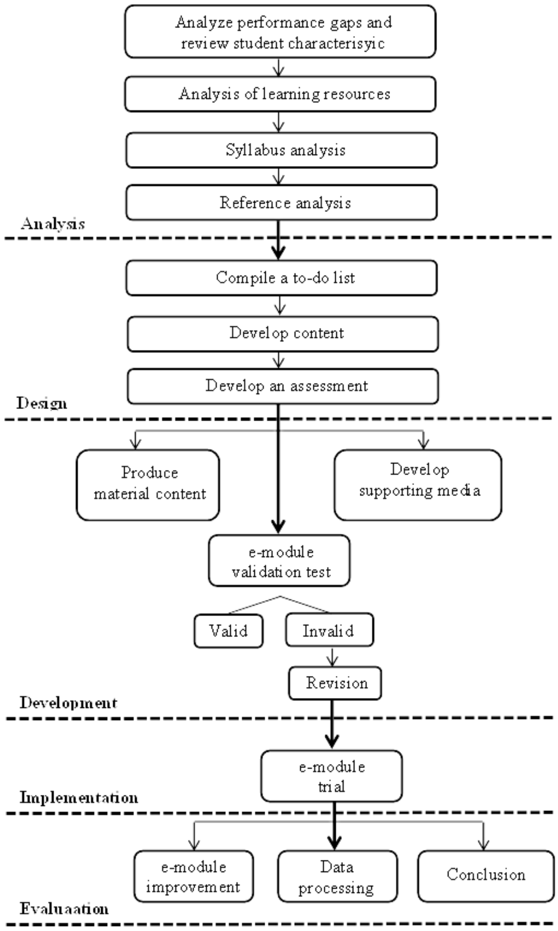

Figure 1. Research Design Flow

The research began with the Analysis phase, which involved several key assessments. A Gap Analysis was conducted to identify the current conditions at the school under study, determining the need for the e-module. A Characteristics Analysis examined the learning conditions and characteristics of the students. Resource Analysis identified the necessary resources, including learning environments, concepts, instructional tools, and teacher support, all of which influence the success of the learning experience. A Syllabus Analysis was also performed to align the Grade XI chemistry syllabus with the basic and core competencies, ensuring the learning objectives were effectively met.

In the Design phase, the focus was on creating the learning experiences required for the e-module. This phase involved preparing the application and arranging tasks aligned with the PBL model. Attention was given to content coverage, language accuracy, presentation, and graphical elements to ensure effective learning. Assessment strategies, including pre-tests, post-tests, and formative tests, were designed to align with the objectives and indicators.

The Development phase involved transforming the design into the actual e-module content. This included creating the content, formulating indicators, and incorporating assessment strategies. A lesson plan was developed as a guide for implementing the PBL-based e-module, and supportive media, such as illustrations and YouTube videos, were integrated. Expert validators validated the e-module, and revisions were made based on their feedback.

During the implementation stage, the validated e-module was used in a classroom setting, with one class as the experimental group. The goal was to improve student learning outcomes using the e-module. Following the pilot test, the final stage involved re-evaluating and refining the e-module based on data analysis related to learning outcomes and feedback from student response questionnaires.

2. Participants

This research focused on developing PBL-based e-modules, with the sample selected using a purposive sampling technique. This method involved choosing participants based on specific criteria deemed relevant by the researcher. The study's subjects included 36 students from Class XI MIA at a high Islamic school in Medan during the 2023/2024 academic year.

3. Instruments

The instruments used in this research included an e-module validation sheet, evaluation sheets, a test instrument, and a student response questionnaire. The e-module validation sheet was designed to assess the feasibility of the developed e-module, focusing on content, presentation, language, and graphic validity. The test instrument measured student learning outcomes from the implemented e-module. Initially, the test instrument comprised 40 items, but after validation, it was reduced to 20. The same set of questions was used for both the pretest and posttest. Before deploying the test instrument in the research, an analysis was conducted to evaluate its difficulty level, discrimination power, validity, reliability, and the effectiveness of the distractors. The student response questionnaire was used to gather feedback on the e-module from students.

4. Data Collection

Data collection in this research involved several methods. Interviews were conducted to gain insights into the challenges faced in the chemistry learning process and to identify the need for additional teaching content in schools. The researcher conducted interviews directly with teachers. The e-module validation sheet assessed various aspects, including content validity, presentation, language, and graphics. After experts validated the e-module, the student response questionnaire was distributed to gather feedback on the e-module. A testing method was also employed, involving pretests and posttests with multiple-choice questions to assess students' learning progress.

5. Data Analysis

The experts' validation sheets were analyzed using a Likert scale to determine the percentage of product suitability for the developed e-module. Four expert validators validated the e-module, and the interpretation of the percentage of expert validation sheets is shown in Table 1.

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Table 1. Interpretation of Sheet Percentages

Percentage (%)	Criteria
80.1 - 100	Very High
60.1 - 80	High
40.1 – 60	Medium
20.1 - 40	Low
0.0 - 20	Very Low

Source: Arikunto, 2008

In addition to expert validation, the evaluation questions for the pretest and posttest were validated to ensure they were suitable for use as assessment tools. Improvement in learning outcomes was calculated using the N-gain test (Normalized Gain Score), as shown in Equation (1):

$$\mathbf{g} = \frac{\boldsymbol{posttest - pretest}}{\boldsymbol{maximum\ value - pretest}} \quad (1)$$

The classification of the normalised gain values is presented in Table 2.

Table 2. The classification of the normalised gain values

Criteria	Range
Low	g<0.3g < 0.3g<0.3
Medium	0.3≤g≤0.70.3 \leq g \leq 0.70.3≤g≤0.7
High	g>0.7g > 0.7g>0.7

Source: Sudjana, 2005

RESULTS AND DISCUSSION

The results of this development research encompass developing and validating the e-module, student learning outcomes, and student responses to the e-module.

1. E-module Development and Validation

The procedure used for developing the e-module was an adaptation and modification of the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation.

a. Analysis

The first stage of this research involved analysis, during which five key analyses were conducted: performance gap analysis, student characteristics analysis, resource analysis, syllabus analysis, and reference analysis. The findings from this stage revealed that the current learning process in chemistry at the school predominantly focused on delivering content l and questions, relying on conventional methods and discussions. This approach resulted in students often being passive during discussions. Moreover, the existing teaching content, primarily printed books, was monotonous and less interactive, contributing to student disengagement.

The analysis highlighted the need for more dynamic and engaging teaching content, particularly in the colloidal systems' topic taught in the even semester. The current curriculum emphases the importance of creativity, problem-solving, and active participation in the learning process, making it essential to develop teaching content that aligns with these goals.

Effective teaching content must be designed and developed according to specific rules and elements, including consistency, format, organization, and cover design [18]. This concept should be structured around clear learning objectives or targets to maximize student learning outcomes. Enhancing the content in students' books by incorporating additional activities that still need to be fully covered can further support student intelligence [19]. While e-modules are not a novel concept, their adoption has yet to become widespread among students. However, the development of e-module-based learning content has rapidly progressed, offering ease of access and high engagement. Learning becomes more enjoyable with the convenience of studying via smartphones and the internet, coupled with visually appealing content [20]. To ensure continuous learning beyond the classroom, educators are encouraged to develop electronic-based teaching content using specific software, enabling students to access them anytime and anywhere via smartphones or computers [21].

b. Design

The design stage involved creating a draft chemistry e-module based on PBL. Activities at this stage included preparing applications, compiling a task list, developing content, and formulating a PBL-based chemistry e-module assessment strategy. The e-module design illustrated the overall relationship between the components within the e-module and served as a roadmap for its development. Key activities included creating an e-module framework to outline and systematically arrange the content, simplifying the development process, establishing the module's visual design to ensure it was appealing and easy to read, and compiling assessment instruments to evaluate the validity of the developed product. A lesson plan was also compiled to guide learning activities using the PBL learning model in the e-module.

The e-module format was tailored to the needs of teachers and students. The design of the e-module product included a cover providing an overview of the selected topic, a foreword with initial information about the e-module, learning instructions tailored to a contextual approach, a table of contents outlining the structure, and the basic competencies and learning objectives to be achieved. The learning content was contextualized to real-life situations, helping students better understand the content. Quizzes were included for students to complete after mastering the concept, and a summary was provided at the end to highlight key points. The formative test consisted of questions to measure students' mastery of the concept, and assessments were included to evaluate their performance. An answer key was provided to verify the correctness of the responses, and a bibliography listed the supporting sources used in the module's creation.

The test aimed to determine student performance in the learning process and inform students of the support needed to address deficiencies [22]. The preparation of test standards, in the form of pre-test and post-test questions, served as a reference for assessing student knowledge changes. This process emphasised the importance of evaluation in learning, as it was essential for determining whether the learning objectives had been achieved [23]. Thus, preparing test standards was a critical initial step in the design phase, serving as a benchmark for measuring student progress and the overall effectiveness of the e-module [24].

c. Development

The development stage focused on creating and validating the learning resources selected during the design phase. This process involved preparing all the necessary content, concepts, lesson plans, and supportive media to facilitate learning through e-modules. The e-module was structured according to the PBL stages within each main topic and sub-topic. The first stage, problem orientation, involved presenting a real-life problem designed to engage students and encourage active participation in problem-solving. In the next stage, organizing learners, students were tasked with identifying and organizing learning activities related to the problem. This was followed by individual and group investigations, where students were encouraged to gather relevant information, conduct experiments, and work towards solving the problem.

In the development and presentation of work results stage, students presented their findings from group discussions through presentations and participated in open forums with other groups. The final stage, evaluation, required students to formulate conclusions based on their completed learning activities collaboratively.

The concept and content developed during this stage included various components, such as an introductory section with a cover, foreword, table of contents, basic competencies, learning indicators, instructions for using the e-module, PBL syntax, concept maps, and apperception. The core part of the e-module contained PBL-based content on colloidal systems, quizzes, chemistry information, profiles of notable chemists, competency tests, and reflection exercises. The closing section comprised a summary, glossary, answer key, bibliography, and periodic table of elements.

The writing plan or outline of the e-module was divided into three main sections: the introduction, the core part, and the closing part. The topic sequence was arranged according to the learning objectives based on indicators and basic competencies, along with delivery strategies developed during the design stage. The next step was selecting and developing supporting media. The content was presented using the five PBL stages: problem orientation, organizing students, group and individual investigations, developing and presenting work results, and evaluation.

The e-module development was prepared by researchers using the Canva and Flip PDF Professional applications. These applications offer numerous features that enhance the visual appeal of the e-module. Researchers could incorporate images, links, videos, YouTube content, and audio/music and select attractive templates and backgrounds to create a more engaging learning experience [25]. Flip PDF Professional, in particular, allowed the creation of electronic modules with dynamic elements such as animations, audio, and videos, making the learning content interactive and compelling [25]. This software supports various output formats, including HTML, Mac app, FBR, EXE, zip, mobile version, and CD burning. It allows for the easy embedding of YouTube videos, hyperlinks, animated text, and more through simple drag-and-drop or click actions [26]. The file was saved and prepared for validation after developing the e-module using Flip PDF Professional. Four expert validators then validated the PBL e-module on colloidal systems. The aspects assessed during the validation process included content validity, presentation validity, language validity, and graphics validity. The e-module received an average validation score of 91.6%, indicating that it was categorised as "valid/appropriate" according to BSNP criteria. This validation confirmed that the developed teaching concept was suitable for implementation [26].

In addition to the validation assessment, the validators provided feedback and suggestions for improving the e-module—these recommendations aimed to address shortcomings and enhance the quality of the teaching content for learning colloid systems. For example, revisions were made to the cover image to ensure that the PBL syntax names were accurate and complete, and adjustments were made to the problem orientation in learning activity 4 based on expert feedback. The revised cover of the e-module is shown in Figure 2 [26].

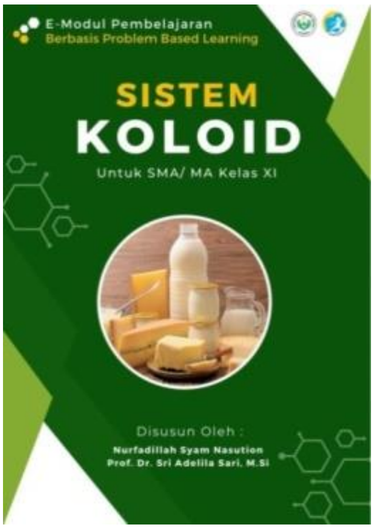

Figure 2. Cover of e-module

The validation process aimed to gather assessments, input, and suggestions for improving and refining the learning module to ensure it was error-free and ready for testing. The next step involved implementing necessary revisions or improvements to the learning module based on the expert feedback received [27]. The developed e-module was declared highly feasible by design, content, and media experts, indicating its suitability for use in the learning process [28].

Another study found that the developed e-module media achieved excellent validity in both content and media validation results [29]. This is consistent with subsequent research, which found that the assessment results of the developed e-module were highly valid, with a content expert validation score of 96.00% and a media expert validation score of 100%, further confirming the module's effectiveness [30].

d. Implementation

The implementation stage was conducted to apply the designed e-module in the learning process. This stage occurred after obtaining validation results for the developed e-module, lesson plan, and all necessary research instruments. Once validated, the e-module was piloted at the research site, involving a class of 36 students—the trial aimed to assess the practicality and effectiveness of the e-module in a real classroom setting. Initially, students were given a pretest to evaluate their prior knowledge. Following this, the e-module was introduced, and the learning process was carried out using its contents.

After the learning session, students were administered a post-test to measure any improvements in their understanding and skills. A student response questionnaire was also distributed to gather feedback on the module's usability and effectiveness. The trial began with instructions on using the e-module, explaining its components and the learning activities it included. Students engaged in various activities presented in the e-module, such as watching instructional videos, taking quizzes, and reading content, all aligned with the PBL.

Finally, the implementation stage concluded with an evaluation to measure the improvement in student learning outcomes through post-tests and feedback collection via the student response questionnaire. This process was essential to determine the module's suitability as meaningful and effective teaching content.

e. Evaluation

The evaluation was the final step in analysing the module's effectiveness during implementation. This process aimed to identify any remaining shortcomings or weaknesses in the e-module. The e-module was considered suitable as teaching content if no further revisions were necessary. Generally, the developed e-module had several advantages: it featured an attractive design, included a comprehensive concept, and incorporated learning videos that facilitated the problem-solving process. It also provided spaces for evaluation, such as quizzes and competency tests, and offered engaging chemical information related to colloid systems.

Revisions were made using suggestions and feedback from content and media experts, as recorded on the validation questionnaire sheet and aligned with the assessment rubric. Additionally, feedback from the trial responses during the implementation stage was evaluated. This evaluation process was essential for refining and perfecting the developed product, ensuring it was high-quality and error-free, making it a reliable and effective teaching tool.

2. Student Learning Results

A pretest was administered to assess the improvement in student learning outcomes before the learning process began using the Problem-Based Learning (PBL) e-module. After completing the pretest, which served as a measure of student readiness, the researcher proceeded with the learning process in the experimental class, utilising the developed e-module as the primary teaching content. A post-test was then conducted to evaluate any improvements made using the PBL-based e-module. An N-gain test was performed alongside hypothesis testing using a t-test to measure the improvement in student learning outcomes.

The research results indicated that the average scores for the pretest and post-test were 43 and 87.36, respectively. The average N-gain obtained from these tests was 0.76, placing it in the "high" improvement category. These results significantly increased student learning outcomes following the PBL-based e-module on-topic colloid system. A recapitulation table of the N-gain test results was created to facilitate the data analysis. Additionally, based on the post-test scores, the hypothesis test results revealed that the average student learning outcomes exceeded 75, leading to the acceptance of the alternative hypothesis (Ha). Thus, it was concluded that using the PBL-based chemistry e-module significantly improved student learning outcomes on the colloid system topic. The detailed analysis of the research data can be seen in Table 3.

Table 3. N-gain Test Results

Class	Average		N-Gain	Category
	Pre-test	Post-test		
Experiment	43	87,36	0,7695	High

The results of the pre-test and post-test scores can be seen in Figure 3.

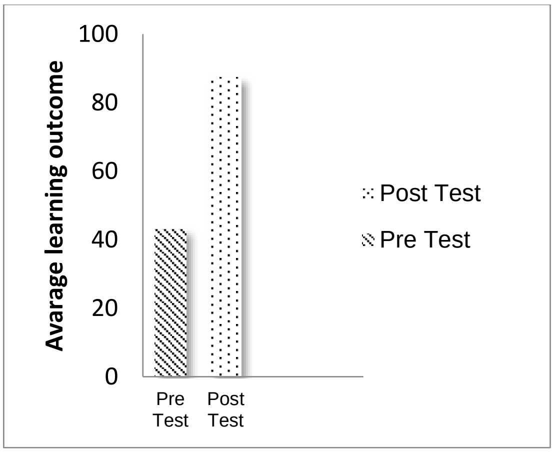

Figure 3. Student learning outcome data

Based on these results, the findings align with several other research outcomes. For example, one study found that student learning outcomes using the N-Gain test showed a value of 0.79 (high), with an interpretation of 79.13% (practical), leading to the conclusion that PBL-based e-modules are particularly effective for teaching thermochemical concepts [31]. Similarly, this study's results are consistent with prior research indicating that learning with electronic modules yields better results than traditional methods without e-modules [32]. Supporting this, another study showed that post-test learning outcomes among participants scored 82%, which falls into the good category and is interpreted as above the minimum completeness criteria (KKM) [33]. These findings are further reinforced by previous research demonstrating the accepted analysis test results proving that digital modules can significantly enhance student learning achievement (Ho was rejected, and Ha was accepted), thereby validating the hypothesis [34]. This confirms that developing electronic-based modules can effectively improve student learning outcomes [35].

3. Student Response

Questionnaires consisting of 24 questions were distributed to assess student responses to the implemented e-module. The questionnaire focused on content accuracy, clarity, language use, and the quality of illustrations and images. A total of 36 students participated in evaluating the e-module. The research results showed that the average percentage of student responses was 87%, indicating that the PBL-based e-module on the topic of the colloid system was categorised as "very good" for use as teaching content in the learning process at school.

Students reported that the e-module enabled them to learn independently, and they appreciated the attractive page flip design. They also agreed that the videos, images, and illustrations within the e-module facilitated a better understanding of the concept. The e-module provided opportunities for self-reflection, allowing students to evaluate their comprehension of colloidal topics. On average, students felt that the e-module stimulated their thinking. There were no significant criticisms or suggestions for improvement, as students considered the e-module very effective.

These findings align with other research. For instance, one study found that the average total score of student responses to an e-module was 124.4, with a percentage of 86.4%, categorising it as "very good" [36]. Similarly, another study reported that student response questionnaires yielded "very good" criteria, with average percentages of 84.99% for individual tests, 86.66% for small group tests, and 87.19% for main trials, concluding that PBL-based e-modules are well-suited for learning [37]. Furthermore, another study found that the average score of student responses to e-modules as teaching content was 3.43, categorised as "Interesting" [38].

4. Theoretical and Practical Implications

The implications of this research are significant in both theoretical and practical aspects. The developed e-module aids in enhancing students' understanding of the concept during the learning process, thereby facilitating the achievement of learning objectives. Theoretically, this e-module, designed with a Problem-Based Learning (PBL) approach, aligns with contemporary educational theories emphasising active, student-centered learning. By integrating real-world problems into the learning content, the e-module fosters critical thinking and allows students to relate theoretical knowledge to practical applications in their daily lives.

The e-module is a versatile teaching resource that can be seamlessly integrated into classroom instruction. Teachers can use the e-module to enrich their teaching strategies by incorporating multimedia elements such as videos, animations, and images, making the learning experience more engaging and interactive. The e-module also supports distance learning, offering flexibility and accessibility to students outside the traditional classroom setting. This adaptability is particularly valuable in today's educational landscape, where blended and online learning environments are becoming increasingly common. By providing a resource that is both theoretically sound and practically useful, this research contributes to developing effective teaching content that enhances student engagement, understanding, and overall learning outcomes.

CONCLUSION

. Based on the research and development findings, it can be concluded that the developed e-module was assessed as valid and appropriate for instructional use, achieving an average validation score of 91.6%. This indicates that the e-module meets the criteria for effectively utilising it as teaching content in the learning process. Furthermore, the module's effectiveness as an instructional tool is supported by its ability to significantly improve students' learning outcomes, as demonstrated by an N-gain score of 0.76, which falls within the high criteria. This suggests that the e-module is suitable and effective in enhancing student achievement.

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